Mitigation of loads due to near field blast

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ABSTRACT
A preliminary numerical investigation has been conducted into the suitability of different geometric designs in mitigating loads due to a near field explosive blast. Blast loading in the near field is dominated by detonation product flow. The investigation focuses on mitigating the loading due to the momentum transfer of detonation products when they interact with structures. This is done by changing the geometric design of the structure to redirect the blast wave. The three-dimensional models of the blast events were developed using the AUTODYN® hydrocode. The blast was modelled using Eulerian multi-material elements while the structures were modelled using Lagrangian shell elements. A number of geometric configurations were modelled for a range of blast locations to determine their suitability for use in structural design.

KEYWORDS
Blast Loading; Blast Mitigation; Finite Element Analysis (FEA)

INTRODUCTION

Near Field Blast Loading

The propagation of a blast wave can be broken down into four regimes. These are described by Ritzel (2006) as being the detonics, near-field, mid-field and far-field regimes. A description of these regimes is presented in Figure 1.

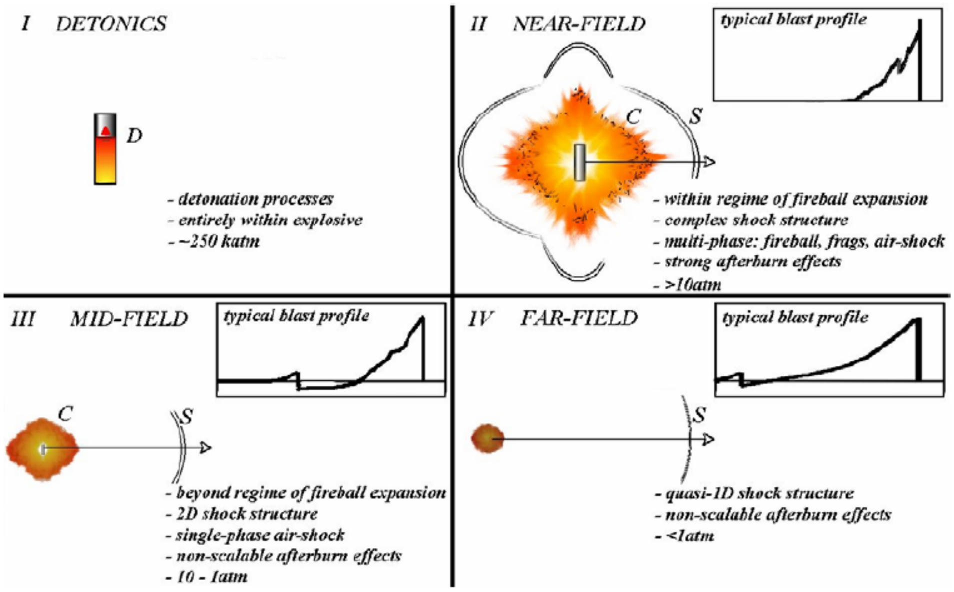

Figure 1 Four regimes of blast wave propagation (Ritzel 2006).

At the location of a target, the distribution of energy from an explosive is dependant on the size of the explosive charge and the distance from it to the target, as this governs which blast regime describes the propagation of the blast wave. In the near-field, the energy is dominated by the internal and kinetic energy of the detonation products. In the mid-field and the far-field the energy is contained within the shockwave as there is no detonation product flow at this distance from the charge.

Identifying the regime in which the blast loading for a particular explosive/target interaction occurs is important when investigating the response of a target. As the majority of the energy in the near-field of a blast wave is the kinetic energy of the detonation products, measuring the force on the structure due to the change in momentum of the detonation products is important. Mitigating blast loading in the near-field requires a reduction in the momentum transfer to the structure. This can be achieved in two ways; either the blast wave can be altered before interacting with the structure or the structure can be designed to reduce the momentum transferred to it.

Geometric Effects on Blast Loading

The focus of this investigation is on utilising the geometric properties of the structure to reduce the momentum transferred in the near-field during a blast event. Needham (2010) provides an example of the use of numerical simulations to analyse the near-field loading on a building from an explosive charge. He also states that “the loading of a structure depends strongly on the architectural design and geometry of the exterior of the building”. The effect of geometry on blast loading can also be implemented in the design of blast barriers as well as armoured vehicle design.

This preliminary investigation into mitigating near-field blast by using structural geometry will focus on the blast loading of a vehicle hull. It should be noted that the small target geometries and charge sizes do not represent scaled versions of any specific vehicle hull or explosive size. Small scale experimental investigations into hull shapes have been conducted by Chung Kim Yuen et al. (2010), Benedetti (2008) and Genson (2006). All of these investigations showed that as the internal angle of the hull was reduced, the vertical momentum transferred was reduced. This is expected as in all of these investigations the charge is placed directly under the centre of the hull. Inclusion of off-centre charge locations in hull shape experiments was performed by Child (2009), but due to a lack of consistent data, a definitive comparison between centre and off-centre charge locations was not possible.

METHODS

Numerical modelling was used to analyse the response of different hull geometries subjected to near-field blast loading. The AUTODYN™ hydrocode was used to run the simulations while the hull geometries were generated in ANSYS DesignModeler™.

Defining the Blast Loading

Some armoured vehicle hulls utilise their shape to protect against landmine loading. Rather than use soil, the charge was modelled as being placed in a steel pot. The steel pot acts to confine the charge and produce a focused blast that has similarities in loading to a landmine event.

The explosive and air were simulated using 3D multi-material Euler elements. The steel pot was modelled using solid Lagrange elements and the targets were modelled using shell elements. The model was set up to simulate the loading from a C4 charge of 11.3 g being detonated within a steel pot. Figure 2 shows a cross-section of the model setup with a flat plate target. Due to the inherent symmetry in the model, only half of the hull was required to be modelled. The use of a symmetry axis reduces the number of elements in the simulation and reduces the processing time.

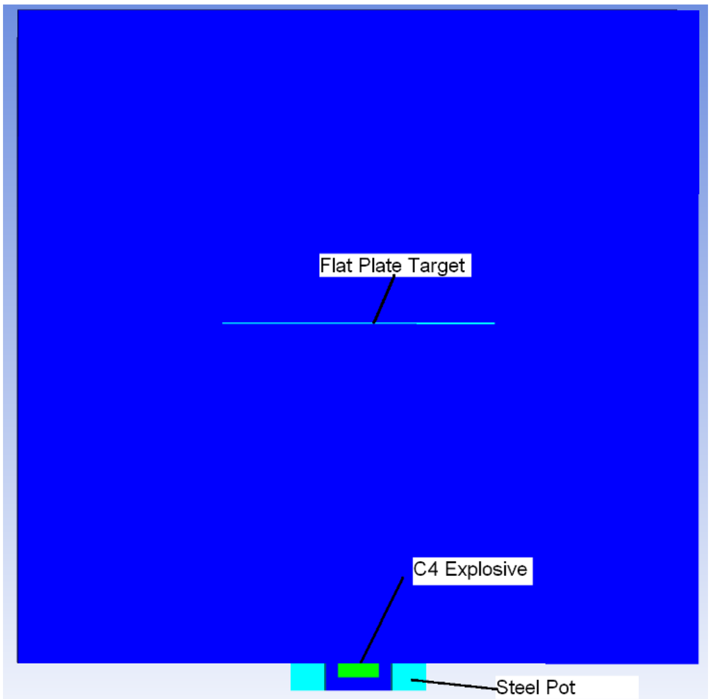

Figure 2 Arrangement of model with flat plate as target.

The dimensions of the Euler grid were 500x500x500 mm. After a convergence study was performed on the mesh density, the mesh selected contained 100x100x100 elements. The Euler grid was positioned such that one of the faces coincided with the axis of symmetry. Flow-out boundary conditions were applied to the other faces in order to prevent reflection of the blast wave. The cylindrical C4 charge had a radius of 15 mm and a height of 10 mm. The cylindrical steel pot left a clearance gap of 10 mm in all directions between itself and the charge. Its outer radius was 50 mm with an inner radius of 25 mm and a height of 20 mm. The material model used for C4 was the Jones-Wilkens-Lee (JWL) equation of state (EOS) (Dobratz and Crawford 1985). The material model used for the steel pot and the target hulls is the 4340 steel material model (Johnson and Cook 1985), with a linear EOS and a Johnson-Cook strength model. No failure model was used for the steel in these simulations.

The effect of the blast loading on the hull was measured by the linear momentum transferred to the target hulls. The analysis of momentum transfer is then broken down further, into the vertical, horizontal and total linear momentum transferred to the target hulls, where the total linear momentum is defined as the addition of the vertical and horizontal momentum.

Targets Investigated

A total of five different geometries were investigated. The five geometries consisted of a flat plate, three v-hulls of differing internal angle and a convex hull. Figure 3 shows the different geometries used in this investigation. Every hull had a projected area of 200 x 200 mm. The thickness of each hull was 1 mm. The standoff distance was measured from the top surface of the hulls to the top surface of the C4 charge. This distance was chosen to reflect the fact that the addition of geometrically shaped hulls to existing flat hulls would mean the 'ride height' or vertical position of the existing flat hull would be fixed. The geometries of the hull were selected to be similar to other small scale experiments, but the specific dimensions were arbitrary as the intention was not to use a scaled version of a specific armoured vehicle.

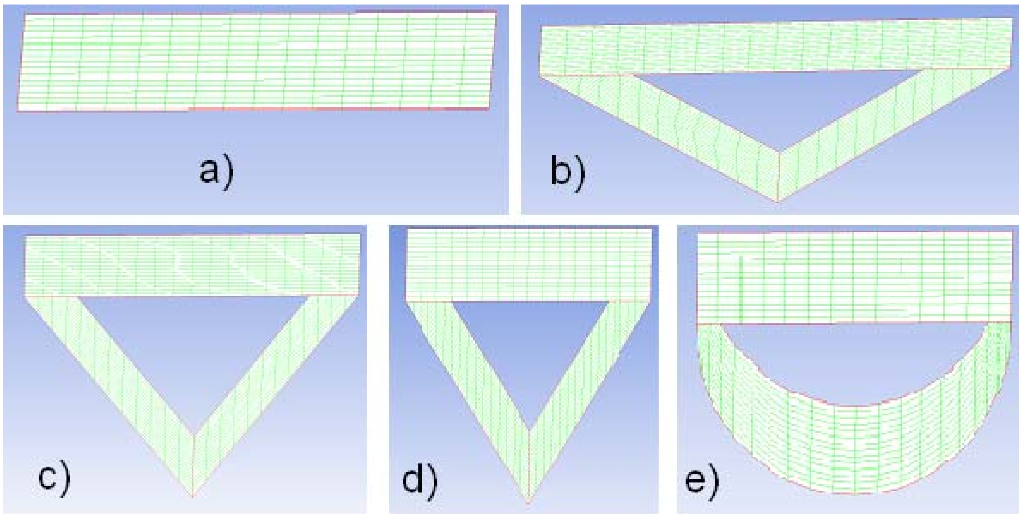

Figure 3 a) Flat plate b) 120˚ v-hull c) 90˚ v-hull d) 60˚ v-hull e) convex hull.

For each hull shape, models were run at three different standoff distances from the explosive charge which was centrally located beneath the target hulls. The standoff distances selected were measured vertically from the top surface of the C4 charge to the top surface of each hull shape. The standoff distances modelled were 250 mm, 300 mm and 350 mm. In addition to investigating the effect of standoff distance on the different hull shapes, the location where the charge was placed was altered from the central location. This resulted in two further charge locations being investigated for each hull shape in addition to the central charge location. The charge locations for these simulations were measured horizontally from the centreline of the hulls and were situated such that the detonations occurred at half and full span of the hull. These additional simulations were run at a standoff distance of 300 mm, measured vertically from the top surface of the C4 charge to the top surface of the target hull. This resulted in a total of 25 simulations being run in this investigation.

RESULTS AND DISCUSSION

Effect of Hull Shape

A comparison between the five different hull shapes, at different standoff distances is shown in Figure 4. In all of these simulations the steel pot was placed directly under the centreline of the target. Figure 4 shows that there is a clear advantage in using the geometry of a structure to deflect some of the blast loading. In the case of the v-hulls, the vertical momentum transferred to the structure was shown to decrease as the internal angle was reduced. The convex hull gave results that were similar to the 120˚ v-hull which is due to the similarities between their geometry around their centrelines. Figure 5 shows the percentage change in vertical momentum transferred to the different hull shapes when compared to the flat plate at the corresponding standoff distance.

Figure 5 shows reductions in the vertical momentum transfer when compared to the flat plate of 46% for the 60˚ v-hull and 31% for the 90˚ v-hull at a standoff distance of 250 mm. This is comparable to the results found by Chung Kim Yuen et al. (2010), where there was a 42% reduction for the 60˚ v-hull and a 31% reduction for the 90˚ v-hull. The percentage reduction in vertical momentum transfer for the 120˚ v-hull when compared to the flat plate at a standoff distance of 250 mm was 15%. Experimental results from Chung Kim Yuen et al. (2010) show a 23% reduction in vertical momentum transfer for the 120˚ v-hull. This small difference is most likely due to the differences in charge size and target size used in the two investigations.

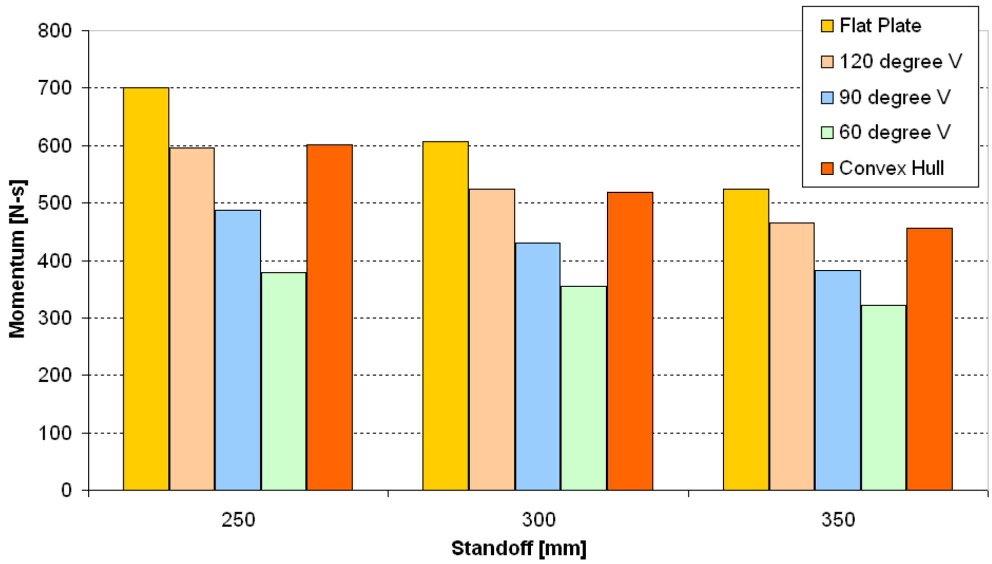

Figure 4 Comparison between vertical momentum transferred for different hull geometries and standoff distances for charges placed under the centreline of the hull.

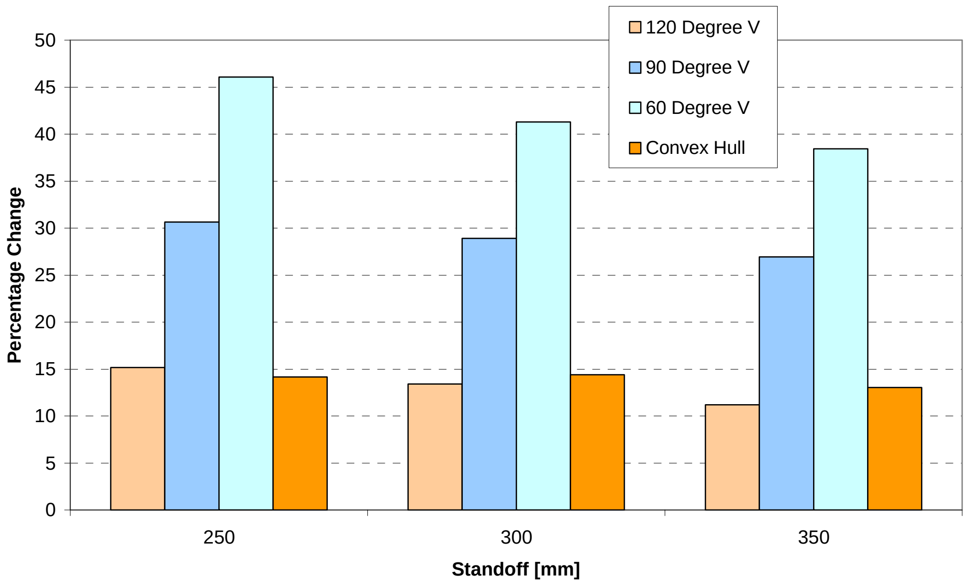

Figure 5 Percentage reduction in the vertical momentum transferred to different hull geometries when compared to the flat plate at the corresponding standoff distances for charges placed under the centreline of the hull.

Effect of Standoff Distance

As the standoff distance between the charge and the target increased, the vertical momentum transferred was reduced. Figure 4 shows that the flat plate, the convex hull and the 120˚ v-hull had the largest reduction in vertical momentum transferred with the increase in standoff distance, however they also recorded the highest vertical momentum transfers. It was found that the percentage reduction in vertical momentum transfer for an increase in standoff distance was similar for all hull shapes except the 60˚ v-hull. The reason for this difference for the 60˚ v-hull is not understood at this stage. It was found that the convex hull had a higher vertical momentum transfer than the 120˚ v-hull at a 250 mm standoff distance but recorded a lower vertical momentum transfer than the 120˚ v-hull at a 300 mm standoff distance. This is likely due to the varying angle of the convex hull. As the standoff distance increases, the radial spread of the blast wave results in different angles of incidence between the blast wave and the target hull. As the standoff distance increases the blast wave interacts with the steeper angles of the convex hull, which results in a larger reduction in the vertical momentum transfer when compared with the 120˚ v-hull.

Effect of Charge Location

A comparison of the vertical momentum transfer between the 5 different hull shapes, using different charge locations is shown in Figure 6.

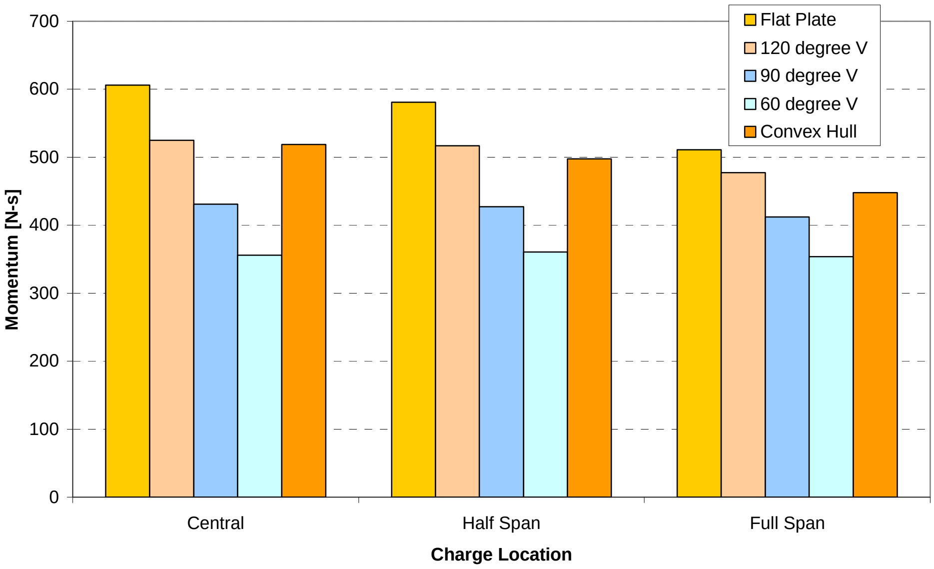

Figure 6 Comparison between vertical momentum transferred for different hull geometries at different charge locations at a standoff distance of 300 mm.

Figure 6 shows that in all cases except the 60˚ v-hull at half span, as the charge was positioned away from the centre there was a small reduction in the vertical momentum transferred to the target. Whilst there was a reduction in the vertical momentum transferred, the reduction was below 5% for all geometries at half span. This is only a minimal reduction considering the additional horizontal momentum that is transferred to the target when the charge is placed at half and full span.

The minimal reduction in vertical momentum transfer as the charge is moved off-centre is explained by the incident angle between the target hulls and the blast wave. Whilst, the blast wave from the steel pot is focused, it still spreads radially. For centreline charges the blast wave will always interact with the sides of the v-hull at an angle, which reduces the vertical momentum transfer due to deflection of the blast wave. For off-centre charges, whilst some of the blast wave will miss the target hull, a portion of the blast wave interacts with the side of the hull directly perpendicular to the hull's surface. Hence whilst there are some losses in the vertical momentum transferred when compared to the centreline charge location from part of the blast wave missing the vehicle, due to the perpendicular interaction of part of the blast wave with the target hull, only a minimal reduction in the vertical momentum transfer is observed. In addition to the vertical momentum transferred to the hulls, for off-centre charge locations there is a significant amount of horizontal momentum transferred to the hulls.

Figure 7 shows the horizontal momentum transferred to the different hull geometries at different charge locations. It shows that the horizontal momentum transferred increases as the internal angle of the v-hulls reduces. This is the opposite of what was found for the vertical momentum transfer to the target hulls. Figure 8 shows the total momentum transferred to the targets for different charge locations. All results presented are for a standoff distance of 300 mm. Figure 8 shows that the total linear momentum transferred to the targets is actually higher for the v-hulls than the flat plate for the full span charge location. Whilst the total momentum is higher, the breakdown in momentum is different, with the v-hulls having a higher percentage of horizontal momentum than the flat plate.

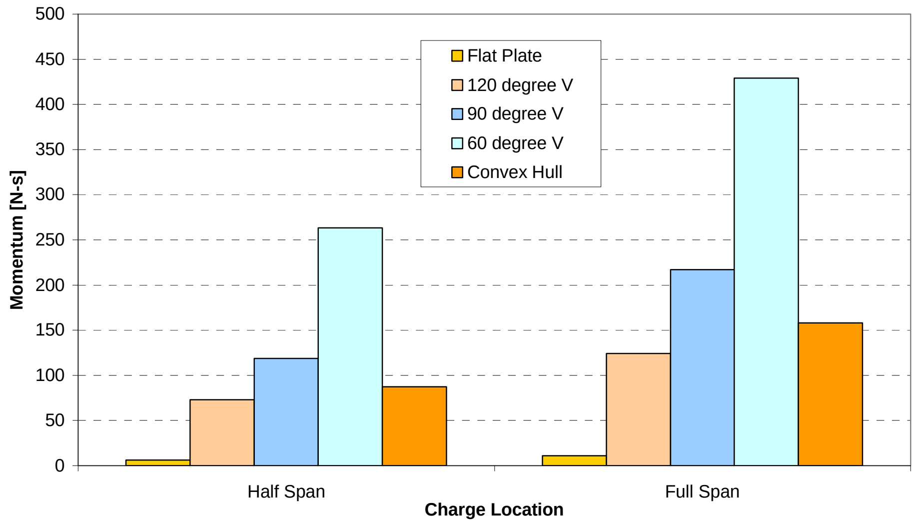

Figure 7 Comparison between horizontal momentum transferred for different hull geometries at different charge locations.

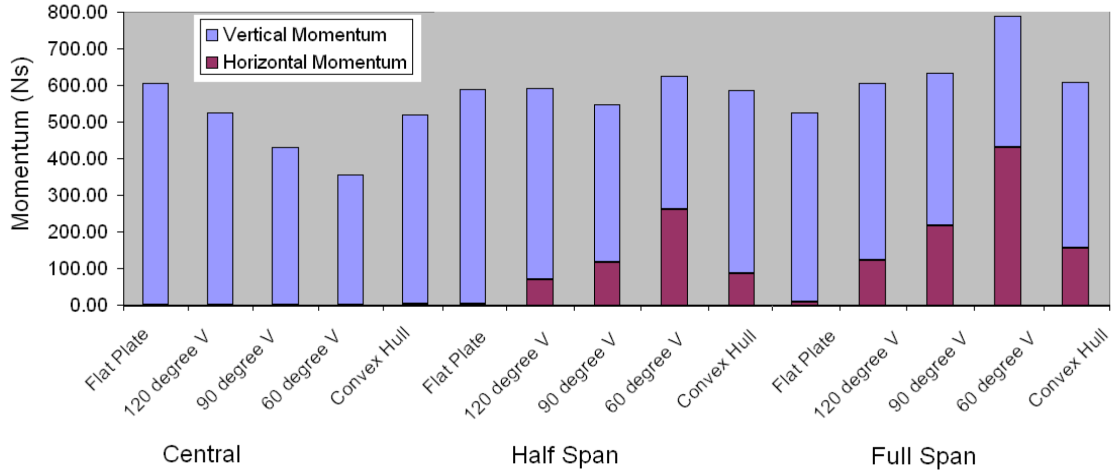

Figure 8 Breakdown of total momentum transfer to targets for different charge locations.

Limitations of Analysis

At this stage this investigation has only detailed the momentum transferred to the structures. In addition to recording the momentum transfer, it is important to understand the effects of hull geometry, standoff distance and charge location on structural deformation. In addition, this work was performed with an arbitrary target size, explosive size and standoff distance. The changes in momentum found will vary depending on the relationship between these variables.

CONCLUSIONS

The results for the vertical momentum transferred to the different target geometries subjected to near-field blast loading matched well with experimental results in the literature. It was shown for this particular arrangement of charge size, standoff distance and target width that the vertical momentum transferred to a structure could be reduced by up to 46% by the addition of a v-shape. There was also a clear reduction in the momentum transferred to the structure as the standoff distance increased.

The charge location was also shown to have a significant effect on the momentum transferred to the structure. Whilst there was only a minimal reduction in the vertical momentum transferred to the different targets when the charge location was moved, there was a significant change in the horizontal momentum transferred. Based on this assessment one must always consider the different loading conditions a structure may be subjected to before optimising the geometry of the structure to mitigate near-field blast loading.

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