D R Makwana et al. International Journal of Recent Research Aspects ISSN: 2349-7688, Vol. 4, Issue 4, Dec 2017, pp. 427-431

Numerical Evaluation and Study of Effects of Mine Blast on V-hull of Wheeled Combat Vehicle

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Abstract: 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. To reduce the vulnerability of the vehicle to anti-vehicular mine blast is relying heavily on the numerical simulation to help design and optimize design of armour systems. This paper deals with the simulation and analysis carried out on the V-hull of a wheeled combat vehicle. Numerical analysis revealed that there is significant energy absorption because of the use of deformable V-plate for vehicle hull. One of the great challenge faced during the evaluation of the vulnerability of the vehicle to mines blast is not only assessing the structural response of the vehicle but also evaluating the damage caused to the vehicle due to the acceleration induced due to blast. This paper presents the results of a simulation performed with LS-DYNA using 8kg TNT under the belly of a wheeled combat vehicle. Local deformation, acceleration, stress and peak pressure values were obtained and analysed as results of analysis.

Keywords: Blast protection, Simulation of Armoured Vehicles, Mine blast

1.0 Introduction

The design of the hull plays a vital role in the blast propagation. There are multiple shapes like V, W, U are being used for designing the hull. They have their merits and demerits based on the vehicle configuration. Trembley et al. (1998) [1] performed field experiments and found that a V-shaped hull will only be propelled a third of height compared to a flat hull expesed to the same amount of explosive. Farhadi and Paykani (2013) [2] concluded that V-plates are superior than flat-bottom plates in resisting load transfer from explosive blast. S.Ukrande (2017) [3] concluded that deflection for the deep V-hull is the most effective and it was minimum deflection and also the manufacturing difficulties are less compared to W-hull . The efficiency of the impact of the explosion on hull bottom depends on the magnitude of shockwave resulting from the detonation of the mine explosive. The shockwave pressure impulse effecting the vehicle underside, particularly under a flat bottom late is much higher . The flat hull gives more face area to the blast and so gives more space to propagate the blast. Keeping the shape of the hull in such way that to cause minimum blast propagation and minimum damage to the occupants. Simulations have been carried out using different shapes of the vehicle hull, to find out the effectiveness of the plate angle Under flat bottom plate, the blast wave gets reflected pressure pulse, hence the resultant overpressure is higher compare to V-plate where the pressure gets deflected due to V-shape. Manfred (2009) studied the effects of mine blast on the vehicle structure.

Madhu and Bhat (2011) [4] described that the main mechanisms that can be incorporated into the design of vehicles and equipment to render protection against the blast effect of mines are;

(i) Absorption of energy,
(ii) Deflection of blast effect away from the hull, and
(iii) Keeping adequate distance from detonation point.

The effect of blast against the hull of vehicle can be reduced considerably by incorporating steel plates at an angle to direction of blast, because highest pressure are generated only when the blast direction is at a 90^0 angle to the plate. This approach has led to the introduction of V-hulls, which have been successfully used in the protection of light-and medium sized vehicles against mines.

A charge of 8 kg TNT was used to load the vehicle model. The effect of blast was simulated and the results were analysed. A finite element model of the wheeled combat vehicle was prepared using CAD software. Simulation of penetration events requires a numerical technique that allows one body (Penetrator) to pass another. Sahu and Gupta (2013) [5] mentioned that 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 blast pressure was calculated by Sadovsky, Brode and Henrych formulas [6].

2.0 Mine blast propagation

When a high order explosion is initiated, a very rapid exothermic chemical reaction occurs. As the reaction progresses, the solid or liquid explosive material is converted to very hot, dense, high pressure gas. The explosion products initially expand at very high velocities in an attempt to reach equilibrium with the surrounding air, causing a shockwave. A shockwave consist of highly compressed air travelling radial outward from the source at supersonic velocities. Only 1/3rd of the chemical energy available in most high explosive is released in detonation process. The remaining 2/3rd is released more slowly as the detonation products mix with air and burn. This after burning process has a little effect on the initial blast wave because it occurs much slower than the original detonation. As the shockwave expands, pressure decreases rapidly (with the cube of distance) because of geometric divergence and dissipation of energy in heating the air. The detonation is the process of a pressure wave blast wave propagating chemical reaction to initiate behind it. The initial pressure near the explosive can be as high as 2,00,000 Atmosphere and temperature can be as high as 6000° C [6].

When the shock wave impinges on a surface that is perpendicular to the direction it is travelling, the point of impact will experience the maximum reflected pressure. When the reflecting surface is parallel to the blast wave, the minimum reflected pressure or incident pressure will be experienced. The magnitude of the peak reflected pressure is dependent on angle of incidence, peak incident pressure, which is a function of the net explosive weight and distance from the detonation.

Figure 1 [7] shows how a Mine blast propagates in the actual manner. The actions of the blast above the ground and below the ground are clearly mentioned in this figure. The explosive contains metal and plastic pieces, which is to be placed below the ground to react on the application of pressure. The explosion produces flame, fragments and blast wave with inclusion of some debris. The detonation process can be characterized by three phases: explosive interaction with the soil, gas expansion to the surface and soil ejecta interaction with vehicle [8]. In the present study soil ejecta is not considered for simulation in order to simplify the analysis.

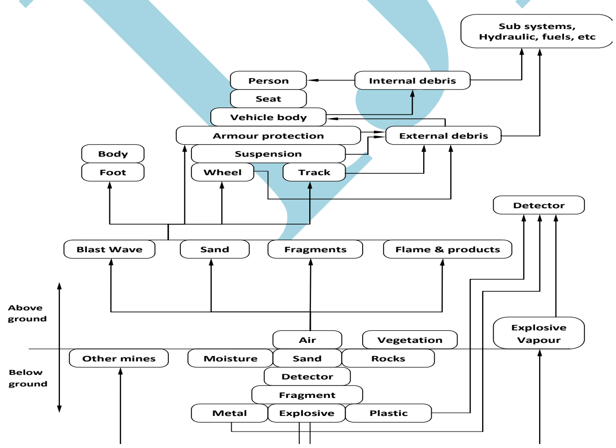

Figure 1: Mine blast propagation

3.0 Simulation / FE Analysis Approach

3.1 Model Geometry

The model used in the present analysis is improved version of Wheeled APC. The hull geometry is designed in such a way to reduce the effect of the blast. The shape of the hull bottom considered as shallow kept as V-shape. The turret, hatches, and interior bulkheads have been removed as they have a negligible effect on the response of the vehicle hull in the first few microseconds of the event, 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 much more 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 model 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, only the bottom V-hull portion with a simplified axles and gear box have been considered for further loading and analysis. The dimensions of the vehicle model are 7150mm X 1775mm X 1995 mm (L X B X H). The complete vehicle model is shown in figure 2 and 3. The stand-off is 450 mm. The location of the blast is exactly at the centre of hull plate.

The high hardness steel plate having thickness of 8mm is used for the V-hull of the model and it has hardness in the range of 300-350 BHN and the hull is made of 5mm high hardness steel. The stiffeners are of 8mm thickness provided in the V-hull to restrict the upward movement of the plate. The deformable V-plate reduces the risk of damage due to blast pressure and fragmentation intrusion into the crew compartment. The V-hull portion is directly faces the blast fragmentation, so to reduce the process time and to achieve quick results, the focus is on V-hull portion only.

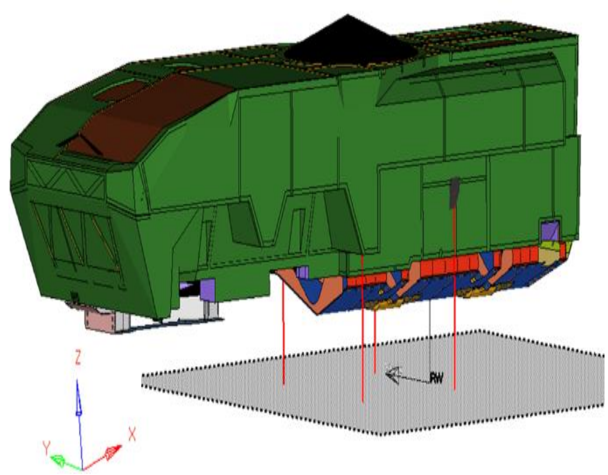

Figure 2 : Vehicle model with 450mm stand-off

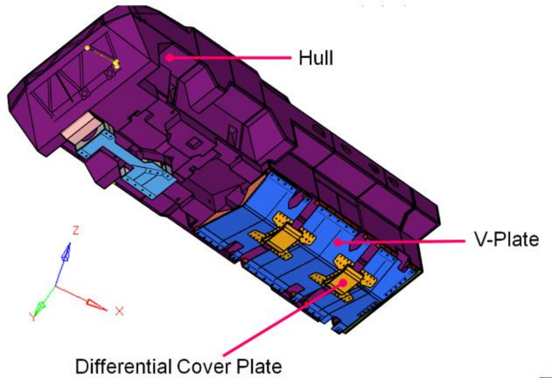

Figure 3 : Bottom view of V-hull

3.2 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 (Quad elements). The model mesh consists of 2,42,694 nodes and 2,43,895 shell elements. The vehicle bottom V-hull is shown in figure 4. The hull is restricted in all DOF as the prime interest is to observe the maximum deformation of the V-plate due to blast load. It is assumed that the explosion is taking place above the ground and the detonator is not buried in the soil.

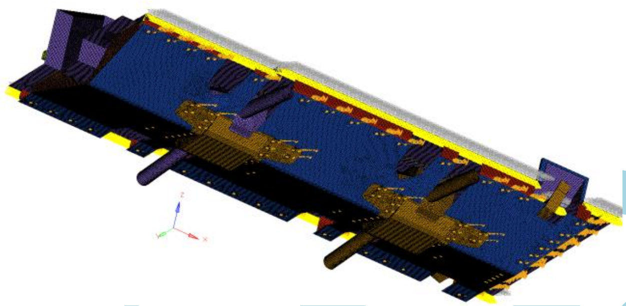

Figure 4 : FE model of V-hull

The structure of the hull is high strength steel having hardness in the range of 300-350 BHN. MATL3material card was used for V-hull i.e. MAT_ELASTIC_PLASTIC [9]. The values for card format are as under.

Table 1 : Material properties of V-Hull

Property	Value
Mass density (RHO)	7850 kg/m^3
Young's modulus (E)	210 kN/mm^2
Yield strength (SIGY)	1100 N/mm^2
Poisson's ratio (NU)	0.3

3.3 Charge

The explosive ignited at the centre and a 'Programme burn' model is commonly used with a burn fraction enhancement. This approach is mainly used with hex-elements. The evolution of the explosive after ignition is described by the Jones-Wilkins-Lee (JWL) equation of state [10], which defines pressure as;

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

Where,

V - Relative volume

E - Internal energy and ω, R_1, R_2 are constants

The structural response of the vehicle mainly depends on the blast pressure and the stand-off. The analysis mainly depends on the acceleration generated inside the hull and finally transmitted to the occupants. The CONWEP function was used in order to generate blast equivalent pressure distribution on the hull. CONWEP assumes the exponential decay of pressure with time.

For shell elements, *LOAD_BLAST is used to define air blast function for the application of the pressure loads from the detonation of conventional explosives. *LOAD_BLAST function reproduces a field of vectors on the target's nodes that changes with time. The mass of the hull is considered as 1.108 ton. The V-plate is weighing 750kg. The implementation is based on the report by Randers-Pehrson (1997) [11] and Bannister, where it is mentioned that this model is adequate for study of vehicle response due to blast from land mines. This option determines the pressure values when used in conjunction with the keywords: *LOAD_SHELL , *LOAD_SEGMENT_SET or *LOAD_SEGMENT [12].

3.4 Loading Model

The vehicle hull model is developed using HyperMesh and the simulation of blast loading is done by LS-DYNA. The model is used to predict the maximum damage area due to the blast of 8 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 LS-DYNA pre-processor, the input data like element thickness, properties of material, boundary conditions and loading was assigned to the vehicle model.

3.5 Result interpretation through LS-PREPOST

The blast is a microsecond phenomenon. The von-Mises stress values of V-hull are shown in figure 5 followed by displacement values of V-hull in figure 6. As the detonation starts, the explosive emits the energy in the form of heat which finally becomes the blast wave and acts as a pressure wave on the vehicle structure. The penetration of the splinters depends on the hardness of the armour. Harder the armour, smaller will be the penetration [13]. The maximum displacement is found 59mm which is within the permitted limits. The max displacement of 150 mm was permitted. The max stress is found 1100 MPa, which is within the yield limit of plate. The Max values for Von-

Mises stress are coming close the contours of the vehicle due to stress concentration in that region.

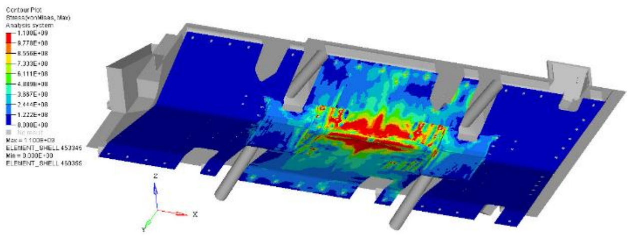

Figure 5 : von-Mises stress on V-hull

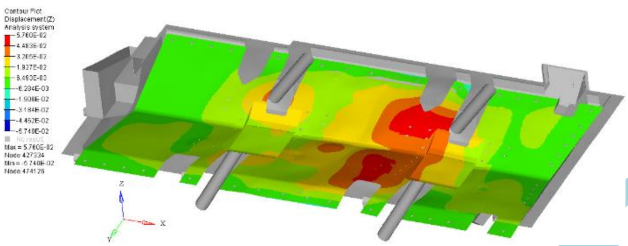

Figure 6 : Max displacement on V-hull

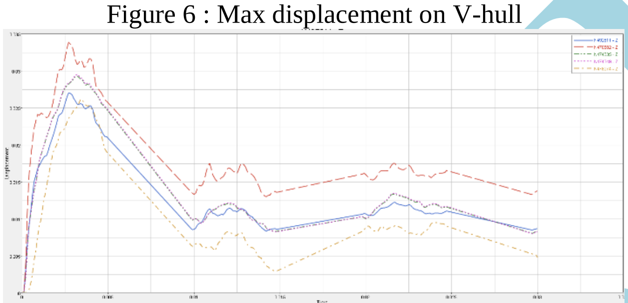

Figure 7 : Nodal displacement on V-hull

As shown in figure 7, the nodal displacement on the V-hull is found in the range of 35-38 mm. The graph shows only few selected nodes on the V-plate where blast wave strikes in the beginning.

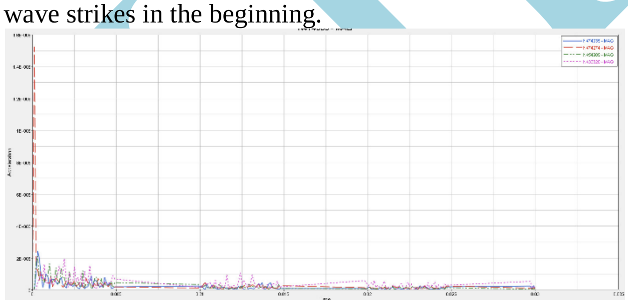

Figure 8 :Acceleration on V-hull

Figure 8 shows peak acceleration values are in the range of 1520 mm/ms^2 for approximately 0.005 second. As the duration is very small, the fatal effect will be less.. Based on the effect of the variation in acceleration and duration on tolerance capacity of human being, it is seen that beyond 100g < 0.01 second is fatal [14]. The above acceleration values are on the V-hull. By using secondary energy absorption mechanism, the acceleration values can be brought down further. It is observed that due to compression of spines and snaps necks, the soldiers inside get killed due to the instant acceleration caused by blast.

4.0 Conclusion

The impulse is a function of total stand-off distance and plate angle. The V-hull deflects the blast up and away from the crew cabin, the use of other secondary mechanisms will help to absorb the blast energy. The V-shaped design of hull could neutralise the overall blast effect compared to flat shaped hull design. But to achieve higher protection against mines, more study and analysis is required.

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