Simulation of Impact Proof Testing of Electronic Sub-Systems

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Abstract

The purpose of this paper is to document the development of a new simulation tool which is being employed to simulate the deceleration vs. time pulse imposed on electronic systems during impact tests as shown in Figure 1. The simulation tool has also been employed to predict the stress, strain, fracture, and structural failure of electronic sub-systems. Cannon tests and rocket propelled sled tests are the standard test methods employed to “proof test” the successful operation of hardened electronic systems under extreme operating conditions. The proof test consists of placing the electronic sub system into a generic steel carrier and launching into concrete or soil blocks. The peak deceleration is determined by the lower stiffness material which is the concrete / soil. Previous LS-DYNA and “Hydrodynamic” code simulations of these tests required super computers, expert consultants, extensive computer run times, and relatively high cost. The new LS-DYNA concrete material model (*MAT 159) with eroding contact option, allows rapid simulation of impact penetration and by-passes the need for excessive computer run times often required for Arbitrary Lagrangian Eulerian (ALE) LS-DYNA models and equation of state (EOS) material models. This paper describes a simple, robust, and fast running, LS-DYNA application for simulating high g cannon and sled tests. This application will run on a Dell workstation employing one Intel processor and accurately predicts; deceleration, stress, strain, fracture, and overall deformation and damage of electronic systems

Figure 1. Rocket propelled sled tests of sub systems at NAWC China Lake CA.

Purpose

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Background

Cannon tests and rocket propelled sled tests are the standard test methods employed to “proof test” the successful operation of hardened electronic systems under extreme operating conditions. The proof test consists of placing the electronic sub system into a generic steel carrier and launching into soil or concrete blocks. The peak deceleration is determined by the lower stiffness material which is the concrete / soil. Previous LS-DYNA and “Hydrodynamic” code simulations of these tests required super computers, expert consultants, extensive computer run times, resulting in relatively high cost. The new LS-DYNA concrete material model (*MAT 159) used with eroding contact option, allows rapid simulation of impact penetration and by-passes the need for excessive computer run times often required for Arbitrary Lagrangian Eulerian (ALE) LS-DYNA models and equation of state (EOS) material models. This paper describes a simple, fast running, LS-DYNA application for simulating high g cannon and sled tests. This application will run on a Dell workstation employing one Intel processor and accurately predicts; deceleration, stress, strain, fracture, and overall deformation and damage of electronic systems. For simulation of aircraft or vehicle impacts, the carrier model shown in this paper should be replaced by a model of the vehicle.

Scope

Two impact cases are presented in this paper. Over 25 impact cases have been investigated to date with an average agreement of 15% between test and simulation results.

Approach

LS-DYNA input parameters and control parameters are presented which enable the non-expert user to conduct simulations of the above cited cases. The new LS-DYNA application is "robust" in that it runs relatively stable, fast, and does not experience early termination error problems. The key to the new application is the employment of the new material model (*MAT_159) and employment of the eroding contact option which allows progressive deletion of solid elements. The concrete blocks have steel reinforcement rods with one foot spacing and steel outer frame edge supports. The steel reinforcement in concrete structures is important in static stress analysis but is normally not included in high speed impact simulations wherein progressive fracture failure occurs. In order to reduce equation solver time, the simulations employ 1/4 or 1/2 symmetrical models of the carrier and target blocks. LS-DYNA post plotting software allows the results to be reflected so as to be presented as ½ or full models as shown in the current paper. The steel edges for the concrete blocks steel are modeled as a boundary condition; that is, the outer (single point constraint) nodes are constrained in the "normal face direction". The "soft contact option" is employed in all cases. The concrete is modeled with solid elements as a uniform material without rebar and "free of voids and defects"; therefore crack propagation is not simulated in the present examples. The finite element model units are inches, seconds, pounds force, and mass = weight / gravity constant.

The carrier is modeled with solid elements as a linear elastic material with no plastic deformation; that is material type, *MAT_1. The carrier may also be modeled as *MAT_24 with input of the actual stress strain curve. This results in small plastic deformation of the carrier and some eroding of its nose, which is in agreement with cannon test results with a low angle of impact and low stress. For extremely over stressed (over strained) carriers the use of *MAT_24 material card may result in a "negative volume" error message resulting in early termination of the computer simulation. The system may be modeled as a quarter or half model whenever symmetry allows.

The LS-DYNA deceleration pulse which best correlates with on board data recorders was found to be the rigid body acceleration of the entire rigid body which the accelerometer is housed in. Also the filter should be set to a Butterworth (BW) filter set at 220 Hz or set at the same frequency as the on board data recorder. For a 220 Hz BW filter the rigid body deceleration pulse of the electronic sub-system and carrier becomes nearly the same. This deceleration pulse can be plotted in LS-POST via loading the Binary plot "dplot" file and selecting HISTORY / MATERIAL / select part / RIGID BODY ACCELERATION / PLOT / SCALE (.00259 for English units in g) / FILTER / BW / SEC / 220.

The concrete model *MAT_159 allows specification of concrete erosion. All the examples in this paper employ an eroding constant of ERODE =1.08 which allows erosion of solid concrete elements when damage exceeds 0.99 (full damage is 1.0) and the maximum principal strain exceeds 0.08. Erosion does not occur if ERODE is less than 1.0. This material model also provides automatic regulating of the mesh as discussed in reference 1. The maximum strain increment can be specified, for example INCRE=1.0E-10, in the *MAT_159 input card which will help avoid early termination due to negative volume errors. Material model *MAT-159 was also employed to model soil / sand with settings of pre-damage 0.99, ERODE=1.08, soil / sand density, and the lowest possible compression strength, 3,000 psi.

The contact interface employed in this paper is eroding surface-to-surface with the concrete blocks as master and penetrator as slave.

The contact sliding friction coefficient may be small for concrete blocks in which fracture occurs. The present examples were submitted with friction coefficient values of 0.10 or 0.20 which results in good correlation with the test results.

The mesh size shown in the current examples is relatively course. The simulations were also run with an eight times finer mesh to check for convergence. The smallest realistic mesh size for the concrete / soil is determined by the average aggregate size of the concrete / soil.

Unconfined compression modulus input in *MAT-159 is a civil engineering standard static test measurement of the concrete relative modulus and strength. Normally three test measurements are taken per concrete block resulting in a variation of 500-900 psi between measurements. The confined Young's modulus is higher and the dynamic modulus is also higher. Reference 5 discusses dynamic properties of concrete under high strain rates. A compression modulus input value of 1.6 to 1.8 times the average static unconfined test value was found to produce a good match with test results when rate effect is turned on; IRATE=1. The examples in this paper employ these factors. A calibration test run is recommended in order to determine the proper input value for a family of concrete blocks.

This paper presents one method and one set of input values which produce simulation results which compare well with the test results investigated to date. Other concrete sets may require different input values for ERODE, friction, and dynamic modulus factors.

Results

A typical proof test is shown below and consists of a generic carrier with electronic sub-system impacting a series of layers consisting of; concrete, soil, concrete, air, and concrete.

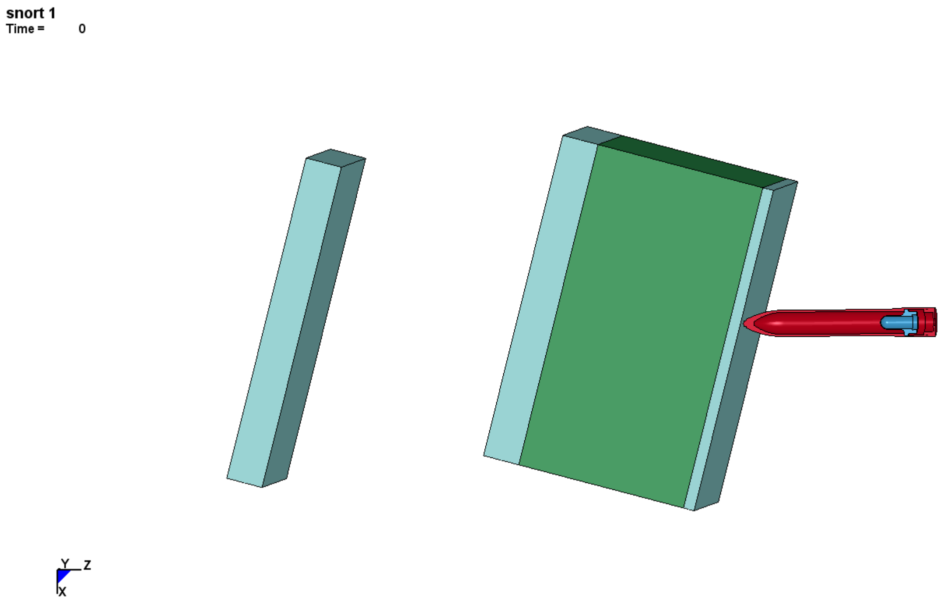

FIGURE 2. Simulation starts of impact.

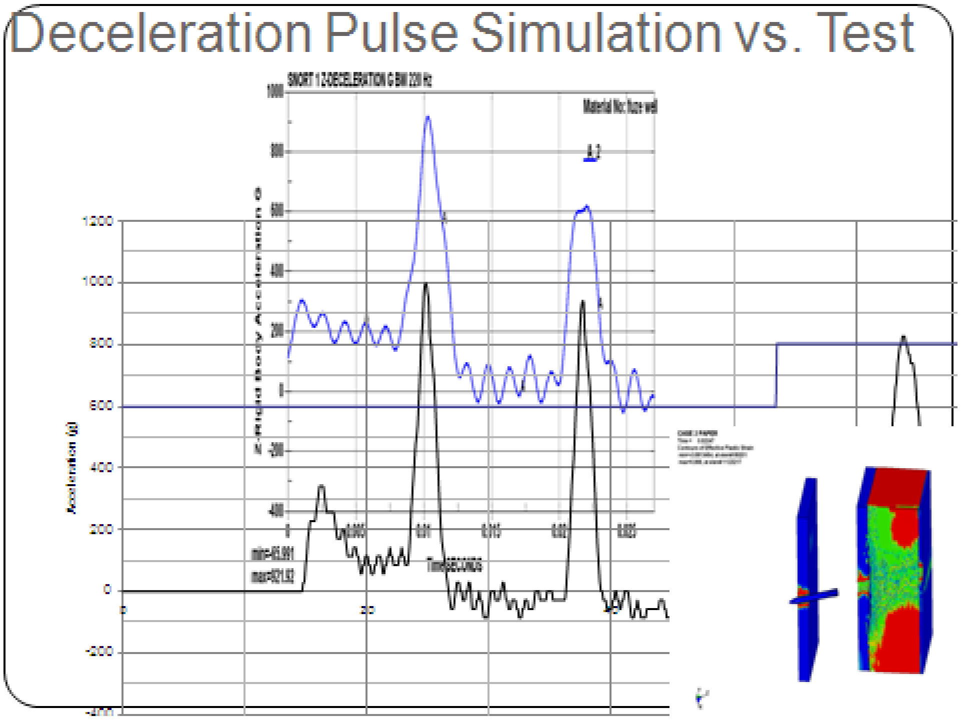
Deceleration Pulse Simulation vs. Test

FIGURE 3. Simulation of Z-acceleration with 220 Hz Butterworth filter shown in blue vs. on board test data recorder with 220 Hz Butterworth filter shown in black.

LS-DYNA output includes the stress and strain of all elements at each time step of the simulation. A sub-system pass / fail simulation decision can be established by comparing the maximum stress or strain to the dynamic ultimate strength or ultimate strain for each material. LS-DYNA allows the user to specify the ultimate strain and then allows an option to “delete over strain elements”. This option allows simulation of progressive fracture of each over strain component.

Figure 4 represents a second more severe impact case wherein a typical LS-DYNA output plot was generated displaying the predicted deformation on a “generic sub-system” at time step 0.01 seconds after impact into concrete. In this second impact case, the test conditions are severe enough to cause failure of many of the components. Figure 4 shows; the center disk is compressed and cracked. The top die cast aluminum bulkhead fractures. The mid bulkhead displays large deformation. The bottom plates are compressed and display large deformation. The outer housing displays a visible “buckle” deformation shape. This simulation result agrees with post test inspection results but this comparison is not included in the present paper.

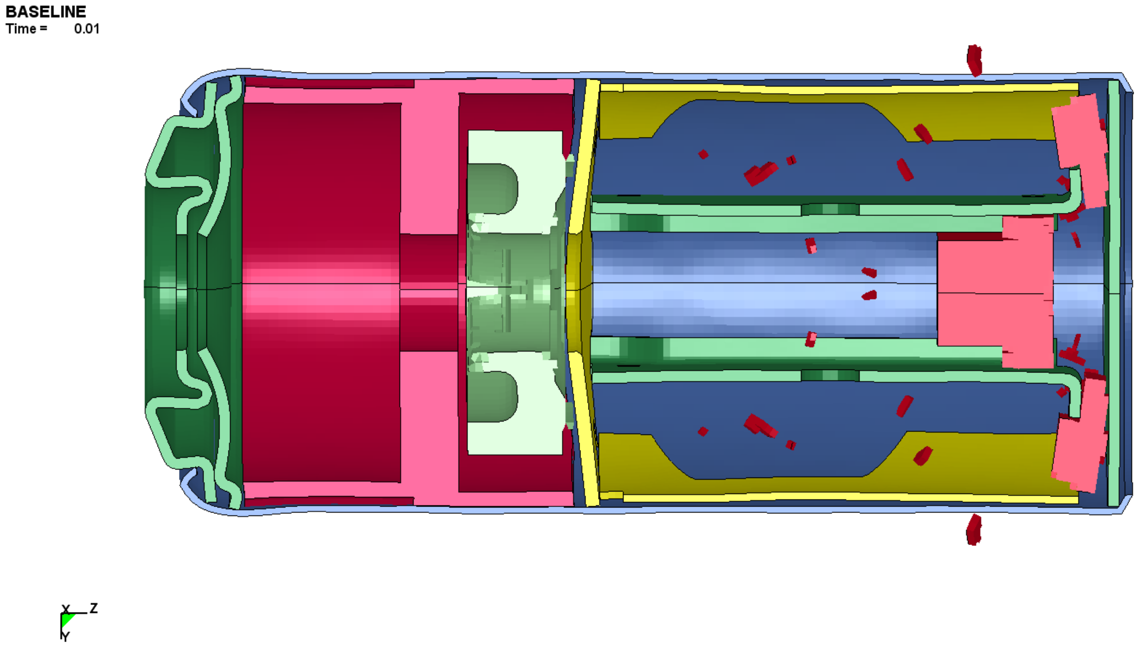

FIGURE 4. Simulation of generic baseline sub-system at time step 0.01 showing cracks, fractures, mid bulkhead crush, bottom plate compressed, and outer housing “buckle” deformation.

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Conclusions

A new application of LS-DYNA has been developed by NAWCWD to calculate the deceleration time pulse experienced by sub-systems during impact tests. The simulation results are in good agreement with test data. The new simulation tool will find application in evaluation of systems. It also is being employed as a standard method of specifying performance requirements, and allows calculation of deceleration, stress, strain, and fracture failure under a wide range of impact conditions.

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