A simulation strategy for prediction of debris due to internal explosion of an earth-covered magazine

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Abstract

For safety and land saving, it is important to study the breakup of earth covered magazine (ECM) due to internal detonation. As experimental study of such problem is very expensive, time consuming and with many limitations in scaling, data collections and analyses, numerical simulation using advanced modelling techniques provides a valuable alternative approach. In this study the commercial dynamic solver LS-DYNA [1] is adopted to carry out the simulations of the magazine breakup by using the cohesive element model. The introduction of cohesive element with zero thickness reduces the time step of calculation dramatically. Hence, it takes several weeks or even several months to run the fully 3D model with cohesive element. In order to make the computation time affordable, here a short-cut strategy is proposed to study the magazine breakup by numerical simulation.

Keywords: Earth covered magazine (ECM), Short-cut, Cohesive element, LS-DYNA, Break-up, Computation.

Introduction

Upon accidental internal explosion, an ammunition magazine will break up and debris formed will be ejected out at high speed. The debris could impact on the neighboring structures or people and may cause damages and causalities. The size of the hazard zone due to ejected debris is a critical factor to meet the design requirements of minimum safe clear distance to the nearby inhabited buildings or facilities. Due to the nature of the problem, full-scale or scaled experimental study on the high speed debris trajectories is deemed to be very costly. A feasible alternative is to harness the power of the modern computing technology to conduct numerical simulations, together with verification by a limited number of field tests. In numerical simulation, a physics-based modelling procedure has to be established to simulate the dynamic response and the breakup process of the earth covered magazine (ECM). These simulations were based on the general dynamic analysis package LS-DYNA [1] which has been used extensively in solving dynamic problems (impact, crash, penetration, explosion, etc.).

The present simulation involves quite a few simulation aspects: blast loading, fluid solid interaction (FSI), structural breakup, etc. The breakup modelling is critical to determine the debris distribution, their velocities and their flight distances. In this study, cohesive law and cohesive elements are introduced to simulate the reinforced-concrete (RC) ECM breakup. In the cohesive law/element approach, FE elements are connected to each other through inter-element faces by cohesive elements. These cohesive elements, sometimes referred as ñinterface elementò, are inserted along the all element interfaces. Fractured surface will be formed along FE mesh interface once the cohesive element fails. The introduction of cohesive element with zero thickness will reduce the time step of calculation dramatically. Hence, it will take several weeks or even several months to run the fully 3D model considering these time-consuming modeling techniques - cohesive element, blast loading simulation, FSI, contact, etc.

In order to make the computation time affordable, here a short-cut strategy is proposed to study the ECM breakup by numerical simulation. The aim is to obtain the debris flying trajectory and landing position. The short-cut strategy can be summarized as follows:

Step 1 of the short-cut strategy

Full 3D LS-DYNA run

The internal explosion in magazine produces the shock wave, the reflective pressure and gas pressure. The blast loading is exerted on the magazine, leading to magazine breakup and flying. The velocity of the formed debris will increase very fast in the stages of shock wave and the reflective pressure, then increase steadily to a constant velocity by the gas pressure. So the Step 1 of the short-cut strategy is to run the full 3D LS-DYNA model until to the steady stage. Fig. 1 gives the full 3D model.

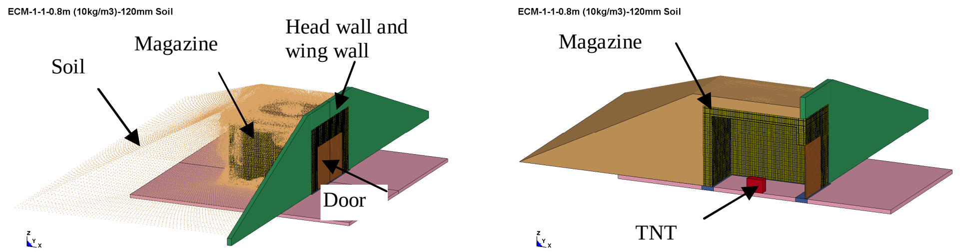


Figure 1. The full 3D model of ECM

Strip 3D LS-DYNA run

Based on the full 3D model, a strip is cut out along the symmetric plane with certain thickness. Fig. 2 gives the strip 3D model of ECM. This model saves quite a lot of calculation resources and can run to the end. Then the complete velocity information of debris can be obtained. Fig. 3 shows the velocity of both ECM models. The velocity curves are very similar. So the strip model velocity can be used to generate the full 3D model velocity.

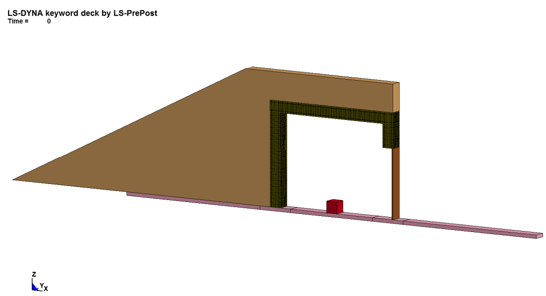
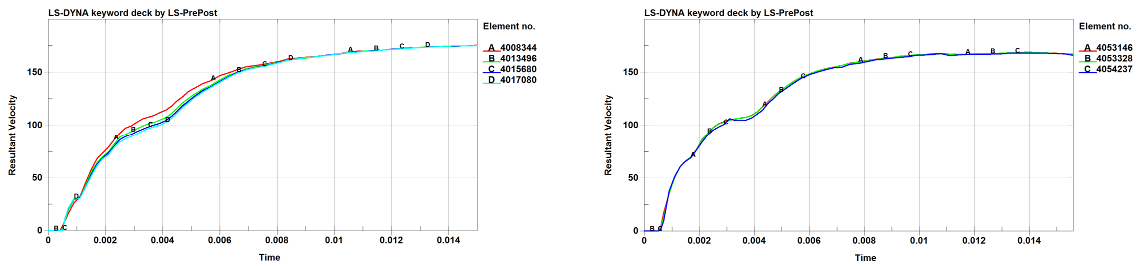


Figure 2. The strip 3D model of ECM



(a) Full 3D model velocity for big debris **(b) Strip model velocity for big debris**

Figure 3. Velocity for both models of ECM

Step 2 of the short-cut strategy

Develop the velocity formulas for typical part of ECM

Based on the known velocity curves of typical part of ECM from complete running of full 3D models, velocity formulas are set up according to fitting method.

Step 3 of the short-cut strategy

Generate the debris velocity

Based on the velocity formulas and the velocities of the strip model, the velocities after the short running of full 3D model are integrated to be a launching velocity for all debris.

Step 4 of the short-cut strategy

Form the debris

The full 3D model runs only for short time, so the debris has not formed completely. Based on the nodal velocity, the gap of two neighbor elements will be calculated to determine whether there is a separation occurred.

Obtain the debris launching trajectory and debris landing distribution

The simulation of strip model is stopped after the overpressure is observed to almost zero. The analysis of subsequent ballistic trajectory is then taken over by our in-house program, namely DeThrow II. Firstly, conversion of the LS-DYNA results to DeThrow II input file has to be done. From the LS-DYNA results, the debris information is derived which includes debris size, geometry, volume, the characteristic, the projected area, the aspect ratio and also the velocity and locations. Secondly, debris flight path is calculated by solving the governing equation of flight trajectory, taken into considering of the drag coefficients, the cloud effect and the ricochet of debris. Details of DeThrow II are described in the in-house report [2].

IBD

The ultimate objective of this study for debris distribution of magazine breakup under internal explosion is to address the operational need with regard to the safety/hazard zone around a magazine. The hazard zone is defined as a patch of area on plan such that the lethal threat level exceeds one hazardous piece of debris per 56 m^2. A piece of debris having kinetic energy of more than 79 J is considered hazardous or lethal. The Inhabited Building Distance (IBD) is an index radius of the smallest circle that encompasses the hazard zone totally.

Conclusions

In order to study the debris distribution of ECM breakup under internal explosion, Numerical simulation has been carried out by LS-DYNA. To make the numerical simulation more effective, a short-cut strategy is proposed.

References

[1] LS-DYNA Keyword User's Manual, Version 971. Livermore Software Technology Corporation (LSTC), USA, 2007.

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