Available online at www.academicpaper.org
Academic @ Paper
ISSN 2146-9067
International Journal of Automotive Engineering and Technologies
Vol. 2, Issue 4, pp. 130 – 139, 2013

International Journal of Automotive Engineering and Technologies
http://www.academicpaper.org/index.php/IJAET

Original Research Article

Blast diffusion by different shapes of vehicle hull

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Received 31 May 2013; Accepted 05 November 2013

ABSTRACT

In many parts of the world, the blast is a frequent occurrence case. Blast damages humans as well to the property. The physics of blast is very complicated for analysis. Hence, researcher have been studying physics of anti vehicular (AV) mine explosion, explosive interaction with soil, gas expansion, interaction of explosive product with vehicles, human effects from AV mine explosion etc. Many strategies were discussed to mitigate the blast effect. To protect the military vehicle, many design measures are suggested. One of the measures could be the effective design of the shape of vehicle hull, which can dissipate blast energy in effective way. An analytical study on blast energy dissipation through different shaped hull of military vehicle is discussed in this paper. These vehicle hulls have same cross sectional perimeter and length is also kept same. Various responses after blast are studied on these hulls and comparison is done for an effective dissipation of blast energy.

Keywords: AV mine explosion, vehicle hull, energy of explosion, energy dissipation, finite element analysis

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1. INTRODUCTION

In recent past the terrorist attacks and guerrilla warfare are becoming more and more frequent. Hence the research on protection against landmine threats to army vehicles, buildings and personnel have been having an increasing role. Many researched have been studying the complicated chemistry of the blast and identifying measures to mitigate the blast energy. Ramasamy et al. (2009) gave a glimpse on anti-vehicular (AV) mines and their damages; mitigate the blast effect, enhancement of armor on the base of the vehicle etc. They highlighted the physics of AV mine explosion, explosive interaction with soil, gas expansion, interaction of explosive product with vehicles, human effects from AV mine explosion etc. Many strategies were discussed to mitigate the blast effect.

Olson et al. and Nurick (1993, 1995) analyzed stiffened and un-stiffened clamped square mild steel plates under uniformly distributed blast load. The strain rate sensitivity was predicted to unstiffened plate in different modes. Wang (2001) presented a benchmark work of simulation of explosion in soil and air using LS-DYNA commercial code and Eulerian formulation. From this report it appears that for a landmine explosion simulation results are in a satisfactory agreement with experiments. Brill et al. (2000) simulated mine blast using LS-DYNA on an armored personnel vehicle and compared to a full test. Different approaches to the numerical analysis of this complicated event are presented and results are compared. In particular the blast load is applied using the standard engineering model (CONWEP) because of the obvious computational advantages of this approach. However, a fully coupled finite element analysis simulating the interaction between the blast wave, the detonation gases and the vehicle was also performed. The use of the LS-DYNA component dummy models for the simulation of the occupants is also illustrated. The numerical simulations using LS-DYNA hydro code were in good agreement with the experimental results.

Fallet (2008) did a presentation on numerical simulation to estimate damages created by a mine explosion. He simulated the explosion with 6Kg of TNT under the front wheel of a civil pick up using RADIOSS software. The arbitrary Lagrange Euler (ALE) method for fluid and explosive modeling was adopted. HYBRID III dummies were used to estimate damages caused by the blast wave. The methodology developed could be extended for design and development of test shield of vehicle hull.

Tremblay et al. (1998) performed field experiments and found that a V-shaped hull will only be propelled a third of the height compared to a flat hull exposed to the same amount of explosive. Schneck (1994) categorized mine resistant vehicles into four categories i.e. 1st generation to 4th generation, based on the sophistication of the design and the ability to retrofit current vehicle platforms. The 1st generation vehicle has improvised protection kits fabricated by soldiers in the field while 4th generation vehicle is equipped with a monocoque mine resistant hull. Ngo et al. (2007) presented a comprehensive overview of the effects of explosion on structures. An explanation of the nature of explosions and the mechanism of blast waves in free air is given. Their paper also introduced different methods to estimate blast loads and structural response.

Manfred (2009) studied the damage of vehicles caused by anti-tank mines. The author subdivides the blast load into a close-field effect with the bulge in the belly plate and the global effect which accelerates the total vehicle with enormous force (magnitudes) and leads to damage on separated masses. The loads exerted by the shock waves and by the acceleration are discussed in detail. Craig (1996) reviewed the protection of light skinned vehicles against landmines. The review covered the field expedient, retrofitting, body modification and monocoque construction.

Many guidelines manual are laid for fundamentals of protective design for conventional weapons. One such manual is

TM 5-855-1(1986) by U.S. Department of army. This manual provides the procedures for the design and analysis of protective structures subjected to the effects of conventional weapons.

The typical hull shapes with same length and cross sectional perimeter is shown in Fig. 1.

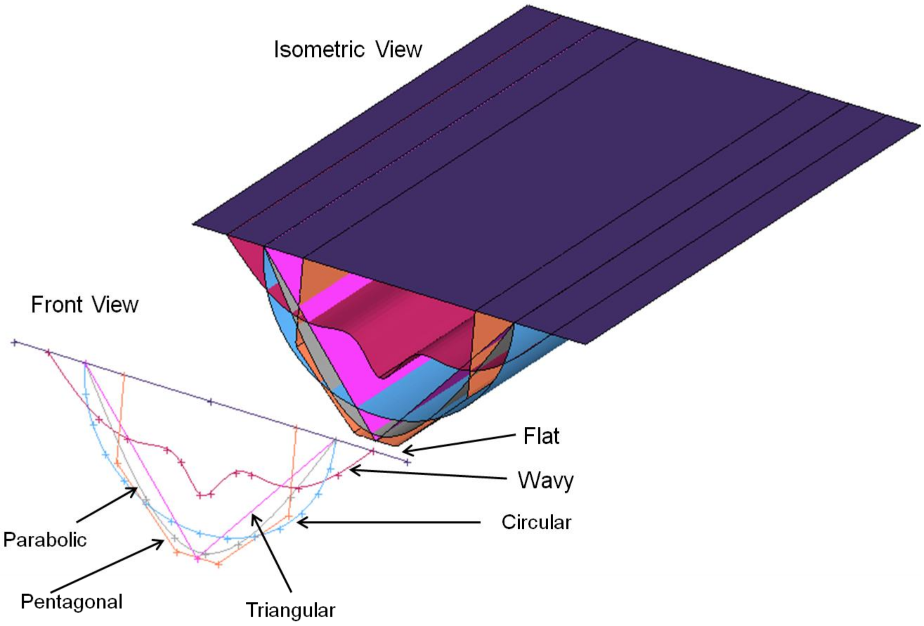

Fig. 1: Different shapes of hull with same cross sectional perimeter and length

2. Explosion Phenomenon

Detonation (triggered by vehicle) is a process whereby a shock-wave propagates through a chemical compound and initiates a rapid, exothermic and explosive chemical reaction in its wake (Fig. 2). The explosion phenomenon is described by Ramasamy et al. (2009). The chemical reaction releases the potential energy of the explosive via a phase transformation process. The detonation wave releases a mass of superheated and high-pressure gas. The pressures are typically of the order of 1.4 – 3million psi whilst temperatures are of the order of 2000°C to 6000°C. For a landmine the detonation processes can be characterized by three phases: explosive interaction with the soil, gas expansion to the surface and soil ejecta interaction with the vehicle. In the present study the soil ejecta are not considered in calculation.

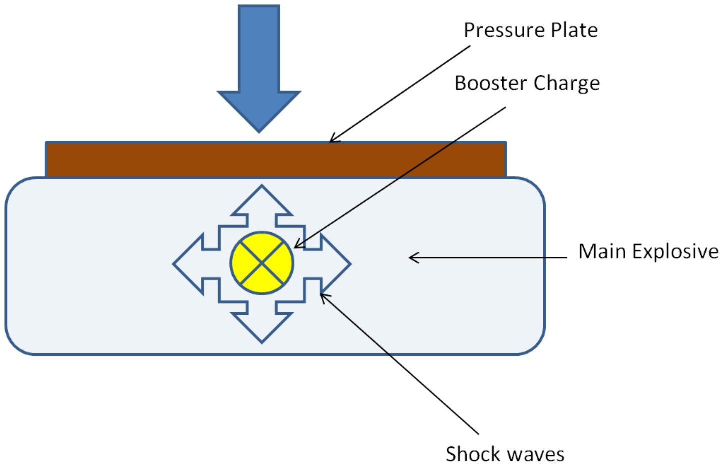

Fig. 2: Activation of the pressure fuses causing the initiation of the booster charge within the landmine

3. Finite Element (FE) Simulation

Finite element simulations were carried out for different hulls to study their response to explosion as explained below.

3.1 FE Model Building through HyperMesh

The Altair product HyperMesh (2012) is used for FE model building. Hulls are presented with shell elements at mid plane surface. Accurate FE model generated through HyperMesh gave good solver convergence.

3.2. Solving the problem through LsDyna

LsDyna (2012) explicit solver is used for solving the attempted study. It offer wide variety of material modeling and provide lot of contact algorithm according to situation.

3.2.1 FE setup

The structural behavior of an object or structure exposed to blast wave may be analyzed by dealing with two main issues. Firstly, blast-loading effects, i.e., forces that are resulted directly from the action of the blast pressure; secondly, the structural response, or the expected damage criteria associated with such loading effects. It is important to consider the interaction of the blast waves with the target structures. The structural response will depend upon the size, shape and weight of the target.

CONWEP load function was applied in order to generate the blast equivalent pressure distribution on the hull. In LS-DYNA CONWEP function is called with *LOAD_BLAST card. This card uses computer program CONWEP (CONventional WEaPon) (1991). CONWEP assumes the following exponential decay of the pressure with time.

$$p(t) = p_{s0}\left[1 - \frac{t - T_{\alpha}}{T_0}\right] e^{\frac{-A(t-T_{\alpha})}{T_0}}$$

where p(t) [kPa] is the pressure at time t, p_{s0} [kPa] is the peak incident pressure, T_0 [ms] is the positive phase duration, 'A' is the decay coefficient (dimensionless) and T_{α} [ms] is the arrival time.

The inputs that it requires are the following:

-TNT equivalent mass;

-Stand-off distance

-Type of burst

The schematic to load function for this problem is shown in Fig. 3.

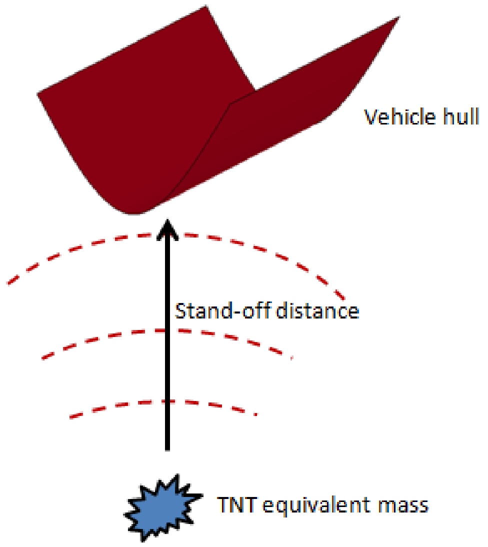

Fig. 3: Load function CONWEP

*LOAD_BLAST is used to define an air blast function for the application of pressure loads from the detonation of conventional explosives. The implementation is based on a report by Randers-Pehrson and Bannister (1997) where it is mentioned that this model is adequate for use in engineering studies of vehicle responses due to the blast from land mines. This option determines the pressure values when used in conjunction with the keywords: *LOAD_SHELL.

The compressibility of media (air) etc is beyond the scope of the study. The hull attached to vehicle mass is free to move upward due to the blast. The hull is represented in mid plane by Belytschko-Lin-Tsay (1998) shell element in LSDyna which is computationally efficient alternatives to other shell elements. It is assumed here that explosion is taking place on the land surface and detonator is not buried in the soil.

For applying the distributed pressure load over one shell element or shell element set, the numbering of the shell nodal connectivity's must follow the right hand rule as shown in Fig. 4, with positive pressure acting in the negative t-direction.

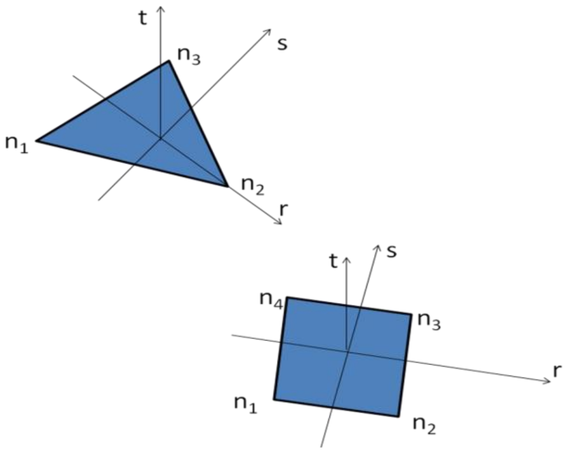

Fig. 4: Nodal numbering for pressure segments in three-dimensional geometries

*LOAD_BLAST function reproduces a field of vectors on the target's nodes that changes with the time. The FE setup has two main components i.e. vehicle hull and detonator. The vehicle upper portion is not considered in this analysis. The laden mass of 30T is rigidly connected to vehicle hull through rigid as shown in Fig. 5. Since the floor and side wall of the vehicle are connected to the edge of the hull, the acceleration could be transferred to floor and side wall through the edges.

All the hulls have same cross sectional perimeter of 3.15m, length of 6 m and thickness of 5mm. Miilux armor steel 500 plates with yield of 1.25KPa & ultimate 1.6KPa@8% strain was used in the analysis. The detonator is taken spherical shape and is equivalent to 6kg of TNT. The detonator is kept 850mm below the centre of hull. The measurements were made at mid bottom (element 1 & node 1) and at mid top edge locations (node 2) as shown in Fig. 6, along with loaded conditions.

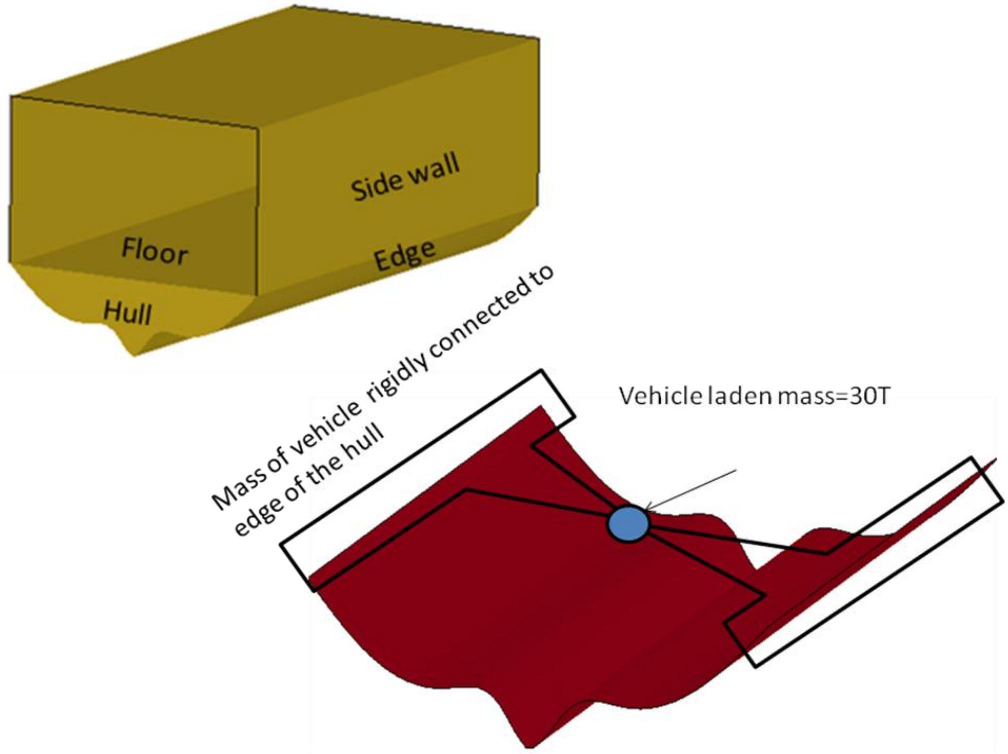

Fig. 5: Vehicle laden mass rigidly connected to upper edge of hull

3.3 Result interpretation through LS-PREPOST

LS-PrePost (2007) is used for result extraction. This is an advanced interactive program for processing the results from LS-Dyna analyses. The user interface is intuitive and easy to use. All data and menus are designed in a logical and efficient way to minimize number of mouse clicks and operations. Variety of result data can be handled with this software and plotting the result graphs is also easy in this software.

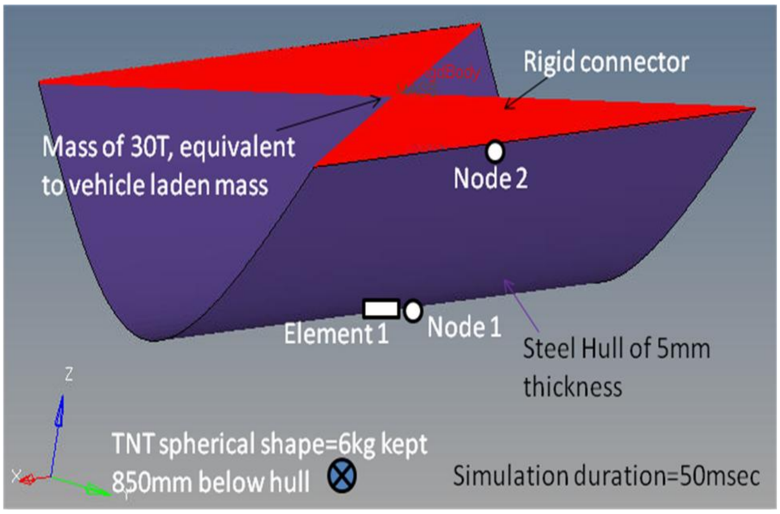

Fig. 6: Response measurement points and load condition to hull

4. FE results

The global response of structural elements is generally a consequence of transverse (out-of-plane) loads with long exposure time (quasi-static loading), and is usually associated with global membrane (bending) and shear responses. Therefore, the hull blast loading is referred to as membrane/bending failure.

The FE result correctness is judged by energy balance of the system. Fig. 7 shows energy balance graphs for parabolic hull as an example.

It is evident from the graph that unwanted energy like hourglass and sliding are less which is pre requisite of the simulation. The total energy is contributed only through kinetic and internal energy of the material.

Top edge response is measured in terms of acceleration. This acceleration is very important in view point of damage inside the vehicle. Fig. 8 shows the deflection pattern at half of the blast study period i.e. 50msec, energy balance, mid top edge acceleration & mid bottom stress.

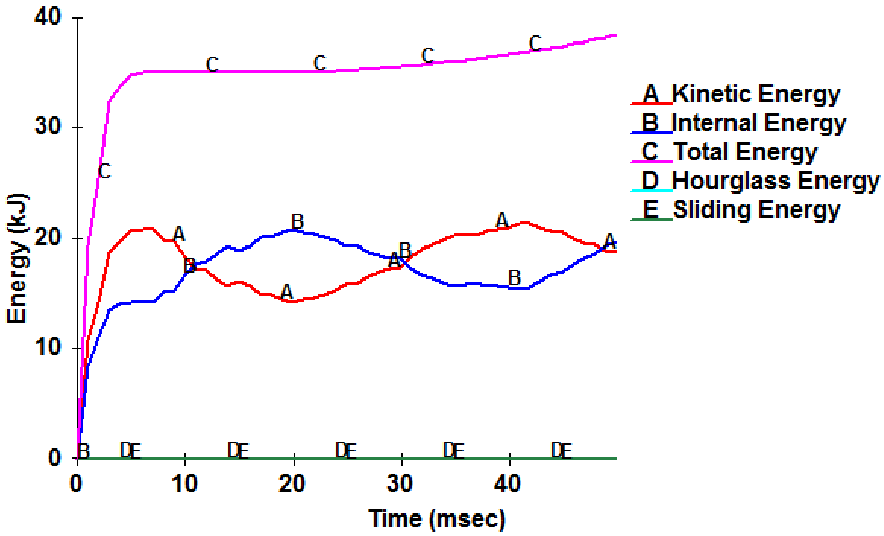

Fig. 7: Energy balance graph of parabolic hull

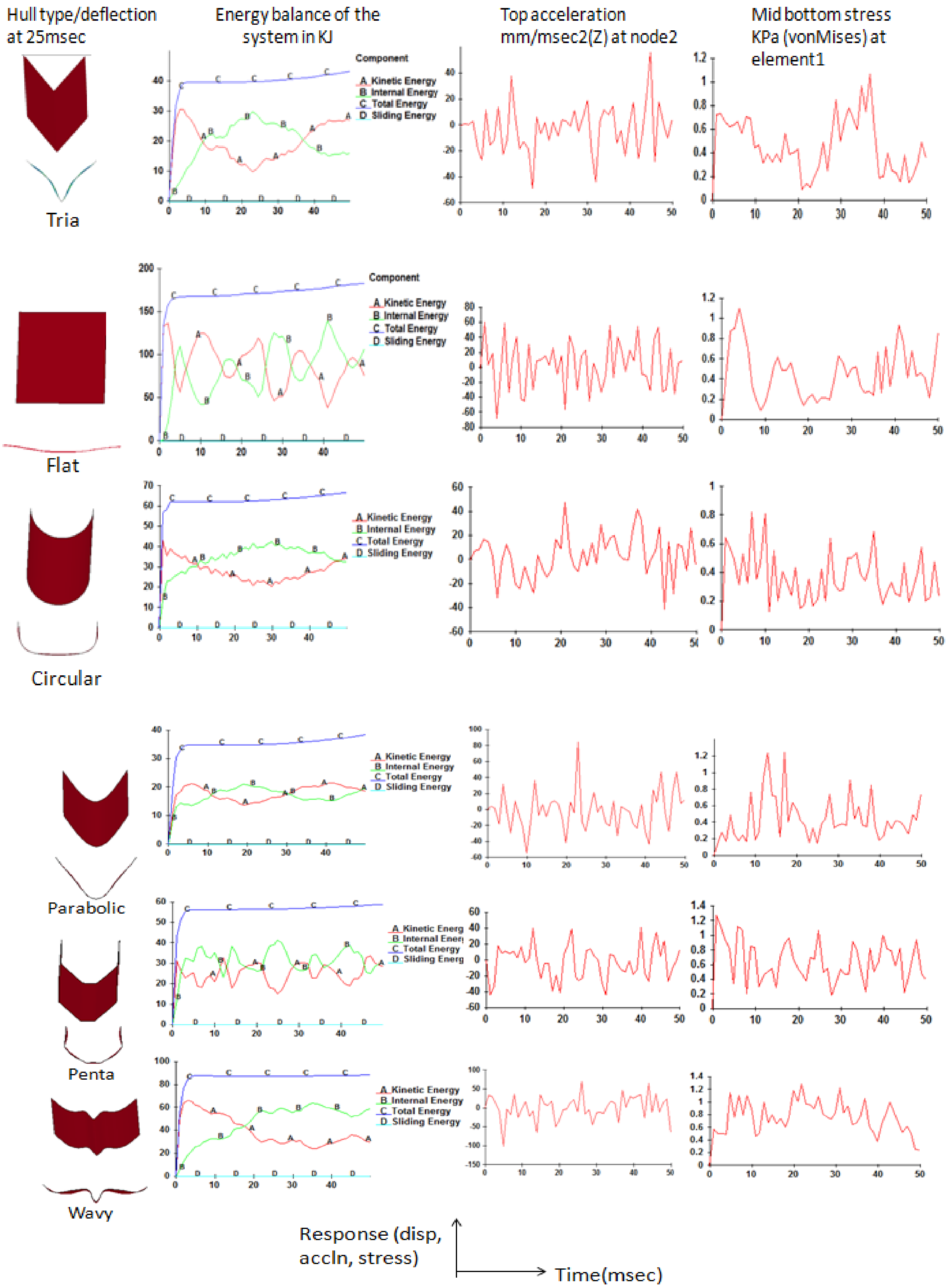

Fig 8: Various responses of the Hulls

Maximum mid displacement is observed for wavy geometrical hull, followed by half circular hull. Negative displacement is noticed for parabolic hull due to its side's compression inside due to blast pressure, which forces bottom points to go downward. Triangular shape hull give least positive Z direction displacement as compared to others as shown in Fig. 9.

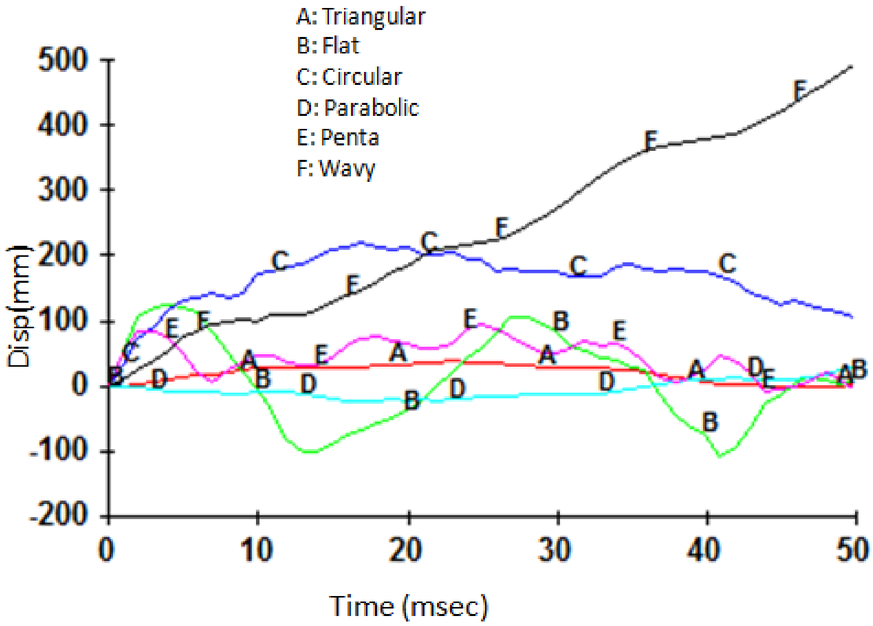

Fig. 9: Vertical displacement of mid bottom point of hulls

5. Discussions and Conclusion

From the above results below inferences are drawn.

1) The total energy is maximum for flat shape hull and least for parabolic and triangular shape hull. The triangular and parabolic shape hull could dissipate energy well, as compared to flat hull. Figure 10 illustrates the impact of the shape of the hull on the propagation of pressure wave resulting from the detonation. If pressure value at the wave front is resolved into two components: one normal to the hull P_n and one tangent to the hull P_t, it can be seen that normal component is much less in case of a V-shaped (triangular) hull compared to flat-bottomed hull. This is the reason for effective dissipation of energy in triangular hull.

2) The kinetic energy is well dissipated by parabolic shape hull and hence its kinetic energy is least among all shapes (refer Fig. 8).

3) The fluctuation in kinetic energy is observed in flat shape hull. This may be attributed to its flatness which did not give proper direction for energy dissipation after blast. Fluctuations were also noticed for pentagonal shape hull which can be attributed to its construction with five flat plates join together. These plates vibrate in different phase generating fluctuation in kinetic energy.

4) The fluctuation band of acceleration at mid top edge (node 2) and stress at mid bottom (element 1) are less for triangular and parabolic shape hull.

5) In overall comparison, parabolic and triangular shape hull stand better for energy dissipation and could be adopted for better blast protection.

This kind of findings has been stated by Ramasamy et al. (2009). They stated that the detonation products flow better along a V-hull than the flat hull; thereby reducing the impulse transferred to the vehicle. Robson (2011) stated that the US army is going to use "double-V hull" Stryker armored personnel carriers in Afghanistan, in hopes the new design will better protect troops against deadly roadside bombs. Janusz (2011) stated that one of the means of increasing the resistance to mine explosion is using a V-shaped hull or mounting a V-shaped armor mounted above the frame. These technical solutions allow for the explosion energy to be dissipated therefore mitigating and minimizing its impact on the hull underside.

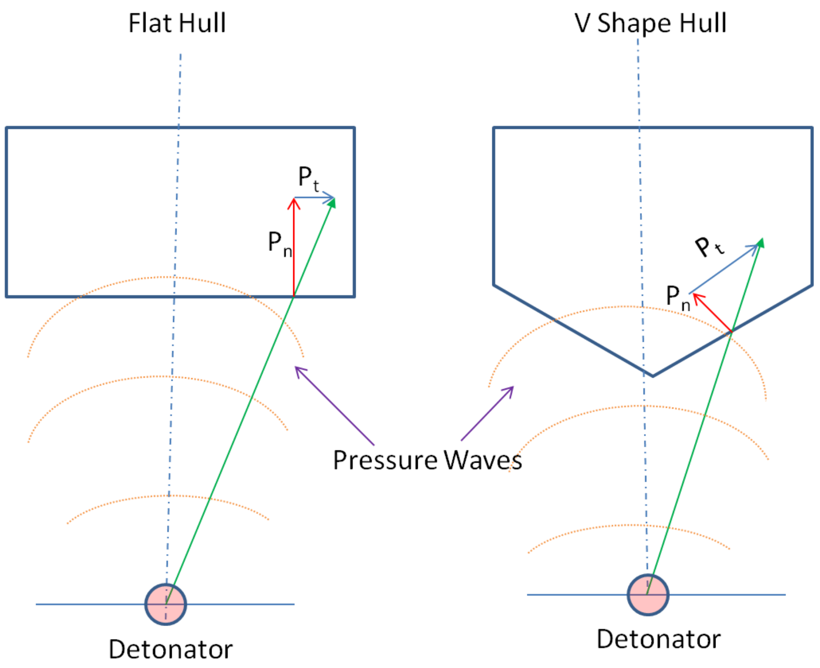

Fig. 10. Graphic representation of the impact of pressure wave on flat-bottomed hull and V-shaped hull

This article contributes towards the finite element (FE) analysis usage to simulate highly transient explosive phenomenon. The LSDyna software capability to solve such highly transient phenomenon is explored and methodology established for analysis. The result gives first cut idea towards choosing hull shape for better performance for the dissipation of explosive energy. Also with FE help the acceleration and displacement responses could be measured at desired locations. Also it could be further used for very minor details like stress\strain across cross section & pressure distribution on hulls etc. This method could save time and money by avoiding physical testing.

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