LS-DYNA Implicit for Dent Performance Evaluation

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Abstract

Present day engineering design involves complex CAE analyses using both linear and non-linear methods. Most companies use multiple software tools for different types of analyses. Several reasons, including cost are driving companies to investigate lesser number of FEA tools so that they can use a single solver for most of their structural analyses. LS-DYNA has been traditionally used for explicit analysis like crash and metal forming. Recent enhancements in the versions of LS-DYNA enable us to evaluate it for implicit analysis.

The success of an automotive design is determined by its ability to meet the expectations of the customer with respect to cost, performance and styling. Dent performance is an important factor in designing automotive outer panels due to increased customer sensitivity to surface finish and durability. Dent performance is defined as the deflection under certain external loads at the panel outer surface. The external loads can be from many sources like shopping carts or from an adjacent vehicle door in a parking lot.

Dent performance prediction assumes a quasi-static equilibrium solution eliminating the effects of inertia, thereby making it an implicit analysis. Dent prediction analyses are traditionally performed using specialized implicit solvers. In this study, LS-DYNA implicit was used to predict dent performance on several outer panels (doors & hoods). The results were then compared to the corresponding experimental results and to the results from a competing solver. This paper also describes the setup using Altair® HyperMesh®, various analysis parameters and element formulations used for dent analysis.

Introduction

Cost associated with CAE software is driving a lot of companies to reevaluate their spending. This includes either limiting the number of licenses for different software or constantly evaluating the need to use multiple solvers. Additionally, FEA solvers have been expanding their capability and domains to entice the user community to be their single solver for a number of analytical problems. A combination of some of these factors leads us to investigate LS-DYNA for implicit analysis.

A successful automotive design is determined in part by its ability to meet the customer's expectations with respect to cost and performance. In the interest of high fuel efficiency, lighter gauge materials are being used for most outer panels to reduce the weight of the car. The decrease in thickness of the outer panels can lead to lower dent resistance during manufacturing and also in service. Dent performance is an important factor in designing outer panels due to increased demand for high standards of surface finish from customers.

In the automotive industry several types of tests are performed to evaluate the dent performance of the panel. These tests include oil canning and elbow dimpling analysis. In this paper, oil canning and elbow dimpling analyses have been performed on several outer panels (hoods and doors) using LS-DYNA implicit and the results have been compared to the actual test results as well as the results from a competing solver.

Our results spot some interesting trends and highlight the need for detailed benchmarks before solvers can be changed to analyze a specific class of analytical problems. The element formulation and how it compares between solvers is very important in the analysis. Secondly, the selection of the definition for contact is very important while switching the solvers. In addition, the changes to solvers require developing a plan on how to handle individual capabilities of the solvers with respect to rigid element definitions and such.

We found that double precision version of LS-DYNA was needed for stability reasons. We also found out that LS-DYNA consistently predicted lower deflections and permanent set numbers when compared to the other solver for this analysis. The physical test numbers are from actual testing and therefore have been obtained from panels which have undergone strain hardening and thinning during the stamping process. Therefore, the LS-DYNA numbers being closer to the physical tests does not represent more accurate predictions over the competing solver.

In conclusion we have been able to successfully analyze an implicit class of problem namely dent performance using LS-DYNA. The LS-DYNA element formulation is stiffer than the competing solvers. The numbers predicted from LS-DYNA are very close to the actual numbers from physical testing and hence we feel comfortable in stating that LS-DYNA can be used for this type of analysis.

Methodology

Dent Analysis Overview

Two different types of dent tests were performed in LS-DYNA: (1) oil canning analysis (2) elbow dimpling analysis. Dent analysis was performed on the outer panel by applying a point load using a rigid indentor. This involved 2 steps. The first step was identifying the weakest area on the outer panel. The weakest area was identified using modal analysis. The second step was to re-mesh the weakest location locally and apply load at this location and measure the performance. Altair HyperMesh Version 6.0 was used to set-up the dent analysis in LS-DYNA format. Modal analysis was performed using Altair Optistruct Version 6.0.

Elbow Dimpling Analysis Setup

A point load was applied incrementally (in steps) on a 1-inch diameter area using a spherical indentor of 1-inch in diameter at the weakest location. The load was then removed. Permanent-set was measured after unloading.

Oil Canning Analysis Setup

A point load was applied incrementally (in steps) at the weakest location on a 1-inch diameter area using a cylindrical indentor of 1-inch in diameter and 20 mm in height. The load was then removed. Permanent set and deflection at peak load were measured.

Element Selection

Several shell element formulations in LS-DYNA along with certain control cards were evaluated and compared to the formulations with the competing solver. Table 1 summarizes all the different combinations of the parameters studied. LS-DYNA element formulations seemed to be consistently stiffer than those of the competing solver. This benchmarking was done for a non-linear analysis involving no contact – a ramp up load and an unload step using distributed loads.

Table 1: Element Formulation Investigations in LS-DYNA

Solver	Element Type/ Parameters	Integration Points Through Thickness	Peak Deflection (mm)	Von-Mises Stress at Peak Load (MPa)	Permanent Set (mm)
LS-DYNA	ELFORM 2 IGS:2, HGLASS:4 HGLASS COEFF:0.03	2	10.63	159	0.63
LS-DYNA	ELFORM 2 IGS:1, HGLASS:4 HGLASS COEFF:0.03	2	10.15	164	0.62
Competing Solver	Integrated Shell Elements	2	11.91	181	0.67
LS-DYNA	ELFORM 6 IGS:2, HGLASS:4 HGLASS COEFF:0.03	2	9.83	157	0.53
LS-DYNA	ELFORM 7 IGS:2, HGLASS:4 HGLASS COEFF:0.03	2	9.83	158	0.53
Competing Solver	Integrated Shell Elements	2	11.90	175	0.65
LS-DYNA	ELFORM 16 IGS:2, HGLASS:4 HGLASS COEFF:0.03	2	9.26	156	0.46
Competing Solver	Fully Integrated Shell Elements	2	11.16	178	0.62
LS-DYNA	ELFORM 16 IGS:2, HGLASS:4 HGLASS COEFF:0.03	5	9.02	199	0.57
Competing Solver	Fully Integrated Shell Elements	5	11.10	157	0.64

From these investigations, element formulations for the dent analysis were chosen considering the stiffness and the ease of convergence. Using a softer shell ELFORM 2, 6 or 7 made the implicit solution unstable in most cases and so ELFORM 16 formulation was chosen. Table 2 summarizes the final element formulations used in the dent analyses model. The rigid welds representing the spot weld locations were modeled using ‘constrained_rigid_body’ elements. The springs represented the stiffness from adhesives joining the inner to the outer panels and were represented using ‘discrete’ elements. The distributed loads when applicable were applied using ‘constrained_interpolation’ elements. For the cases where contact definitions were used, the loads were applied to the indenter that was modeled using the keyword *LOAD_RIGID_BODY.

Table 2: Element Formulations Used in the Dent Analysis

Type	LS-DYNA Element
Quads/ Trias	‘Elform 16’
Rigids/ Welds	‘Constrained_Rigid_Body’
Springs	‘Discrete’
RBE3 equivalent spiders	‘Constrained_interpolation’

Contact Algorithms

The contact algorithm ‘nodes_to_surface’ type was used to model the interface between the rigid indenter and the panel outer surface. We also evaluated the ‘surface_to_surface’ type of contact but it had convergence problems in some of our runs, so ‘nodes_to_surface’ contact was used for all of our analyses. We did not evaluate any other contact algorithms as these are the most common ones used.

Setup of Analysis Deck using Altair HyperMesh 6.0:

We converted existing bulk data files in the competing solver’s format to LS-DYNA format. The conversions and analysis setup was done using HyperMesh 6.0. HyperMesh allows ease of conversion of analysis models while switching between solvers.

The bulk data files in the competing solver’s format for the models were read into HyperMesh. The element types for most of the elements were automatically switched when we changed the solver template in global panel in HyperMesh. If needed, the models could also be converted into LS-DYNA format by using the ‘convert’ utility in the ‘tools’ page of HyperMesh. For updating element types, user has additional options under the ‘element types’ option on ‘3D’ page of HyperMesh that can be used to switch between various element formulations being used.

Element definitions and section properties were subsequently assigned to all the components. The indenter was modeled as rigid body using a ‘MAT_RIGID’ (MAT 20) material. The outer panel was modeled with shells using a ‘MAT_PIECEWISE_LINEAR_PLASTICITY’ (MAT 24) material.

Contact definitions and parameters were setup between the indenter and the outer panel. Boundary conditions were assigned and implicit control cards were specified using the HyperMesh control cards panel. The deck was exported from HyperMesh in the LS-DYNA format and submitted to the solver.

Solver Selection

LS-DYNA 970_3858_double precision SMP-version using 2 CPUs on a LINUX platform was used for this implicit analysis. Using a single precision or using an MPP-version of LS-DYNA showed some contact-instability induced convergence problems.

Post Processing

Altair HyperView Version 6.0 was used for all the post processing. HyperView has some unique features for comparative post processing. These include synchronized results visualization for FEA from multiple analysis solvers, xy-plotting and video of physical test data. In addition, HyperView has direct readers for many CAE solvers as well as the Altair H3D compressed binary format which made it a single post processor for all our analysis comparisons.

Results

As part of our investigation into the use of LS-DYNA, we compiled our results using two solvers, one being LS-DYNA and the other being the competing solver which we use currently for all our implicit analysis. We based our comparisons between the two solvers only for those parts where we had some physical test data. The tables below summarize our comparisons between the solvers for the peak deflections and permanent set numbers and also with physical test data where available.

We would like to point out that the physical tests were conducted on stamped panels which have a thinning profile and also are work hardened due to the stamping process. The forming effects have not been captured in our analysis which assumes that the panels have a uniform thickness and virgin material properties.

Table 3: Comparison of the Peak Deflections

	Hood Assembly Oil Canning Analysis Peak Deflections (mm)			Front Door Assembly Elbow Dimpling Analysis Peak Deflections (mm)		Rear Door Assembly Elbow Dimpling Analysis Peak Deflections (mm)	
Location	LS-DYNA	Competing Solver	Physical Tests	LS-DYNA	Competing Solver	LS-DYNA	Competing Solver
1	2.30	3.16	2.40	4.00	5.10	2.80	3.20
2	1.61	2.69	2.00	3.40	3.70	2.30	2.90

Table 4: Permanent Set Results Comparison

	Front Door Assembly Elbow Dimpling Analysis Permanent Set (mm)			Rear Door Assembly Elbow Dimpling Analysis Permanent Set (mm)			Hood Assembly Oil Canning Analysis Permanent Set (mm)		
Location	LS-DYNA	Competing Solver	Physical Tests	LS-DYNA	Competing Solver	Physical Tests	LS-DYNA	Competing Solver	Physical Tests
1	0.03	0.04	0.04	0.02	0.04	0.03	0.08	0.09	0.07
2	0.01	0.02	0.03	0.01	0.03	0.01	0.06	0.07	0.05

Discussion

We were able to successfully carry our implicit analysis using LS-DYNA. Though the peak deflections and permanent set numbers are lower than the competing solver it was compared against, they are in reasonable agreement to the test results. Nonetheless, it does not necessarily represent more accurate results. This is because as discussed above, the test panels had been stamped and hence had been work hardened and had a thinning profile.

The LS-DYNA element formulation is stiffer than that of the competing solvers studied. Also, in order to get proper convergence using LS-DYNA implicit analysis, we recommend the use of the SMP double precision version of the solver. This is especially true for models containing 'constrained interpolation' type of elements. We also recommend the use of LS-DYNA version 970 or higher for this type of analysis.

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References

1. Altair HyperMesh, Version 6.0, Altair Engineering Inc., 2003.
2. LS-DYNA Keyword User's Manual Version 960, Livermore Software Technology Corporation, March 2001.