# STRUCTURAL EVALUATION OF A SHIELDED TRANSFER CASK SYSTEM FOR INTRA PLANT SPENT FUEL TRANSFER

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## ABSTRACT

Intra Plant transfer movement of spent fuel between units can be accomplished using a shielded transfer cask anchored to a high capacity trailer supported by pneumatic tires. The spent fuel is contained in a stainless steel canister with a bolted lid to allow for loading and unloading of the spent fuel. In this paper, two separate evaluations are presented to confirm the safety of such a system. The seismic event controls the design of the tie down system used to prevent the transfer cask on the trailer from tipping over. Since the wheeled vehicle has a broad band of possible properties, a series of time histories are perform to define the envelope of loading that could be imposed on the tie down system. The system is assumed to be subjected to a non-mechanistic tip over. A subsequent evaluation is performed using a separate model to ensure that the canister maintains confinement and that the internal structure (basket) maintains the position of the fuel during this event. This analysis employs a detailed model of the shielded transfer cask, bolted canister, basket, and fuel. To capture the nonlinear behavior of the system, each lead brick and the individual elements of the basket was modeled. Results for the transfer cask, canister and basket evaluations show that confinement and the geometric positioning of the fuel are maintained during design basis impact loading.

## INTRODUCTION

Regulations at operating nuclear power plants include requirements on the necessity of maintaining capacity of the spent fuel pools. Power plants with multiple units, each having an individual spent fuel pool, may transfer spent fuel between pools for a period of time to more effectively manage the spent fuel pool site capacity. This approach may be useful while the licensing or construction of a dry storage system for the fuel is in process at the site. To minimize the need for additional hardware, the existing shielded transfer cask at the site, used for loading spent fuel, may be utilized to move the fuel. The foot print of such a system can be minimized by maintaining the cask in the vertical position. Movement of the system is accomplished using a high capacity trailer which precludes the need for a rail system. Movement of spent fuel within the boundaries of a site is not considered to be in the same category as transport of spent fuel outside the site boundaries. Therefore, the requirement of a 9-meter drop of the package onto an unyielding surface is not required. The removal of this requirement significantly reduces the structural design of the system. The condition governing the design is due to the design basis seismic condition. Evaluations show that the system does not tip over due to the bounding seismic conditions at the site. However, the system is designed to maintain confinement of the spent fuel due to a tip over of the system. This method of analysis is a defense in depth approach to assure the safe condition of the package usage at the site. The following paper describes the evaluation of the seismic loading on the system and the tip over of the shielded transfer cask.

## SYSTEM DESCRIPTION

Preparation of the spent fuel for movement is initiated by loading the fuel into a right circular stainless steel canister which rests inside of a shielded transfer cask. The canister opening is designed with a flange to permit the canister to be sealed with a bolted stainless steel lid once the fuel has been loaded into the canister. Fuel positioning inside the canister is maintained by a series of high strength carbon steel disks. The shielded transfer cask containing the sealed canister and fuel is comprised of steel-lead-NS4FR-steel shells to provide radiation shielding as well as sufficient strength to conduct lifting operations. Movement of the cask is performed using two solid trunnions attached to the inner/outer steel shells. The cask is maintained in the vertical orientation during all phases of loading, movement and unloading of the canister.

To move the loaded cask between units, the cask is positioned on a high capacity trailer. The trailer is designed with a suspension system to maintain the bed of the trailer in a level horizontal position during movement. A cable system attaching the cask to the trailer is designed to further restrain the cask from experiencing relative motion with respect to the trailer during the design basis seismic event.

## SEISMIC EVALUATION

The objective of the seismic evaluation was to confirm that the cask containing a canister with fuel remains attached to the trailer and that the system remains upright. An acceleration time history specified in three directions is the input to excite the trailer and cask. The peak time history acceleration was 0.55g's, and the corresponding peak spectral acceleration was 2.9g's at 5% damping. The finite element model used in this evaluation is shown in Figure 1, which defines the geometry of the model as well as the types of elements used in the model. The total cask mass with contents was 82,000 kg. ANSYS (Ref. 1) was used in model and solution generation. The model included the trailer, the cask, and the cables restraining the cask to the trailer. The structural steel forming the trailer frame is represented by beam elements and shell elements represented the trailer deck. As indicated in Figure 1, not all joints of the trailer were welded but included hinges at certain frame connections.

Hand calculations for the cask indicated that the cask shell fundamental modes or some type beam flexural mode would not be excited. The cask model was simplified by using a beam element and a lump mass with rotational inertia to simulate the motion of the cask relative to the trailer. The bottom surface of the cask rests on the compression-only elements representing the trailer deck reaction to the cask inertial loading. The design included attaching cables from the cask to the trailer deck and the cables were modeled using tension only elements. The stiffness and damping of the tires was represented using spring elements (containing damping) in three directions. A value of 7% damping was associated with the tires which is considered to be a minimal value.

The loading to be applied to the model was the motion defined at the wheel locations and gravity. Gravity was applied to the system in a solution step without transient inertia prior to initiating the time history solution. Since reorientation of the structural beam and plate elements was possible during the solution, the analysis option to update the elemental stiffness matrix due to rotation was made active.

In reviewing the parameters which affected the stability of the system as well as the reactions in the cables, the following was considered:

1) Tire stiffness and damping (since this would force the fundamental modes for the trailer system to occur at the peak spectral accelerations of the time history)

2) Orientation of the trailer with respect to the seismic excitation (uncertainty of actual orientation of the seismic motion)

3) Wheel braking system may not be engaged during the seismic event (potentially introducing additional rocking of the system)

The model shown in Figure 1 was used to generate time history solutions for the seven analysis cases shown in Table 1. A summary of the system response is shown in Table 2. For a tip over to occur the cask must rotate by more than 30º. Since the largest tip angle observed was less than 3º, the system remains upright during and after the seismic event. As expected the reduction in the damping resulted in the maximum response of the system and was shown to be the most significant parameter as compared to tire stiffness, model orientation or trailer restraint. Since 7% was considered to be the minimal value, the other cases employed the 7% in the solution. Relative motion of the cask with respect to the trailer is considered to be minimal and therefore, the cask would remain on the trailer.

## CASK TIP OVER EVALUATION

The tip over of the cask in this paper is considered to be a non-mechanistic event since there is no loading in the design basis which could result in the cask being tipped over. The tip over of the system is considered to be an accident event. For this condition, the following items comprise the design objective.

1) Maintain the integrity of the canister confinement boundary including the bolted lid.
2) Maintain the position of the fuel contained in the basket.
3) Maintain the integrity of the fuel.

While the cask itself is not the confinement boundary, it does provide radiation shielding. The evaluation provides important information about the level of the cask local radiation dose after the tip over. For the tip over condition, the cask is assumed to initiate rotation when the system CG is positioned over the edge of the cask base. Stresses developed in the system are minimal during the cask rotation and the analysis is initiated at the instance the cask impacts the ground. The angular velocity at the initiation of impact is computed by conservation of energy and becomes the initial condition of the analysis. To provide a bounding condition for the impact plane, it is assumed to be a rigid surface, and this also provides a simplification to the over all finite element model since the ground does not have to be explicitly included.

The finite element model used in this evaluation is shown in Figure 2, which corresponds to a half symmetry model of the cask with a canister containing fuel. The model, in terms of nodes and elements, was generated in ANSYS, while the solutions were obtained using LS-DYNA (Ref 2). The interfaces between the components described below were defined in LS-DYNA.

Shielded cask

The purpose of the shielded cask is to provide radiation protection and structural support for the canister. It is comprised of a series of shells to perform both functions. As shown in Figure 3, the cask inner and outer shells, which are carbon steel, maintain the position of the lead (gamma shielding) and NS4FR (hydrogenous fire retardant polymer) shells. The inner and outer shells are attached to a ring at the top (Figure 3) and a plate at the bottom (Figure 3). This forms the closed volume for the lead and NS4FR shells. The lead shell is actually constructed from lead bricks. Each brick was modeled independent of the adjacent lead bricks by inserting a 0.02 mm gap between the elements associated with each brick. The interface force between bricks was limited to compression only forces. The lead material comprising the bricks used static elastic-properties for the lead. The NSF4FR shell is as a solid cylindrical shell modeled with elastic properties. The canister rests on the carbon steel doors which form the bottom of the cask cavity. The doors are designed to slide along the rails (Figure 3) to allow the canister to be lowered through the bottom of the cask for certain operations. As show in Figure 3, the bottom plate of the cask is connected to the rails even though the interface between the two is comprised of two dissimilar meshes.

Impact Limiter

To limit the inertial forces generated during the tip over, a foam impact limiter attached to the top of the cask was designed and the finite element model is shown in Figure 3. It is comprised of crushable foam material encased in a stainless steel shell. Crush properties for the foam were obtained from Ref 3 and account for the temperature dependency, the dynamic crush strength, foam orientation (foam crush strength parallel or perpendicular to the pour direction of the foam), and fabrication tolerances. This presented a challenge to the design since the foam crush strength could vary as much as 100% depending on the temperature and tolerances. As noted in Figure 3, the impact limiter has a section removed to account for the presence of the trunnion which is attached to the cask. The trunnions which are used to lift the cask are not explicitly modeled, but the model shown in Figure 3 has the trunnion positioned so as to limit the potential foam crush to a minimum. The impact limiter design prevents the trunnions from coming into contact with the impact plane during the tip over event. The stainless steel shell encasing the foam material is modeled as shell elements with elastic-plastic properties.

Canister

The stainless steel canister is comprised of a bolted lid (shown in Figure 3), welded flange, cylindrical shell, and a bottom plate (shown in Figure 4). The elements representing the lid were modeled to be independent of the bolts and the flange attached to canister shell, which accurately represents the canister shell and lid interaction. The lid is recessed to allow the lateral inertial force on the lid to be transferred directly into the flange as opposed to being resisted by the bolts. For analysis efficiency, the evaluation of the seal compression and bolt stresses were performed with a separate periodic section of the model shown in Figure 3 using static analyses.

Structural Basket and Fuel

The structural basket (identified in Figure 3 and Figure 4) maintains the position of the fuel during and after the tip over. It is comprised of a series of high strength disks which are held in their axial positions by a series of axial rods. The basket is modeled in this detail to accurately determine the extent of contact between the canister and cask. As indicated in Figure 4, some basket slots do not have fuel for this configuration. The impact limiter was designed to permit the fuel inertial loading in Ref 4 to be bounding confirming that the tip over basket stresses in Ref 4 are also bounding. The fuel assemblies shown in Figure 3 and Figure 4 were modeled with reduced elastic modulus.

Tip Over Analysis and Results

Two transient evaluations are performed which bound the response of the impact limiter. The upper limit of the foam crush strength corresponded to the minimum temperature condition (Cold Condition) and tolerances increasing the crush strength to its maximum. This condition resulted in the maximum deceleration of the cask. The lower limit of the foam crush strength corresponded to the maximum temperature condition (Hot Condition) and tolerances decreasing the crush strength. This condition resulted in the maximum crush of the impact limiter which is to prevent the trunnion from contacting the impact plane.

The maximum crush strain for the impact limiter was less than 60% indicating that the foam material will limit the accelerations and prevent the trunnion from contacting the impact plane. The deformation of the impact limiter is shown in Figure 5. The maximum stress for the canister confinement boundary occurred for the Hot Condition (Figure 6) corresponding to a safety factor of 2.20 confirming that the confinement boundary is maintained for the tip over condition. The maximum system acceleration of 21g's was determined by the Cold Condition and resulted in the maximum stress condition for the transfer cask (Figure 6) which corresponded to a safety factor of 1.16 for the transfer cask. This confirmed that the transfer cask maintained its integrity for the tip over condition

## CONCLUSIONS

This paper described a transfer cask system capable of moving spent fuel between units at a site. Analyses confirm that the transfer cask and trailer system remains upright during the design basis seismic condition. An additional analysis of the non-mechanistic tip over was also performed using a detailed model of the canister and transfer cask system. Safety factors greater than 1 were determined for the confinement boundary and the transfer cask.

## REFERENCES

Ref 1 - ANSYS Revision 10, ANSYS INC, Canonsburg PA, USA
Ref 2 - LS-DYNA Rev 970, LSTC Lawrence Livermore, CA, USA
Ref 3 - "Design Guide for Use of Last-A-Foam FR-3700", General Plastics Manufacturing Co., Tacoma Washington.
Ref 4 - Final Safety Analysis Report for the UMS Universal Storage System, Rev. 8A, NAC International, Atlanta, Georgia.

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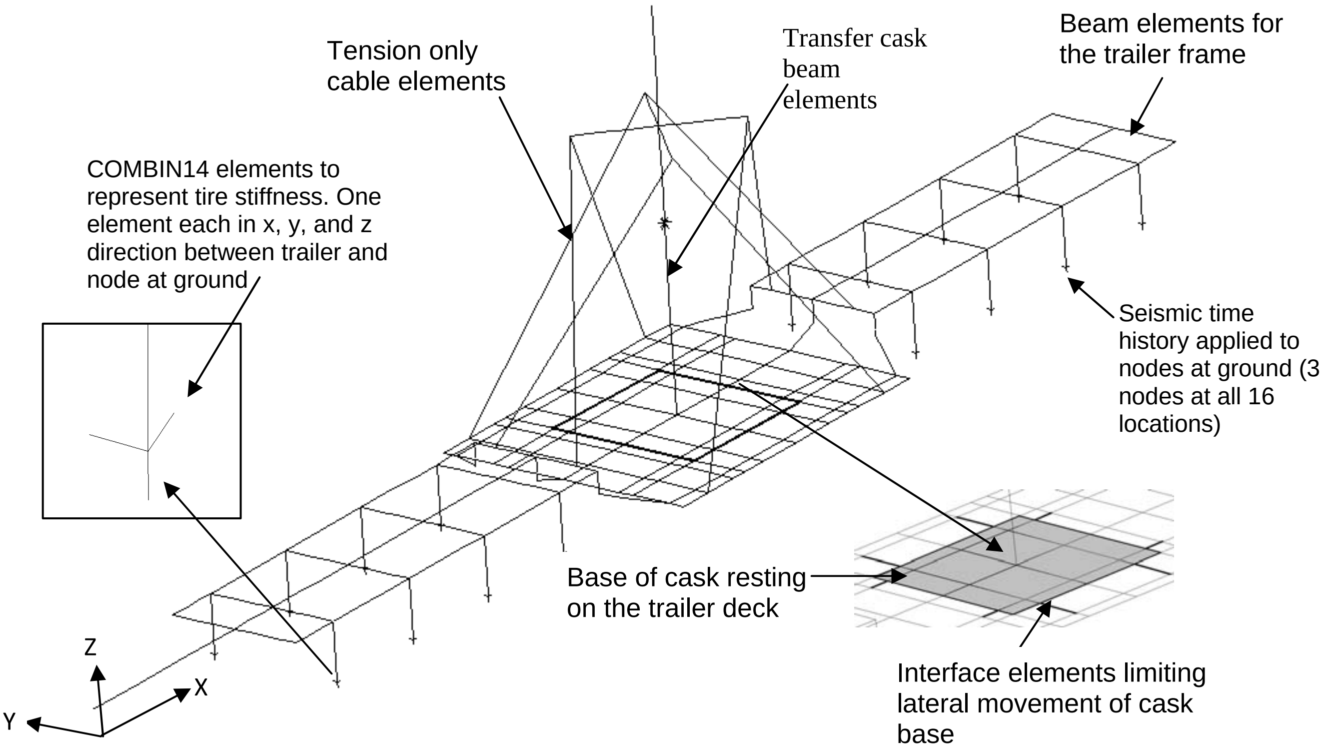


**Figure 1 - Finite Element Model to Evaluate Seismic Motion and Loading**

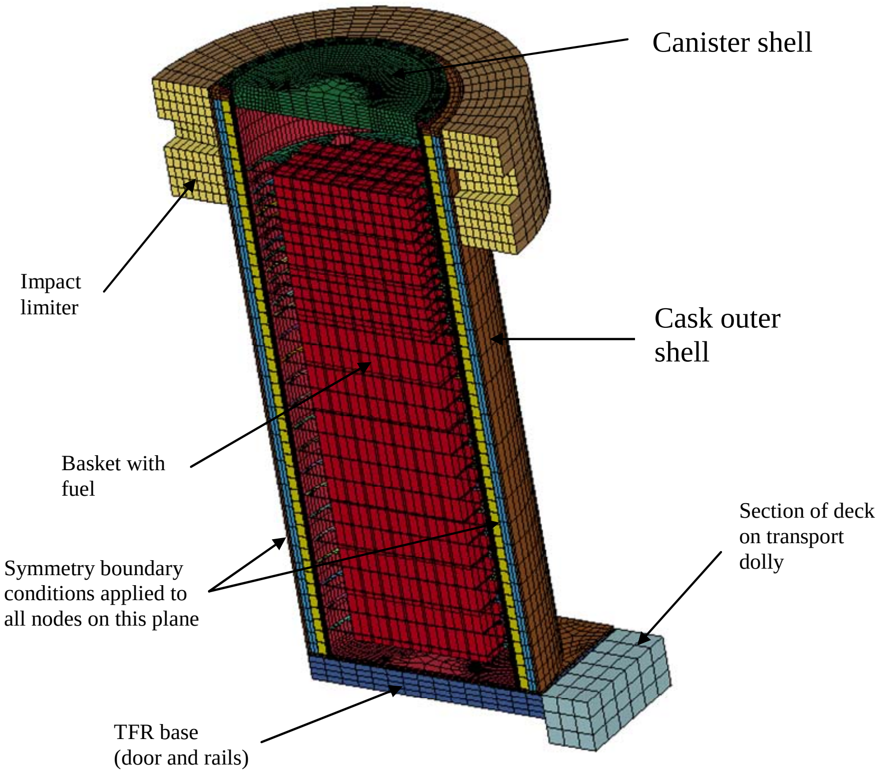


**Figure 2 - Overall View of Finite Element Model of Cask System for Tip Over Evaluation**

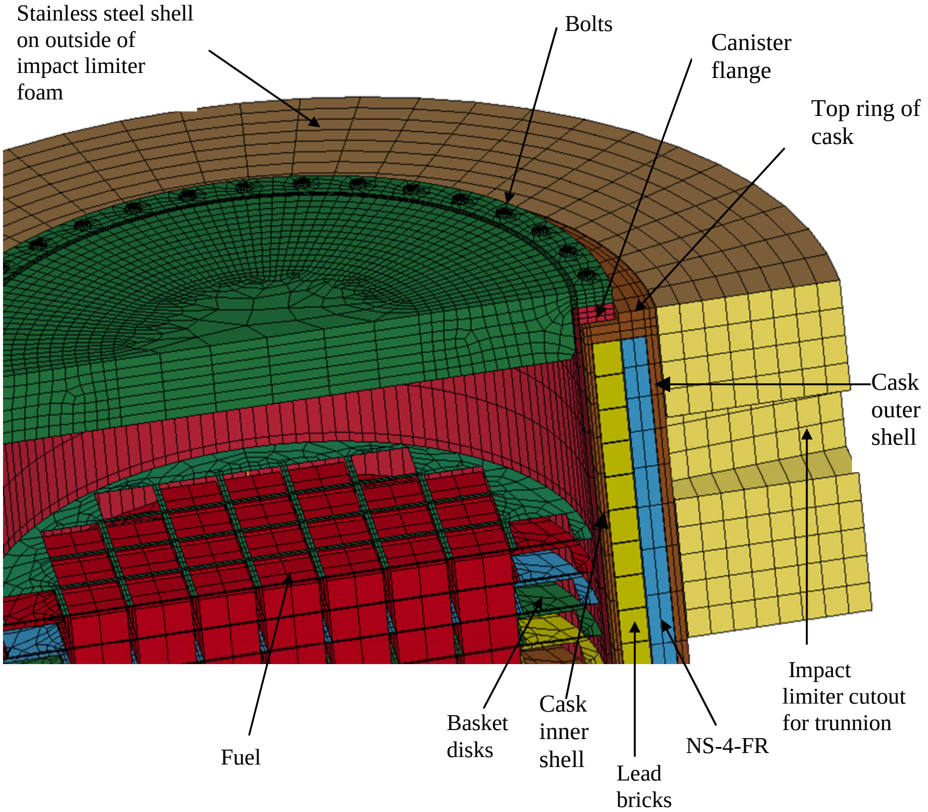


**Figure 3 - Detailed View of Upper Portion of Cask, Canister, Basket and Impact Limiter**

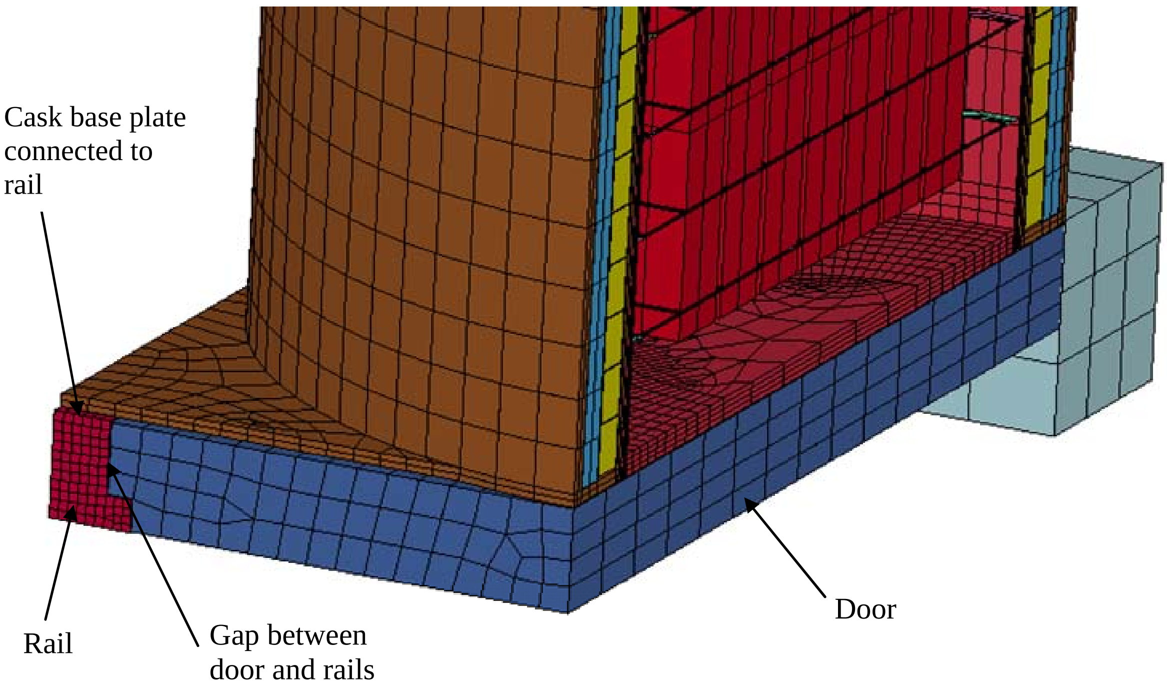


**Figure 4 - Detailed View of Lower Portion of Cask, Doors, Canister and Basket**

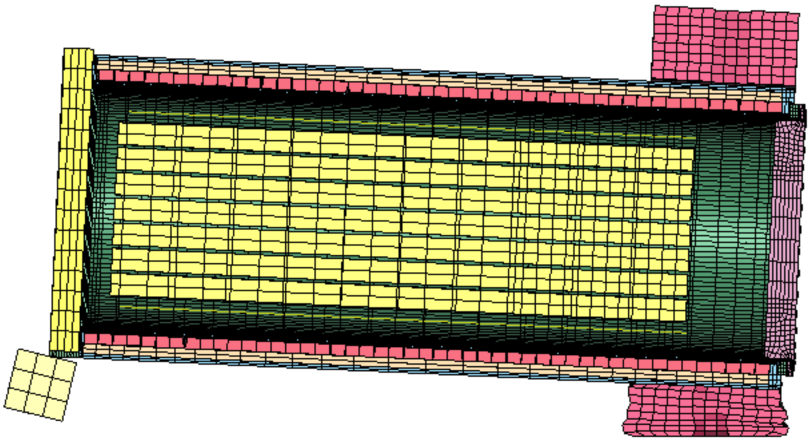

**Figure 5 - Model Deformation for the Hot Condition**

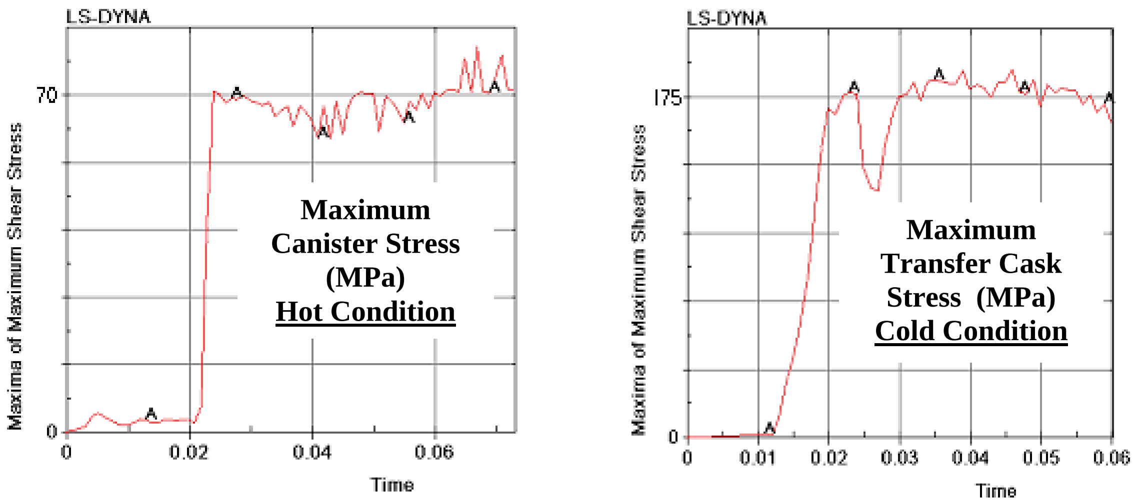


**Figure 6 - Maximum System Stresses**

**Table 1 - Transient Analysis Cases for Seismic Evaluation***

| Case | Description | Comment | Cask Tip Angle(°) |
|---|---|---|---|
| **1** | Tire stiffness K = 900 N/mm, 7% damping | Use provided tire properties | 1.6° |
| **2** | Tire stiffness K = 900 N/mm, 3.5% damping | Reduce tire damping by 50% | 2.6° |
| **3** | Tire stiffness K = 720 N/mm, 7% damping | Reduce tire stiffness by 20% | 1.8° |
| **4** | Tire stiffness K = 1080 N/mm, 7% damping | Increase tire stiffness by 20% | 1.5° |
| **5** | Tire stiffness K = 900 N/mm, 7% damping, interchange seismic excitation X and Y axis | Considers case with trailer-cask system rotated 90° | 2.0° |
| **6** | Tire stiffness K = 900 N/mm, 7% damping, seismic excitation directions rotated 45° | Considers case with trailer-cask system rotated 45° | 1.6° |
| **7** | Tire stiffness K = 900 N/mm, 7% damping apply excitation in the Y and Z directions | Trailer-cask system to freely move in X | 1.6° |

* Figure 1 defines the coordinate axis for the trailer-cask seismic evaluation