A New Way for Multi-piece and Multi-hit Fragment Impact Simulation Using LS-DYNA

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Abstract

The kinetic feature of weapon fragment is many small masses traveling at extremely high velocities and scattering radially from the explosion center. To simplify the fragment impact analysis, people often convert the fragment momentum into a triangular pressure load with very high magnitude and very short duration, and apply the load directly onto the target. This method may over- or under-predict the impact response due to the complicacy of fragment behaviors such as embedment, perforation and ricochet. It might encounter more difficult situation when involving multi-layer impact and penetration problem. This paper proposes a new method for fragment simulation using the contact technique provided in LS-DYNA. A program was developed which can automatically generate the LS-DYNA keyword input of node, part, initial velocity and contact surface cards for multiple pieces and sets of fragments, based on the given information about mass, location, velocity of each fragment, and other user-defined parameters. This method can be applied not only on multi-piece fragment impact simulation, but also on multi-hit problem in a realistic way. Examples of fragment impact on structure are demonstrated.

Keywords: *LS-DYNA, Contact, Fragment, Impact, Multi-hit, Multi-piece, Penetration*

Introduction

With the continuously increasing of computation power, the fragment simulation for cased weapon explosion can be investigated in more and more details. Due to the random feature of the size and kinetic difference of hundreds even thousands fragments, previous studies usually did not model weapon fragments as small mass traveling at high velocity, in stead, a common approach for fragment loading was to convert the momentum of each traveling fragment into a simple triangle pressure impulse with a very short duration and very high peak pressure. On one hand, the pressure loading method eliminates the fragment momentum components tangent to the impact surface which might be a significant contribution to the target damage; on the other hand, this method is hard to accurately count in the effects such as fragment ricocheting off target surface, embedded inside target, or penetrating through the target. Simplifying or disregarding these effects may significantly over- or under-predict the target response. Additionally, it might encounter more difficult situation when the simulation involves multi-layer impact and penetrations. For instance, it is hard to predict the target position on the second layer by the pressure loading method, if the fragment travels with rotational velocity components and has penetrated the first layer. The goal of this research is to design and produce an FEM tool for generating the finite element mesh and other LS-DYNA keyword cards for a given set of fragments with different masses and velocities. It is proposed to apply contact techniques provided in LS-DYNA to simulate the fragment impact phenomenon, in which the effects of ricochet, embedment, and penetration can be simulated in a natural manner. To reveal the use and features of this method, examples of weapon fragments impact on metal sheet and concrete walls are shown.

Methodology

To completely represent the kinetic state of weapon fragments, the key point is to map each fragment into an individual part with the centroid of that part being the fragment location, and assign the corresponding mass to that part and velocity to the nodes. Same material and section cards can be used for all fragment parts from one cased weapon. The raw data required are coordinates, velocities and mass of each fragment, i.e., $\mathbf{x}_{fi}$, $\boldsymbol{v}_{fi}$, and m_{fi} ($i = 1$ *to* n). One can obtain such fragment data from various sources. The issue for determining the fragment mass distribution and velocity components is beyond the scope of this research.

The flow chart for generating LS-DYNA keyword input for fragment parts is given in the following sketch:

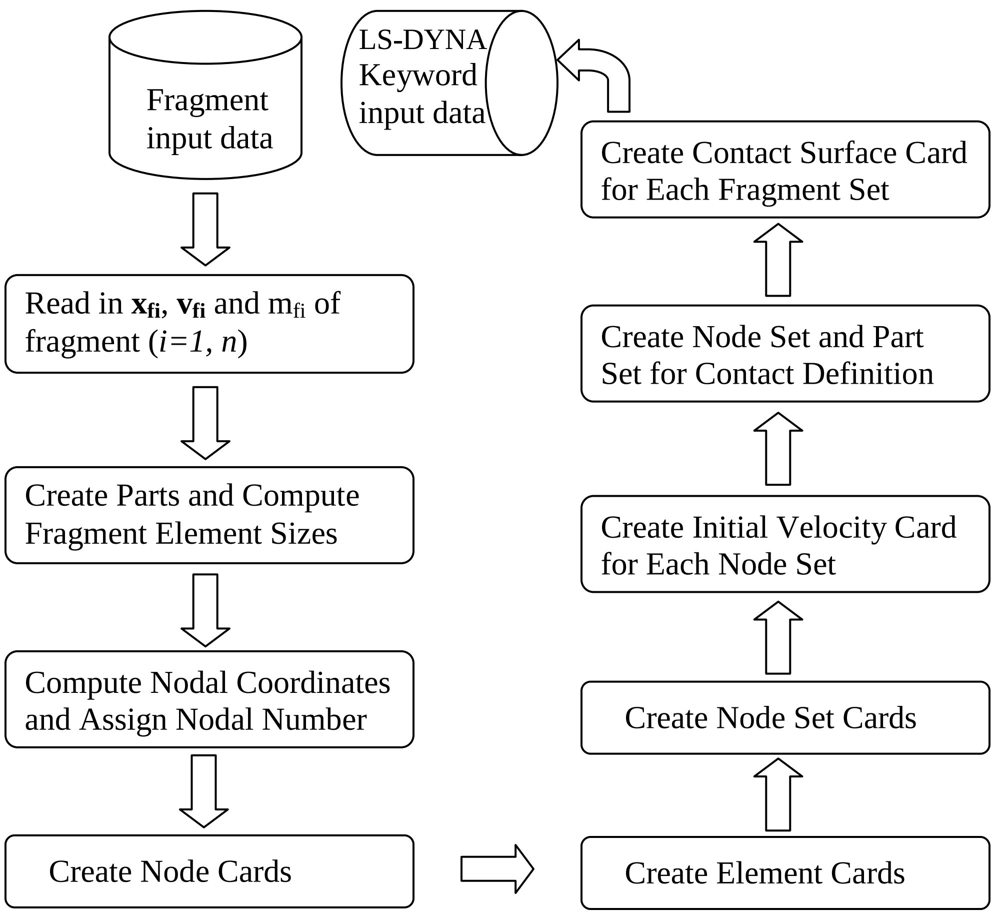


Figure 1 Flow chart for generating keyword input of fragments.

To save the memory and CPU time, the nodes belongs to one fragment set are included within one slave node set. The surfaces of the target are defined as the master contact surfaces. The contact type in LS-DYNA *CONTACT_AUTOMATIC_NODES_TO_SURFACE is used for defining the contact between fragments and target without eroding, or *CONTACT_ERODING_

NODES_TO_SURFACE if eroding involved. One can run the program several times to obtain keyword inputs for separate fragment sets created by multiple cased weapons.

Demonstrations

Single-piece and Single-hit Fragment Impact Analysis

First, a simple finite element model with single-piece fragment impact on a square metal sheet was analyzed. The common triangle pressure loading method and the proposed contact method were compared. The target is a 60 in × 60 in 16GA A36 metal sheet which was embedded within a fixed frame. The sheet was discretized into 3600 LS-DYNA type-16 shell elements and the surrounding fixed frame was modeled as type-2 solid element (Figure 3(b)). To simplify the comparison, both the fragment and target were modeled as elastic materials. The metal sheet was located in a plane far away from the cased generic weapons (Figure 2).

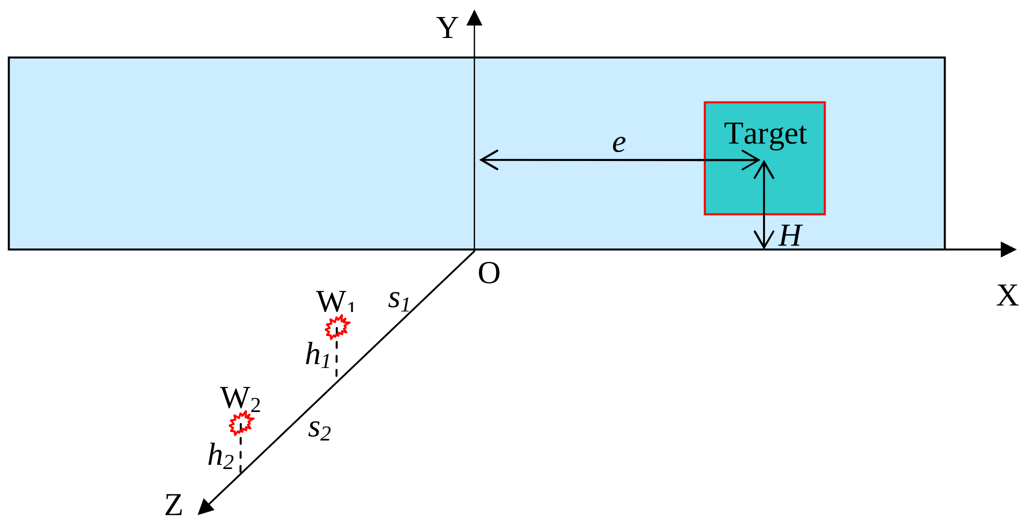
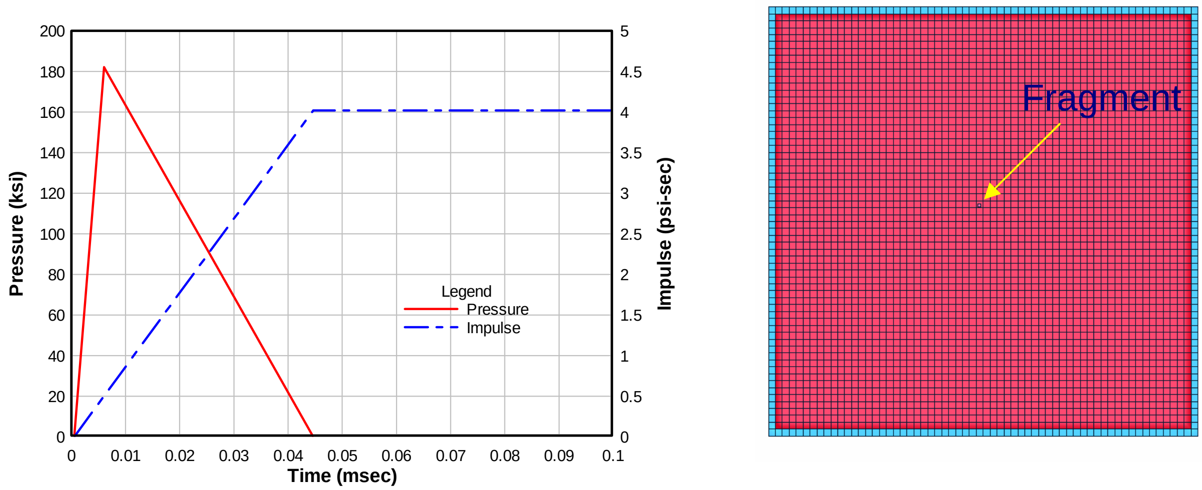


Figure 2 Sketch of the weapon, target and coordinate system.

From the explosion of a light-weight cased weapon, a single piece fragment was taken from the whole set of fragment data (marked by "+" in Figure 7(b)). For contact loading method, the mass of that fragment m_f is 0.0175 lb. The initial velocity components of the fragment before it hit the target were: v_x = 11520 in/sec, v_y = 2289 in/sec, v_z = 68215 in/sec. For pressure loading method, the pressure-time history curve converted from that traveling fragment is shown in Figure 3(a). The pressure was applied only on one shell element located at the impact point; the peak pressure, duration and impulse were 182.1 ksi, 0.0442 msec and 4.02 psi-sec, respectively. These values were adjusted according to some empirical data and the element size used.

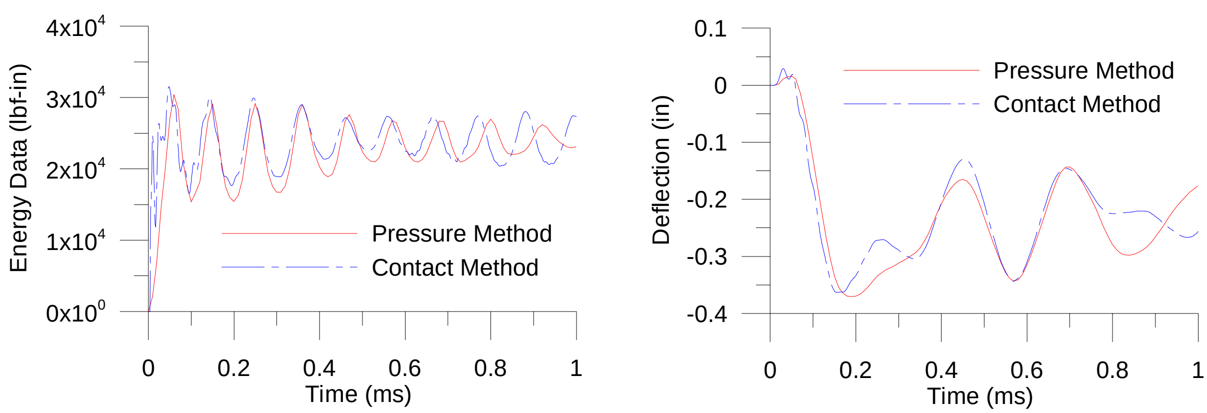
The fragment momentum at each direction are given by mv_x=0.526 psi-sec, mv_y=0.132 psi-sec, and mv_z=3.114 psi-sec, and the resultant momentum mv= 3.161 psi-sec. Therefore, the converted impulse defined by the triangular pressure curve is 27% higher than the momentum carried by fragment. Since the size of fragment is usually smaller than the mesh size of target, a single brick element was used to represent the fragment in the contact method (Figure 3(b)).



(a) (b)

Figure 3 (a) Pressure and impulse time history converted from single fragment impact and (b) the finite element mesh of fragment and target.

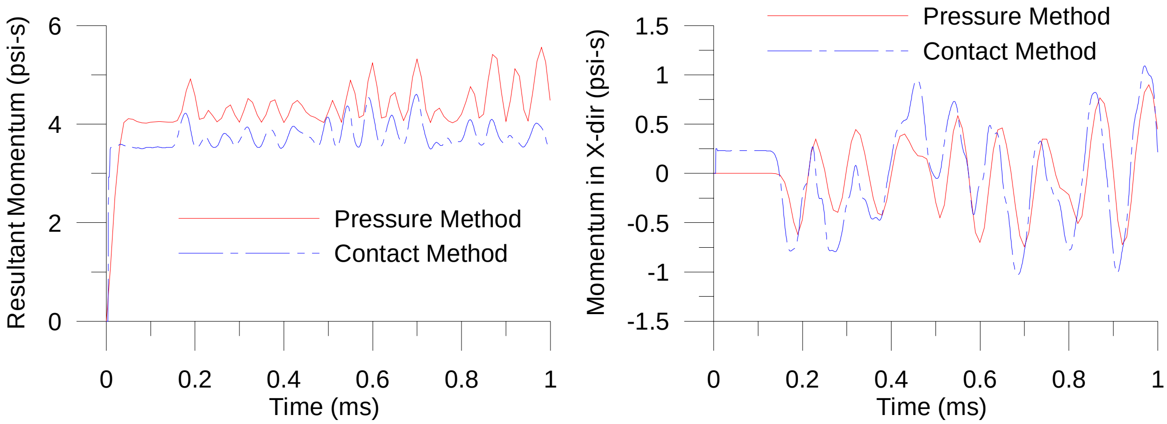
Figure 4 shows the calculated time history of energy (sum of kinetic and potential energy) obtained by the metal sheet. The corresponding deflection history plots of the metal sheet were compared in Figure 4(b). It is shown that the contact method can replicate the major structural response as predicted by pressure method. However, it is evident that the contact method has a faster loading rate which may affect the structural behavior if a rate-dependent material was used. This will be brought out in the following multi-piece fragment impact examples.



(a) (b)

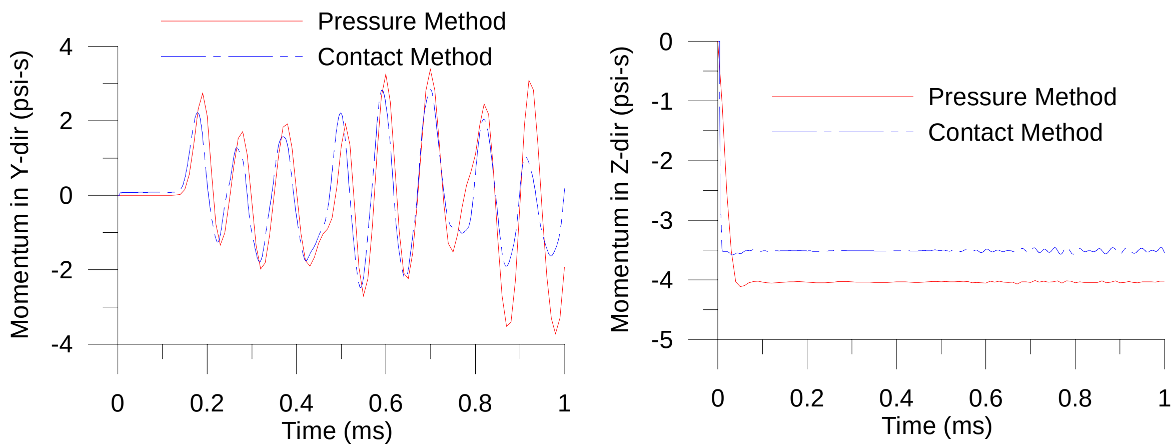
Figure 4 Comparisons of (a) energy; (b) deflection history of target.

From the view of momentum, the pressure method transferred more resultant momentum to the metal sheet through artificial compensation (Figure 5(a)). However, no momentum in tangent directions (i.e., XY plane here) can be transferred by pressure method since the pressure loads are only applicable to the direction normal to the load segments (Figure 5(b) and 6(a)). Oppositely, the contact method directly inherited the momentums in the all directions (i.e. normal and tangent to the target surface).



(a) (b)

Figure 5 Comparisons of momentum history of target (a) resultant; (b) in x-direction.



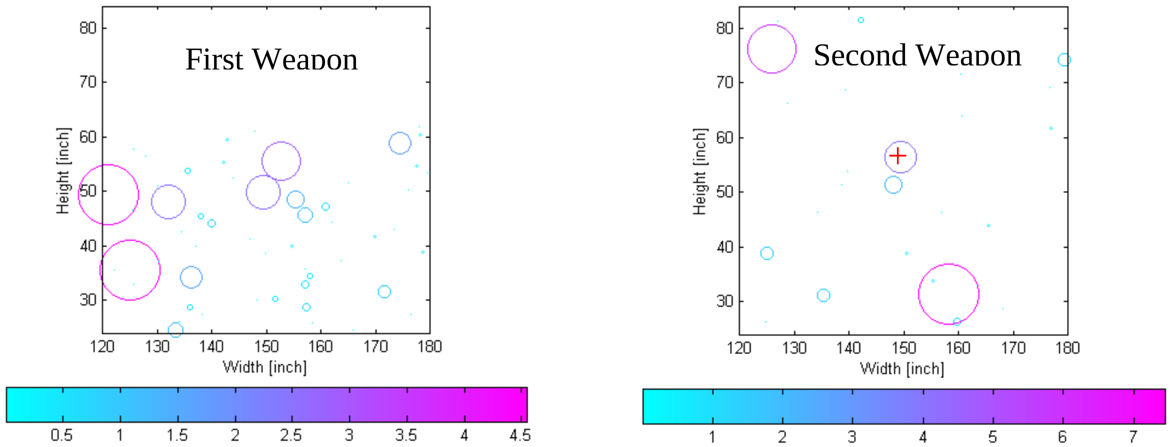
(a) (b)

Figure 6 Comparisons of momentum history of target (a) in y-direction (b) in z-direction.

Multi-piece and Single-hit Fragment Impact Simulation

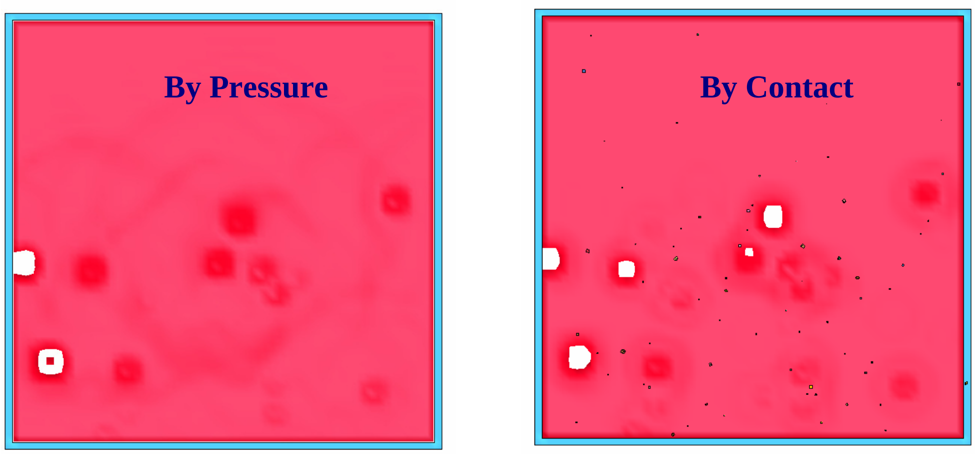
To demonstrate the natural capability of the proposed method for multi-piece and multi-hit fragment impact simulation, fragments originated from two light-weight cased weapons were applied to the same target. The first one has a closer standoff, and another has a standoff of double distance. The corresponding impulse produced by both hits are plotted in Figure 7(a) and (b), respectively. Calculations by both the pressure method and contact method were performed to show the difference between two methods. To see the loading rate effects, the metal sheet was modeled as a rate-dependent material using the LS-DYNA material type *MAT_PIECEWISE _LINEAR_ PLASTICITY with a 45% failure strain.

First, the multi-piece and single-hit fragment impact calculations were performed for both weapons. The deformed meshes after the single-hit from first weapon were shown in Figure 8. It is observed that the contact method predicted more perforations than the pressure method. Figure 9 displays the deformed meshes after the single-hit from second weapon. One may notice that the pressure method created holes close to uniform and smooth shapes, and most holes by the contact method are not uniform or smooth because of the contribution of tangent momentum components. This phenomenon manifests the effects of the tangent components of momentum.



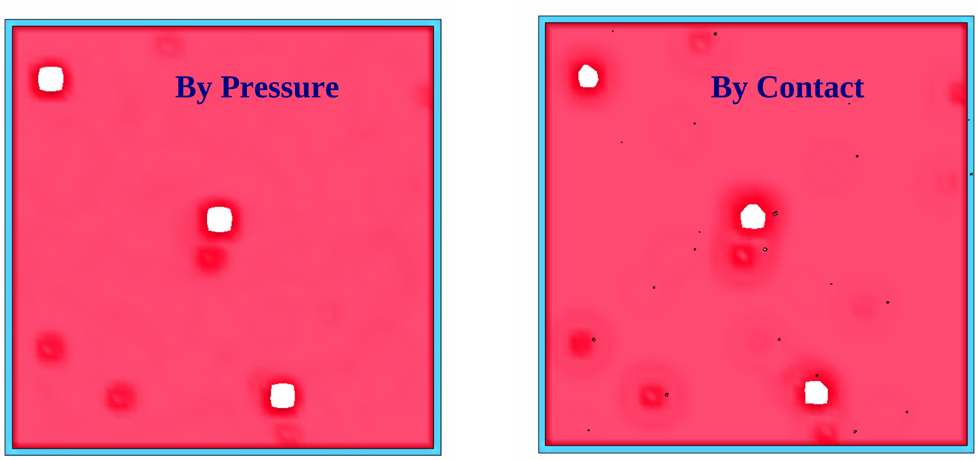
(a) (b)

Figure 7 Impulse distributions of fragments from two cased weapons.



(a) (b)

Figure 8 Deformed meshes after single-hit from first cased weapon.

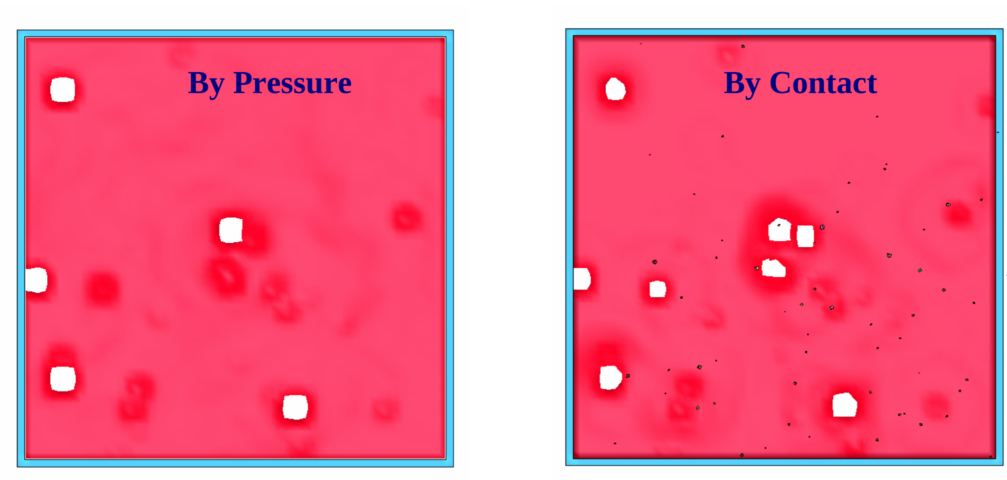


(a) (b)

Figure 9 Deformed meshes after single-hit from second cased weapon.

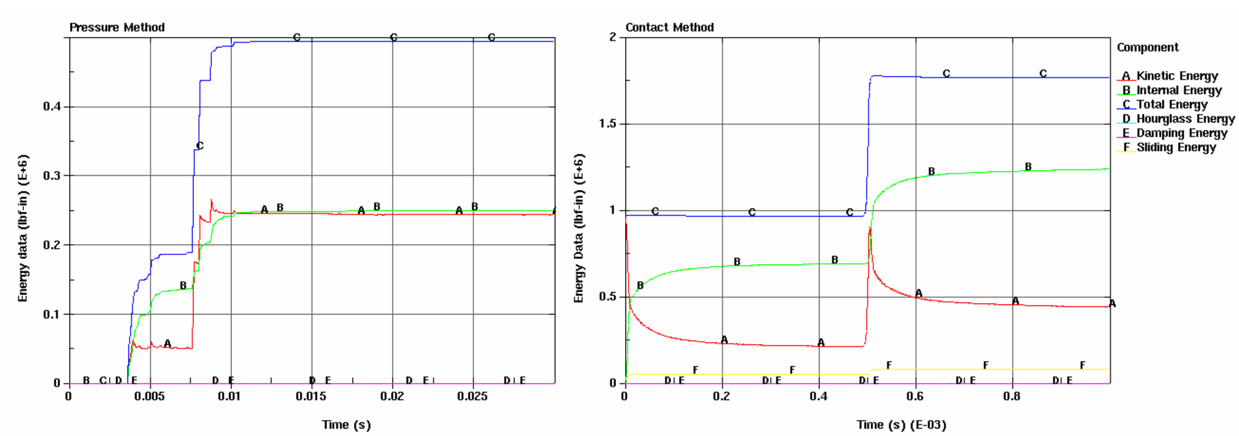
Multi-piece and Multi-hit Fragment Impact Simulation

After the single-hit tests, the multi-piece and multi-hit impact process was investigated by using both the pressure method and contact methods. The two fragment data sets in previous calculations were applied in sequence in the multi-hit simulation. As illustrated in Figure 11, the two energy jumps reflect two sequent hits. The energy shown in Figure 11(a) is the energy obtained by the metal sheet, the one in Figure 11(b) is the energy carried by both the fragments and metal sheet. Figure 10 displays the perforated patterns of metal sheet after two hits. The shapes of the holes created by pressure method are similar and smooth. Considering the radially scattering feature of fragments from the initial weapon location, the response predicted by contact method is more realistic. This also reveals that the pressure method possibly yields more mesh size dependent solutions than the contact method does, since the peak pressures was adjusted based on the size of load segments in order to keep the impulse unchanged.



(a) (b)

Figure 10 Deformed meshes after two hits from both cased weapons.



(a) (b)

Figure 11 Energy history plots corresponding to the multi-hit fragment impact shown in Figure 10 for both (a) pressure and (b) contact methods.

Application to Concrete Wall Simulation

As an example of application, the proposed method was applied to the simulation of fragment impact on a scaled heavy reinforced concrete wall. The wall has a dimension of 8ft long, 4ft high and 10in thick (Figure 12), and is fixed in a concrete frame. The whole wall was discretized into 166,000 solid and 30,000 beam elements. Material properties of Grade 60 rebar and $f_c^{'}$=6ksi concrete were used. The fragments (total 671 pieces) were modeled as rigid material.

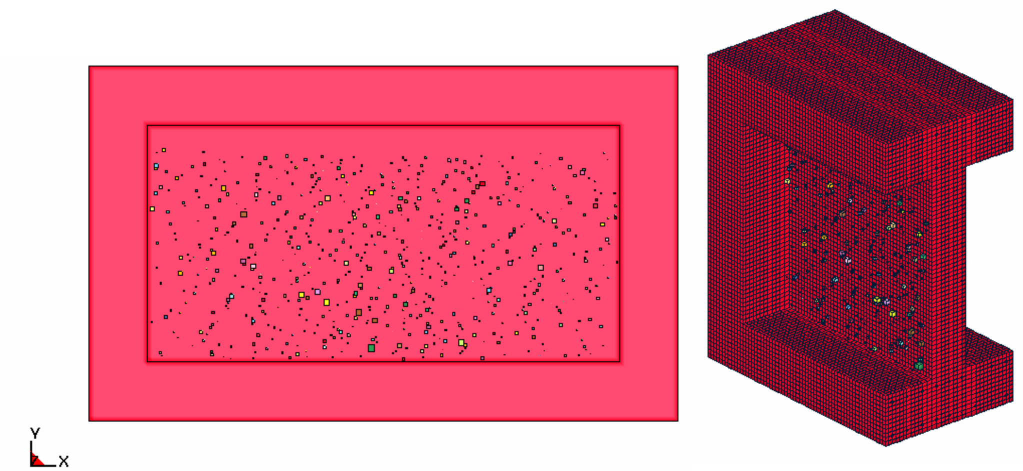
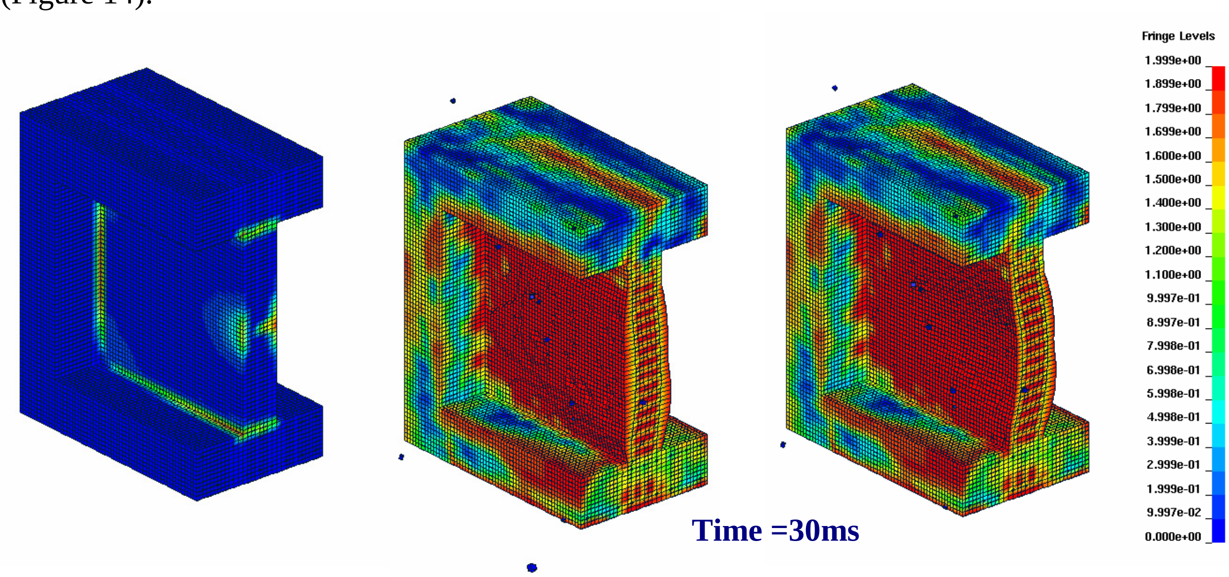


Figure 12 Finite element models of a reinforced concrete wall and fragments.

Three loading scenarios were applied in the simulations: (1) apply blast loading only; (2) apply fragment impact only; and (3) apply both fragment impact and blast loading. The case with blast loading only produced minor damage in the reinforced concrete wall (Figure 13(a)). Fragment impact can yield severe wall damage (Figure 13(b)), spalling was observed at both front and rear wall faces since there was no blast loading after fragment impact. Figure 13 (c) demonstrates spalling only created at rear face. The combination of fragment impact and blast loading can produce a much lager deflection than either of blast loading or fragment impact only cases (Figure 14).



(a) Blast only (b) Fragment only (c) Both fragment and blast

Figure 13 Final damage states of half walls predicted by three different loading cases.

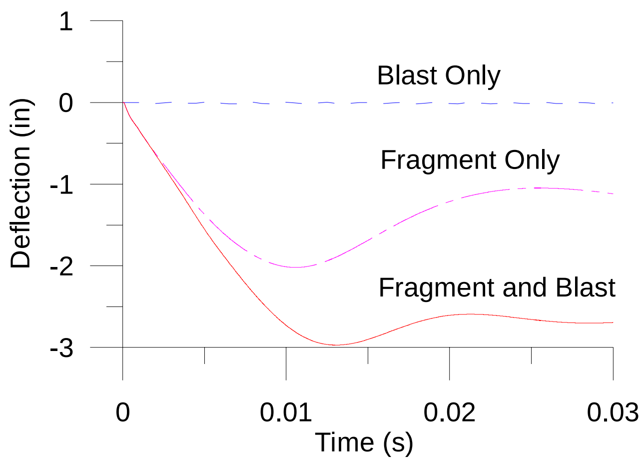


Figure 14 Comparison of deflection time histories predicted by three loading cases.

Conclusions

Through defining different sets of fragments and different contact surfaces, the proposed method has been demonstrated to be capable of modeling the multi-piece and multi-hit fragment impact phenomenon. By combining the material failure criteria or erosion treatment, it can be further applied to fragment impact on multi-layer targets. The key feature of this method, that it unconditionally inherits the momentum carried by fragments, naturally leads to more realistic simulation results. It is also efficient considering CPU expense, though the contact method requires very small time step and a small number of bucket sorts. The initial velocity of fragment from cased weapons is commonly at about 1000~3000 m/s, therefore, the contact duration for most structural analysis is less than half millisecond. As for the pressure method, it also requires a very small time step to guarantee a correct loading path, since the duration of the converted triangle pressure history is normally much shorter than the calculated based on mesh. Suitable damping should be applied when using the proposed method, especially when the fragment parts modeled as rigid materials. A further investigation is necessary for parameters defining more reliable contacts.

References

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