BENCHMARKING OF ANALYTICAL METHODS AND ANALYSIS SOFTWARE USED FOR TRANSPORTATION PACKAGE DROP ANALYSIS

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ABSTRACT

10 CFR 71 regulations [1] require that the containment boundary of a transport package is able to withstand a 30 ft (9 m) free drop unto a flat, essentially unyielding surface. Impact limiters are designed to limit the deceleration experienced by the cask and its contents during the impact. The design and testing of the impact limiters can be long and tedious. Often, the final design of the impact limiters can only be validated with a full or reduced scale drop test; however the drop test is extremely costly and time consuming. This paper presents a simulation using the LS-DYNA computer code to perform benchmark analyses as an alternative to a drop test.

A series of drop tests have been previously performed on a one-third scale mockup of the MP197 Transport Package equipped with impact limiters. The cask was dropped in three different orientations, including a 90º End Drop, 0º Side Drop and a 20º Slap Down. The 90º End Drop was performed with the impact limiters chilled to -20 ºF (-29 ºC) in order to analyze the effect of the low temperature on the impact limiter performance. The impact limiters consist of balsa and redwood, enclosed by stainless steel plates. Balsa and redwood, in the form of wood blocks, provide energy absorption while the stainless steel plates position and confine the wood blocks. The test results include accelerations, maximum crush depths, and impact durations.

This paper presents detailed descriptions of how the LS-DYNA code was used to perform the benchmark analysis. This includes:

- Description of the finite element models of the cask, impact limiters, and unyielding surface
- Material properties
- Boundary and initial conditions
- Results

The results of the LS-DYNA analysis in terms of peak filtered accelerations, maximum crush depths, and impact duration for the three drop cases are presented and compared to the drop test results. It was found that the LS-DYNA analysis results correspond well with the measured impact limiter drop test results. Therefore, the LS-DYNA code simulation can be used to accurately evaluate the impact of a cask with impact limiters.

INTRODUCTION

A series of drop tests have been previously performed on a one-third scale mockup of the MP197 Transport Package equipped with impact limiters. The tests were performed to evaluate impact limiter performance for the 30 ft (9 m) free drop hypothetical accident conditions. The cask was dropped in three different orientations, including a 90º End Drop, 0º Side Drop and a 20º Slap Down. The 90º End Drop orientation was performed with the impact limiters chilled to -20ºF (-29 ºC) in order to analyze the effects of low temperature on impact limiter performance.

Finite element model of the MP197 cask mockup equipped with impact limiters is developed using the LS-DYNA computer program [2]. The LS-DYNA finite element model is analyzed for the same three hypothetical accident conditions as those in the test program: 30 ft (9 m) End Drop (-20ºF) (-29 ºC), 30 ft (9 m) Side Drop (Room Temperature), and 30 ft (9 m) 20º Slap Down (Room Temperature). The finite element analysis results are compared to the actual drop test results.

1/3-SCALE TEST

The test model for the dynamic tests consisted of a solid carbon steel test body with an impact limiter on each end. The test model was constructed to be as close as possible to one-third of the full size packaging.

The four 1/3 scale impact limiters that were constructed are identified as 1, 2, 3, and 4. The various drop test orientations were performed in the following sequence.

Table 1. Summary of Testing Sequence

Test Number	Drop Orientation	Drop Height	Impact Limiter Number	Location of Impact Limiter	Comments
1	0° Side Drop	30 feet (9 m)	1	Top	
			2	Bottom	
2	20° Slap Down	30 feet (9 m)	3	Top (2nd Impact)	Impact limiter #1 was removed and replaced with impact limiter #3; entire test article is rotated by 180 degrees.
			2	Bottom (1st Impact)	
3	90° End Drop	30 feet (9 m)	3	Top	Impact limiter #2 was removed and replaced with impact limiter #4; impact limiter #4 chilled at -20 °F (-29 ^{0}C) for 48 hours before installed to the test body.
			4	Bottom (Impact End)	

Accelerometers were used to measure the inertial g load during impact for the three 30 foot (9 m) drops performed. The accelerometers were mounted to steel blocks, which were welded to the exterior of the test body at 0º, 90º, 180º, and 270º orientations at the approximate center of gravity location and adjacent to each impact limiter. Accelerometers were not mounted in locations that would result in certain destruction of the accelerometer. However, at least ten (10) accelerometers were used during each 30 foot (9 m) drop.

The test setup for each drop is shown in Figure 1 and the resulting deceleration time history for each drop is shown in Figure 2.

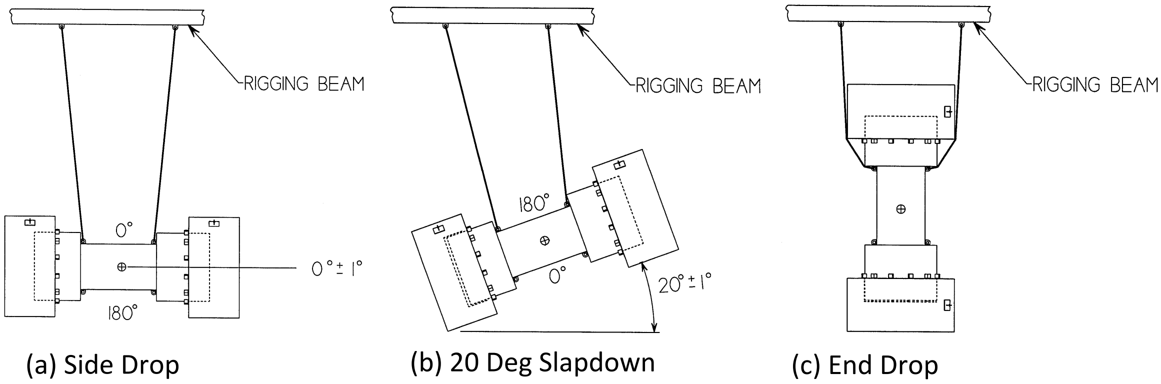

Figure 1. Test Setup

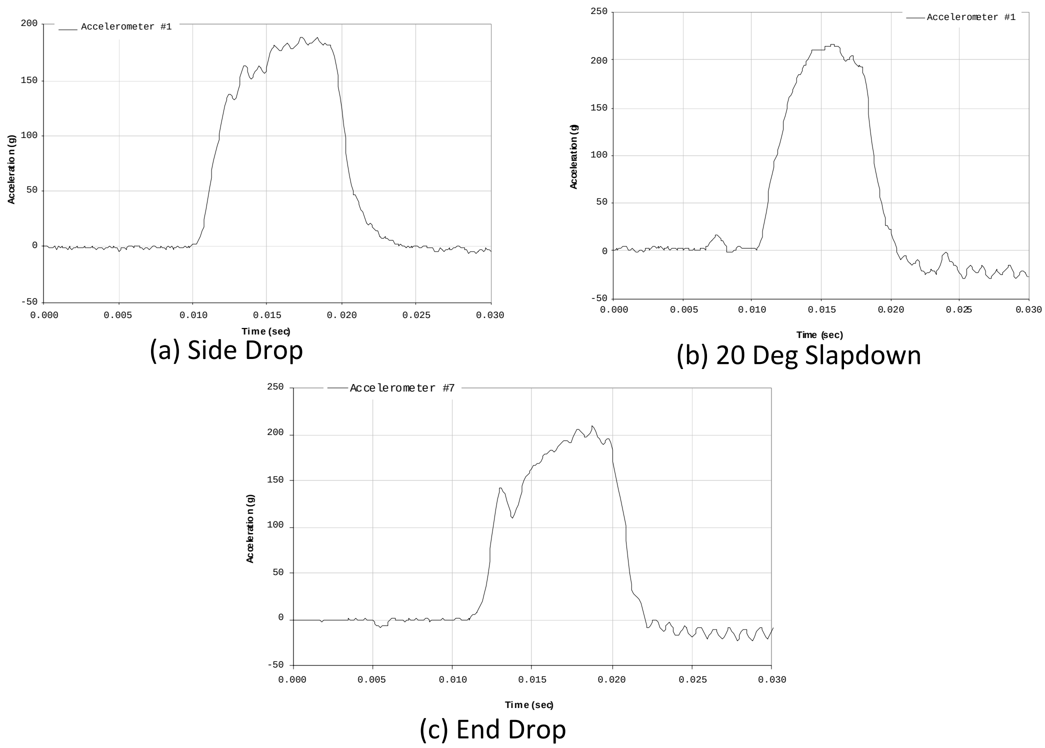

Figure 2. Test Deceleration Time Histories

ANALYSIS

The finite element analysis model is a representation of the test model used for the actual drop tests with impact limiters installed on each end of the cask. The impact limiter model incorporates the individual balsa or redwood sections that make up the impact limiter and the stainless steel cover shell. Additional features such as the impact limiter attachment bolts and alignment tubes are also included in the LS-DYNA model. The impact surface, which consists of a steel plate over a thick concrete pad, is also included in the model.

The impact limiter wood sections, the concrete pad, the steel plate, and the cask mockup are modeled with default LS-DYNA constant stress solid elements. The impact limiter shell is modeled with fully integrated shell elements.

Only one-half of the cask, impact limiters, steel plate and concrete are modeled, as the entire arrangement is symmetric about the x-y plane. Figure 3 shows an overview of the impact limiter finite element model.

The three analyzed drop accident conditions are as follows:

1. 30 ft (9 m) End Drop (-20ºF) (-29 ºC)
2. 30 ft (9 m) Side Drop (Room Temperature)
3. 30 ft (9 m) 20º Slap Down (Room Temperature)

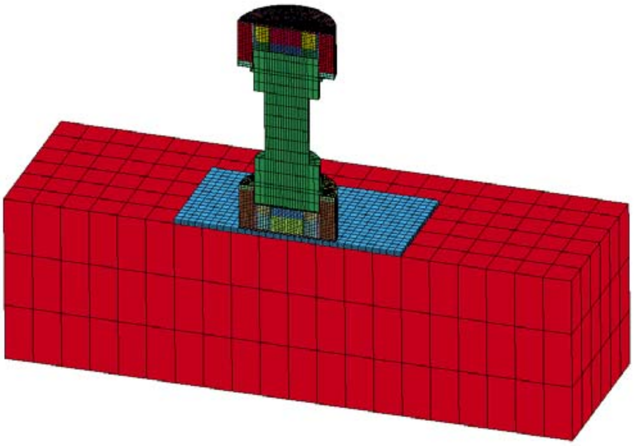

Figure 3. 1/3 Scale Impact Limiter Finite Element Model Overview

<u>Material Properties</u>

The mechanical properties of the steel were taken from ASME [3], and were modeled using the MAT_PLATIC_KINEMATIC material model. The concrete is modeled using MAT_PSEUDO_TENSOR material model, which was developed specifically for granular type materials.

Wood is described as an orthotropic material [4] with three mutually perpendicular axes: longitudinal, radial, and tangential. The highest stiffness and strength are in the longitudinal direction while the stiffness and strength in the radial and tangential directions are nearly equal. Honeycomb type material models are generally suitable for modeling orthotropic material which show extensive compressive behavior, thus the Mat_Modified_Honeycomb material model is used to model the wood in the impact limiters. Typical curve used to define the wood behavior in compression is shown in Figure 4. The values were generated based on the data provided in the Wood Handbook.

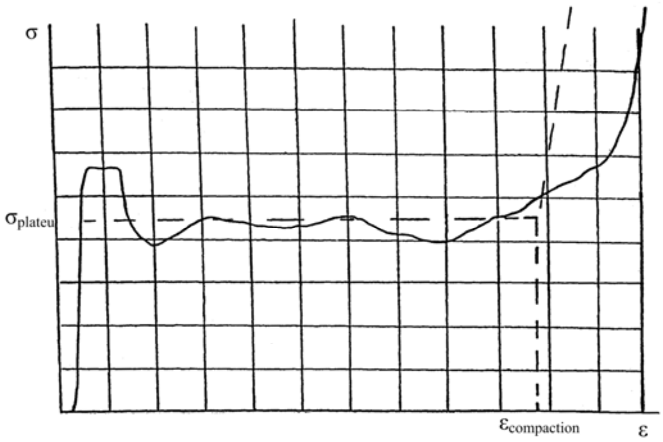

Figure 4. Typical Wood Behavior in Compression

<u>Boundary Conditions and Initial Conditions</u>

Since only one half of the cask and impact limiters are modeled, all nodes on the boundary plane between these sectors are constrained in the out-of-plane direction, yielding mirror-symmetry behavior. The lowest point of the impact limiter shell is initially placed within 0.25 in of the steel impact plate to minimize run time. An initial velocity corresponding to the drop height is applied to the model. The initial velocity computed for a 30 ft (9 m) drop is 527.45 in/sec.

<u>Impact Limiter Benchmark Analysis Results</u>

Table 2 summarizes the results of the LS-DYNA analysis in terms of peak filtered accelerations, maximum crush depths, and impact durations for the three drop cases analyzed and compare them with similar parameters obtained from the test results. The resulting deceleration time histories are shown in Figure 5.

Table 2. Peak Decelerations, Wood Crush Depths & Impact Duration Comparisons

		Test Results	LS-DYNA Model
End Drop (-20 °F) (-29 °C)	Deceleration	195g	197g
	Impact Duration	0.010 sec	0.012 sec
	Wood Crush Depth	2.5 in (63.5 mm)	2.5 in (63.5 mm)
Side Drop	Deceleration	183g	185g
	Impact Duration	0.012 sec	0.014 sec
	Wood Crush Depth	2.75 in (69.9 mm)	2.75 in (69.9 mm)
20° Slap Down 1st Impact	Deceleration at Center of Cask	51g	55g
	Deceleration at Bottom of Cask	108g	105g
	Impact Duration	0.016 sec	0.023 sec
	Wood Crush Depth Bottom Limiter	4.92 in (125 mm)	5.5 in (125 mm)
20° Slap Down 2nd Impact	Deceleration at Center of Cask	96g	123g
	Deceleration at Top of Cask	219g	235g
	Impact Duration	0.009 sec	0.012 sec
	Wood Crush Depth Upper Limiter	2.42 in (61.5 mm)	3.0 in (76.2 mm)

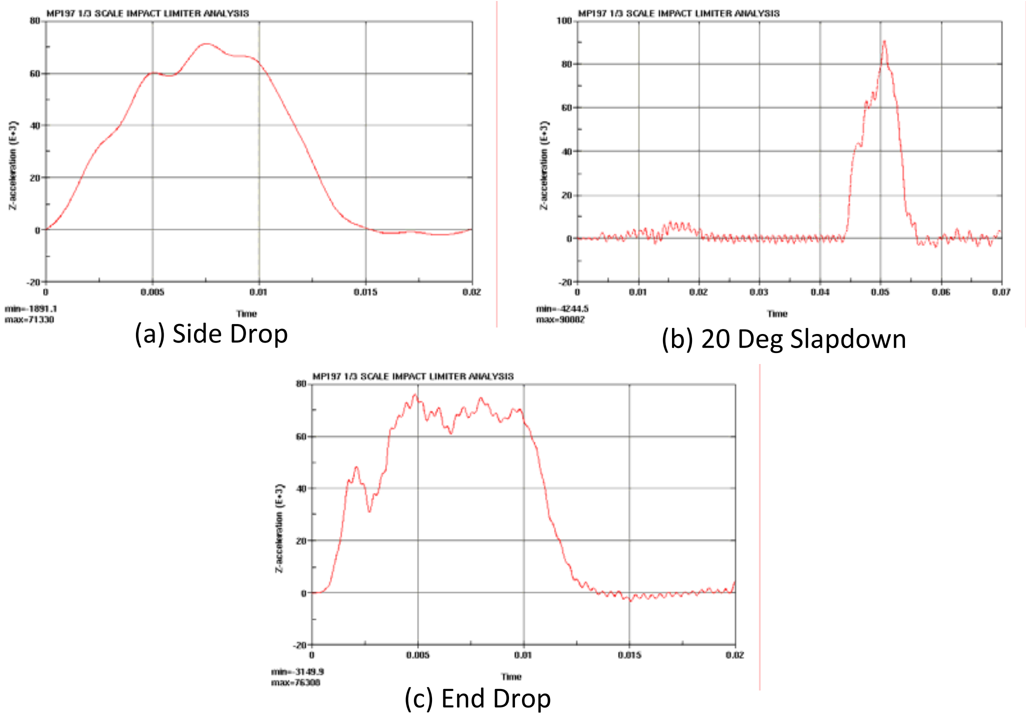

Figure 5. Analysis Deceleration Time Histories

CONCLUSIONS

The analysis results agree well with the measured results of the impact limiter drop tests. The impact time durations match closely with those of the measured results. Wood crush depths are also similar. LS-DYNA analysis results correspond well with the measured impact limiter drop test results. Therefore, the LS-DYNA code simulation can be used to accurately evaluate the impact of a cask with impact limiters.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 71 (10CFR Part 71), Packaging and Transportation of Radioactive Material.
2. LS-DYNA Keyword User's Manual, Volumes 1 & 2, Version 9.71, Rev. 7600.398 August 17, 2006, Livermore Software Technology Corporation.
3. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section II Part D, 2004 including 2006 addenda.
4. Wood Handbook: Wood as an Engineering Material, Forest Products Laboratory, General Technical Report, FPL-GTR-113, United States Department of Agriculture.