THE DEVELOPMENT OF CODE BENCHMARKS

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ABSTRACT

Sandia National Laboratories has undertaken a code benchmarking effort to define a series of cask-like problems having both numerical solutions and experimental data. The development of the benchmarks includes: (1) model problem definition, (2) code intercomparison, and (3) experimental verification.

The first two steps are complete and a series of experiments are planned. The experiments will examine the elastic/plastic behavior of cylinders for both the end and side impacts resulting from a nine meter drop. The cylinders will be made from stainless steel and aluminum to give a range of plastic deformations.

This paper presents the results of analyses simulating the model's behavior using materials properties for stainless steel and aluminum.

INTRODUCTION

Sandia National Laboratories is developing benchmarks for the testing of structural codes to be used for the analysis of nuclear materials shipping systems. The development is occurring in the three phases of: (1) model problem definition, (2) code intercomparison, and (3) experimental verification.

The first phase culminated with the presentation of the problem set at the first Industry/Government Joint Thermal and Structural Codes Information Exchange.[1] The second phase was completed with the presentation of results at the second Industry/Government Joint Thermal and Structural Codes Information Exchange. The results of the intercomparison of codes[2,3] indicated substantial variation in predicted plastic deformations.

The third phase will consist of obtaining experimental results and the redefinition of the problems. The objective of this phase is to provide reliable experimental data for comparison with numerical analyses. This data will be obtained from a series of drop tests performed using stainless steel and aluminum cylinders.

Model Problem Development

The model problems were selected to be cask-like in nature, test the capabilities of the available codes, and yet be of sufficiently simple geometry that experimentation would be straightforward.

The problems chosen for the benchmarks reflect the regulations concerning the hypothetical accident condition of free drop. This drop test is defined as "a free drop through a distance of 9 meters (30 feet) onto a flat, essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected." To limit the initial scope of the problems to two-dimensional impacts, the potential orientations were restricted to end and side impacts. This allows for evaluation of the various codes' material models and large strains capabilities while maintaining relatively simple geometries.

To adequately model nuclear shipping casks, the codes should include an elastic/plastic material model and large deformation capability. These constraints resulted in the problem set shown in Fig. 1.

While these problems examine realistic physical phenomena, they are not all inclusive. Further problems need to address phenomena associated with impact limiters such as the constrained crush of foams and honeycombs, the anisotropic material response of woods, the plastic buckling of fins and brittle fracture. The solutions to these problems may require additional code development as well as experimentation.

Experimental Verification

The model problems were designed so that experimental verification could be obtained. The strain/time data will be obtained with appropriate strain gages. The instrumentation layouts are shown in Figs. 2 and 3. The impact duration will be obtained from strain gage data. The plastic deformations will be determined from pre- and post-test inspections.

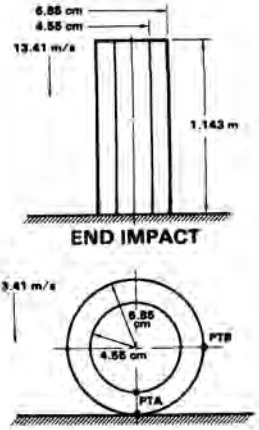

Fig. 1. Model Problem Set.

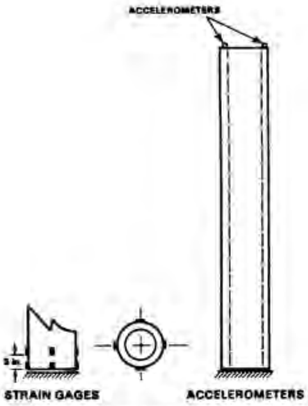

Fig. 2. End Impact Instrumentation.

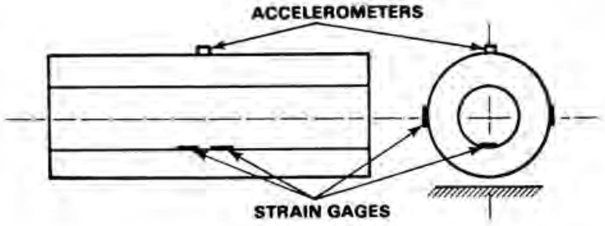

Fig. 3. Side Impact Instrumentation.

Materials

The test articles are made of either stainless steel or aluminum. Stainless steel was selected since it is used in a wide range of casks due to its ductile behavior during impact.

Aluminum is being used to model a more nearly perfectly plastic material. The density and Young's modulus are approximately one third that of steel but the hardening modulus is only one eighth that of the stainless steel. This combination of properties should result in greater plastic deformation even though the lower density will result in an initial kinetic energy equal to one third that of the stainless steel drop tests.

The properties of fully annealed 304 stainless steel and fully annealed 606° aluminum are listed in Table I.

Table I

Material Properties

	304 Stainless Steel	606° TO Aluminum
Young's Modulus (MPa)	1.95° x 10^5	6.885 x 10^4
Poissons Ratio	0.33	0.316
Hardening Modulus (MPa)	2,151	276.
Density (kg/m^3)	7,822	2,714
Yield Stress (MPa)	206.9	55.2

Models

In this section the models used for the calculations are presented. The geometries and initial conditions are given in Fig. 1. The materials properties are given in Table I. These materials necessitate use of an elastic/plastic material model.

The code that is used to perform the analyses is DYNA2D.[6] This is a finite element, explicit integration code. The meshes generated for each impact orientation are shown in Figs. 4 and 5.

The strains are defined as the ratios of the changes in lengths to the original lengths, and the impact duration is determined when the velocity of the impacting end becomes greater than zero indicating the start of rebound.

RESULTS

The results of the analyses show the calculated response of the stainless steel and aluminum test articles.

The gross cask behavior is given in Tables II and III. The impact duration is determined by the stress wave propagation through the test articles. For an elastic wave, the propagation velocity for the stainless steel is 4.99 m/s while for the aluminum it is 5.04 m/s. Each of these implies an impact duration of 0.45 ms. The increased times result from the initial plastic deformation at the impacting end.

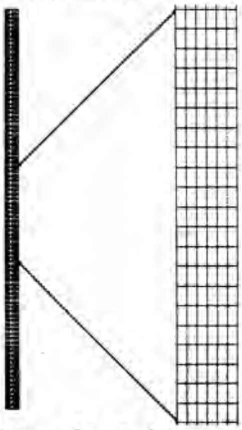

Fig. 4. End Impact Mesh.

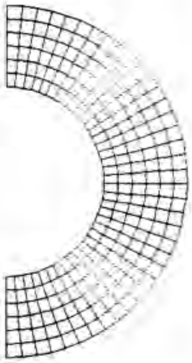

Fig. 5. Side Impact Mesh.

Table II

End Impact Results

Material	Impact Duration (ms)	Final Axial Deformation (%)
Stainless Steel	0.78	0.32
Aluminum	0.8	0.37

Table III

Side Impact Results

Material	Impact Duration (ms)	Horizontal Ovalization (%)
Stainless Steel	0.33	1.00
Aluminum	0.39	1.12

The relative stiffness of each material is reflected in the permanent deformation resulting from plastic deformation. In each orientation the softer aluminum exhibits greater deformation even though the aluminum only had one third of the kinetic energy of the stainless steel at impact.

The strains at selected points are shown in Figs. 6, 7, and 8. Figure 6 shows the hoop strain at the impacting end for the end impact. This figure also indicates the range of expected strains over the 5 centimeter band from the end. This demonstrates a high strain gradient. As anticipated the aluminum has greater deformation in the impact region.

Figure 7 shows the horizontal strain at the inside radius above the impact point for the side impact. Figure 8 shows the vertical strain at the outside radius away from impacting region. The lower vertical deformation of the aluminum in Fig. 8 is the result of the greater plastic deformation; hence energy absorption of the aluminum in the impact region is shown in Fig. 7. This results in less energy available for plastic deformation away from the impact region.

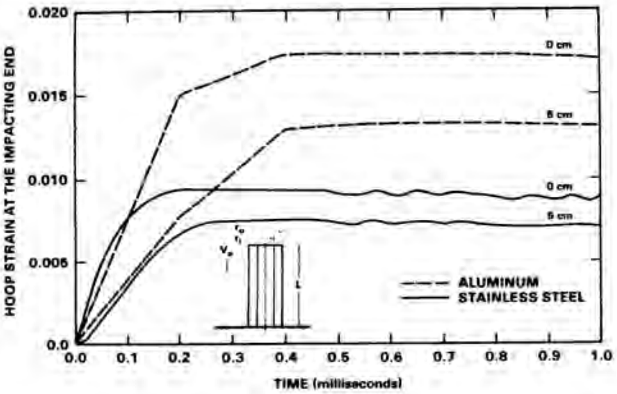

Fig. 6. Calculated Hoop Strain as a Function of Time and Height Above Impact.

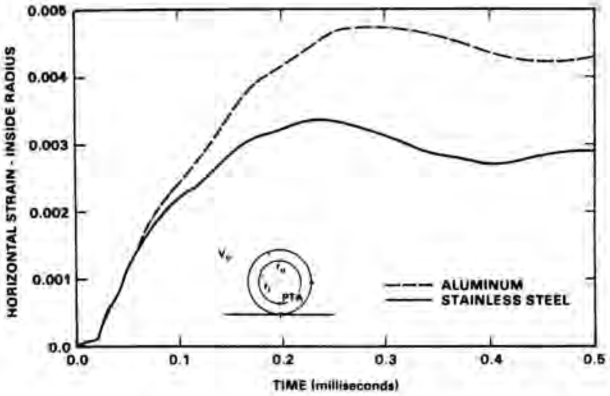

Fig. 7. Calculated Horizontal Strain at the Inside Radius.

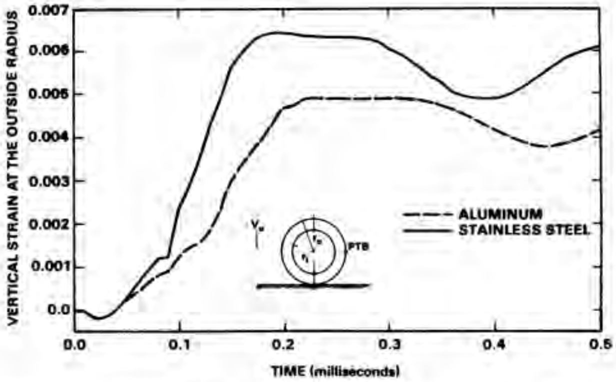

Fig. 8. Calculated Vertical Strain at the Outside Radius.

CONCLUSION

This paper summarizes the experimental plans and expected results for a series of structural benchmark problems. The analytical results indicate the probable differences in deformations that will result from the use of stainless steel and aluminum test articles.

The actual test results will differ due to inevitable variation in the material properties and small variations in the angle of impact. These differences will be available from data taken during and after the actual tests.

References

(1) Nelsen, J. M. (ed), Industry/Government Joint Thermal and Structural Codes Information Exchange Meeting, TTC-0404. Sandia National Laboratories, Albuquerque, NM, 1984

(2) Glass, R. E., Friley, J. R., Olata, H., Nakae, T., Itoh, M., Rasmusson, P., "Structural Code Benchmarking: Impact Response Resulting from the Regulatory 9-Meter Drop," Proceedings of the Symposium on Waste Management, Vol 3, March 1985.

(3) Glass, R. E., Structural Code Benchmarking for the Analysis of Impact Response of Nuclear Material Shipping Casks, SAND84-1855C, Sandia National Laboratories, Albuquerque, NM, March 1985.

(4) Rack, H. J., and Knorovsky, G. A., An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers, SAND77-1872, Sandia National Laboratories, Albuquerque, NM, 1978.

(5) Aerospace Structural Metals Handbook, 1984, Battelle Columbus Laboratories, Columbus, OH 43201.

(6) Hallquist, J. O., User's Manual for DYNA2D An Explicit Two-Dimensional Finite Element Code With Interactive Reasoning, Lawrence Livermore Laboratory, Livermore, CA 94550.