Selection of Cask Shell Material[1]

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INTRODUCTION

Previous cask design experience indicates that the stress analysis and structural stability evaluation of the cask inner shell is a key factor in evaluating the adequacy of the cask's containment boundary. The yield strength of the shell material establishes the thickness required and, hence, the cask weight, which indirectly controls the cask capacity. This study concentrates on the effect of different materials and different shell thickness combinations on the cask capacity.

Nuclear Assurance Corporation used the ANSYS finite element structural analysis code to perform a detailed structural analysis of an existing rail/barge cask. The cask's capacity is 31 assemblies in a burnup credit configuration. The stress results for the inner shell obtained from the ANSYS analysis are used for the buckling evaluation in accordance with the American Society of Mechanical Engineers (ASME) Code Case N-284 to determine the adequacy of the inner shell thickness.

STRESS ANALYSIS METHODS

The stress analysis is performed by the finite element method, utilizing the ANSYS computer program. The cask is analyzed for a 30-foot drop onto an unyielding surface in a horizontal orientation.

The cask is considered as a three-layer (steel-lead-steel) cylindrical tube. The thickness of the lead shell is fixed at 3.2 inches, while the thickness of the inner and outer shells are altered. Table 1 lists the combinations of different inner and outer shell thicknesses that were considered in this study.

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Table 1
Calculated Cask Cavity Diameter for Different
Combinations of Inner and Outer Shell Thicknesses

Outer Shell Thickness (in)	Inner Shell Thickness (in)			
	0.5	1.0	1.5	2.0
2.2	67.65*	66.65	65.65	64.65
2.63	66.79	65.79	64.79	63.79
3.0	66.05	65.05	64.05	63.05
3.5	65.05	64.05	63.05	62.05

Three materials are investigated in this study. They include Type 304 stainless steel, Type XM-19 high-strength stainless steel, and Type HY-85 ferritic steel. The detailed structural analysis, however, was performed using only Type 304 stainless steel. The Type 304 analysis results are applicable to the Type XM-19 stainless steel and Type HY-85 ferritic steel materials because of the following:

1. the elastic moduli of the three selected materials are essentially the same,
2. the difference in Poisson's Ratio is negligible,
3. the yield strength has no effect on the stiffness analysis in the elastic range, and
4. the thermal effect is not considered.

Three-dimensional finite element models were constructed for a cask with a specific outer structural steel wall diameter of 79.45 inches and with the varied inner diameters shown in Table 1. A plot of a typical finite element model used in this study is shown below.

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* Value represents the diameter of the cask cavity. Note that the outside diameter of the cask and the thickness of the lead shell are fixed at 79.45 inches and 3.2 inches, respectively.

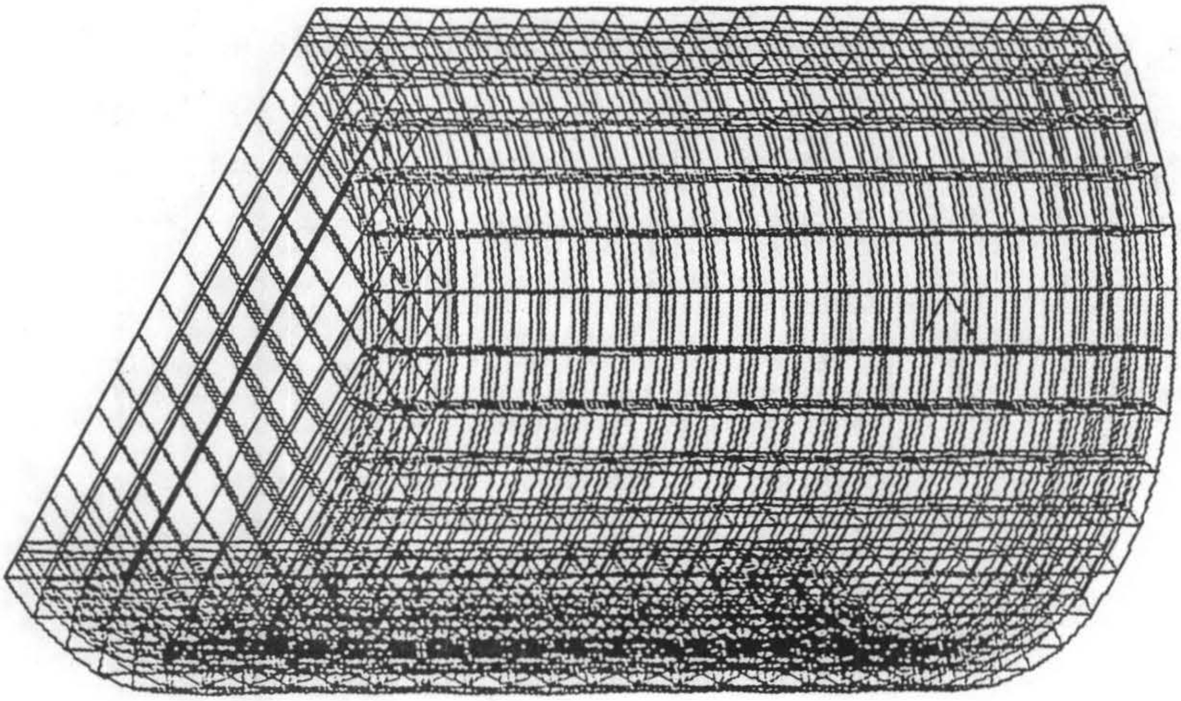

Figure 1 Three-Dimensional ANSYS Model

The following considerations are incorporated in the modeling:

1. Each of the three layers (steel-lead-steel) is modeled as an assembly of three-dimensional brick elements (ANSYS STIF45 element).
2. The solid end is represented by a very stiff grid assembly. The ANSYS STIF4 beam element is used.
3. Only a quarter model is required to evaluate the structural response of a cask for the side drop event because of symmetry conditions.
4. The interface between the lead and steel shells is preset to minimize the modeling effort and computer running time.
5. A variety of combinations of inner and outer shell thicknesses are evaluated.
6. There are a total of 1200 brick elements, 69 beam elements, and 2189 nodes in the model.

Two loadings were considered: the inertial load and the impact load. An inertial load of 55 g was assumed based on a crushable aluminum honeycomb impact limiter design. The inertial load is uniformly applied on the mass of the cask modeled. The inertial load produced by the content is applied as an equivalent pressure on the interior contact surface of the cask along the entire cavity length. The impact load is applied to the finite element model as a distributed pressure over the impact limiter interface surface of the cask. The distribution of impact pressure is assumed to be uniform, in the longitudinal direction, but sinusoidally varied in the circumferential direction.

STABILITY EVALUATION OF THE INNER SHELL

The stress results provided by the ANSYS analysis are used in the stability (buckling) evaluation of the inner shell. The inner shell thickness must be sufficient to satisfy the buckling criteria of ASME Code Case N-284. The yield strength allowables of the materials considered are 30 ksi for Type 304, 55 ksi for Type XM-19, and 85 ksi for Type HY-85. The evaluation is performed in accordance with the ASME Code Case N-284. This Code Case provides the stability evaluation criteria for determining the structural adequacy with regard to the buckling of containment vessels with complex shell geometries and loadings. Analysis procedures and calculation methods for the buckling evaluation are given. The buckling capacity of the shell is derived utilizing the linear classical theory with additional safety factors defined to account for the effects of geometric imperfections, nonlinearity in the boundary conditions, plasticity in material properties, and localized instability. The buckling evaluation is performed by satisfying the interaction relationships developed from the different combinations of the axial (longitudinal) stress, the hoop (circumferential) stress, and the corresponding in plane shear stress.

In accordance with ASME Code Case N-284, three stress components of the ANSYS stress output are considered in the stability evaluation. In this case, SIGY, SIGZ, and SIGYZ in the element coordinate system of the ANSYS finite element model are the associated hoop, meridional, and in-plane shear stresses of the cylindrical shell, respectively. The calculation of stability interaction equations is lengthy and tedious. Therefore, a FORTRAN algorithm is prepared, which can perform the calculation as many times as desired.

The following tables document the results of buckling evaluations for the cask inner shell, using different combinations of material and shell thicknesses.

Table 2
Buckling Evaluation for the Inner Shell
Using Type 304 Stainless Steel

Material	Outer Shell Thickness (in)	Inner Shell Thickness (in)	Buckling Evaluation		
			Failed	Passed	M.S.*
Type 304	2.20	0.50	F		- 0.97
	2.63	0.50	F		- 0.96
	3.00	0.50	F		- 0.96
	3.50	0.50	F		- 0.96
	2.20	1.00	F		- 0.69
	2.63	1.00	F		- 0.65
	3.00	1.00	F		- 0.62
	3.50	1.00	F		- 0.57
	2.20	1.50		P	+ 0.23
	2.63	1.50		P	+ 0.39
	3.00	1.50		P	+ 0.49
	3.50	1.50		P	+ 0.64
	2.20	2.00		P	+ 2.33
	2.63	2.00		P	+ 2.70
	3.00	2.00		P	+Large
	3.50	2.00		P	+Large

* M.S. is equal to $\frac{1}{\text{Maximum Interaction Checking Coefficient}} - 1$. Note it is not the classical definition of margin of safety.

Table 2 indicates that the minimum thickness of the cask inner shell made of Type 304 stainless steel is 1.50 inches, in order to satisfy the stress and buckling requirements. This makes the maximum diameter of the cask cavity 65.65 inches (Table 1), which permits a capacity of 31 fuel assemblies.

Table 3
Buckling Evaluation for the Inner Shell
Using Type XM-19 Stainless Steel

Material	Outer Shell Thickness (in)	Inner Shell Thickness (in)	Buckling Evaluation		
			Failed	Passed	M.S.*
XM-19	2.20	0.50	F		- 0.89
	2.63	0.50	F		- 0.87
	3.00	0.50	F		- 0.85
	3.50	0.50	F		- 0.83
	2.20	1.00		P	+ 0.16
	2.63	1.00		P	+ 0.32
	3.00	1.00		P	+ 0.45
	3.50	1.00		P	+ 0.59
	2.20	1.50		P	+ 6.14
	2.63	1.50		P	+ 6.14
	3.00	1.50		P	+ 6.69
	3.50	1.50		P	+ 6.69
	2.20	2.00		P	+Large
	2.63	2.00		P	+Large
	3.00	2.00		P	+Large
	3.50	2.00		P	+Large

* M.S. is equal to $\frac{1}{\text{Maximum Interaction Checking Coefficient}} - 1$. Note it is not the classical definition of margin of safety.

Table 3 reports that the minimum thickness of the cask inner shell made of Type XM-19 stainless steel is required to be 1.00 inch. The inside diameter of the cask cavity is enlarged to 66.65 inches. This increases the cask capacity (payload) and permits the storage of 32 fuel assemblies.

Table 4
Buckling Evaluation for the Inner Shell
Using Type HY-85 Ferritic Steel

Material	Outer Shell Thickness (in)	Inner Shell Thickness (in)	Buckling Evaluation		
			Failed	Passed	M.S.*
HY-85	2.20	0.50	F		- 0.99
	2.63	0.50	F		- 0.92
	3.00	0.50	F		- 0.90
	3.50	0.50	F		- 0.90
	2.20	1.00		P	+ 1.78
	2.63	1.00		P	+ 2.23
	3.00	1.00		P	+ 2.33
	3.50	1.00		P	+ 2.57
	2.20	1.50		P	+ 6.14
	2.63	1.50		P	+ 6.14
	3.00	1.50		P	+ 6.69
	3.50	1.50		P	+ 6.69
	2.20	2.00		P	+Large
	2.63	2.00		P	+Large
	3.00	2.00		P	+Large
	3.50	2.00		P	+Large

* M.S. is equal to $\frac{1}{\text{Maximum Interaction Checking Coefficient}} - 1$. Note it is not the classical definition of margin of safety.

Table 4 indicates that the use of Type HY-85 ferritic steel as the cask shell material permits a cask capacity of 32 fuel assemblies. The use of Type HY-85 ferritic steel does not result in any additional increase of payload over that of XM-19, and furthermore, could introduce new licensing questions.

CONCLUSION

The analysis results indicate a clear trend in the structural strength and buckling stability of the cask inner shell for different strength materials and varying shell thicknesses. These results supply technical data for the shell material selection and design of future high capacity shipping casks. The payload of each feasible combination of material and inner/outer shell thickness is documented below.

Table 5
Allowable Payload For A Cask
Considering Different Shell Materials

Material	Outer Shell Thickness (in)	Inner Shell Thickness (in)	Lead Shell Thickness (in)	Cavity Diameter (in)	Cask Capacity (# of Assemblies Allowed)
Type 304	2.63	1.50	3.20	64.79	31[*]
XM-19	2.20	1.00	3.20	66.65	32[**]
HY-85	2.20	1.00	3.20	66.65	32

Table 5 indicates that the cask cavity can be enlarged from a 31-assembly to a 32-assembly capacity by using Type XM-19 stainless steel instead of Type 304 stainless steel. The use of Type HY-85 ferritic steel increases the margin of safety in structural strength, but does not result in any additional increase of payload, and could introduce new licensing questions.

It is recommended that Type XM-19 stainless steel be selected for the cask inner and outer shells. The thicknesses required for the inner, lead, and outer shells are 1.0 inch, 3.2 inches, and 2.5 inches, respectively. This arrangement permits a cask cavity diameter of 66.05 inches. The minimum diameter of the cask cavity for 32 fuel assemblies is 65.98 inches.

REFERENCES

1. "'ANSYS' Computer Code for Large-Scale General Purpose Engineering Analysis," Version 4.2B, Swanson Analysis Systems, Inc., Houston, PA.

2. "ASME Boiler and Pressure Vessel Code," Section III, Case N-284, The American Society of Mechanical Engineers, 1986.

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[*] Minimum cavity diameter to allow 31 fuel assemblies is 64.79 inches.

[**] Minimum cavity diameter to allow 32 fuel assemblies is 65.98 inches.