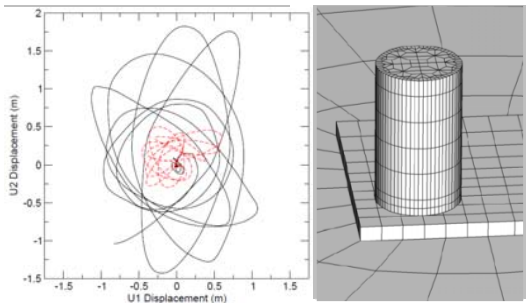
SAND2012-9791C



Sandia National Laboratories

Exceptional service in the national interest

Seismic Considerations for Spent Nuclear Fuel Storage in Dry Casks

International Top-Level Forum on Seismic Safety of Nuclear Power Plants

Guangzhou, China, 21-23 November 2012

Susan Y. Pickering, Senior Manager
John L. Bignell, Principal Member of the Technical Staff
Jeff A. Smith, Principal Member of the Technical Staff
Chris A. Jones, Senior Member of the Technical Staff

Sandia National Laboratories, Albuquerque, NM, USA

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

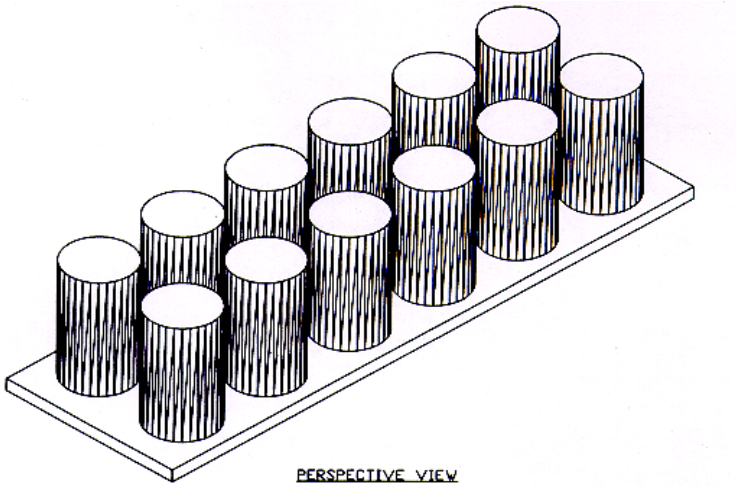
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

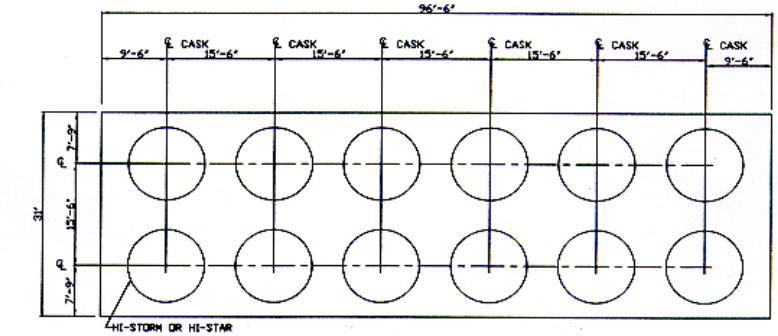
Outline

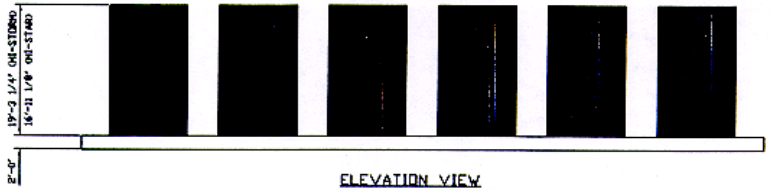
Sandia National Laboratories

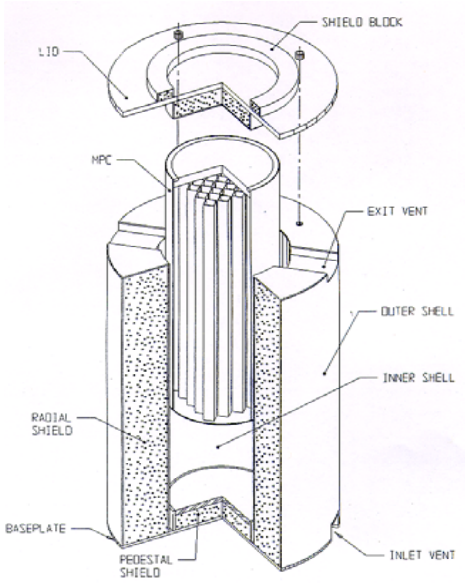
- Introduction/Background
  - What are dry casks storage systems?
  - How are they used and why are they needed?
  - Why are they free-standing?
- Parametric Evaluation Overview
- Coupled Analysis Methodology
- Selected Results
- Conclusions

Vertical Cylindrical Casks

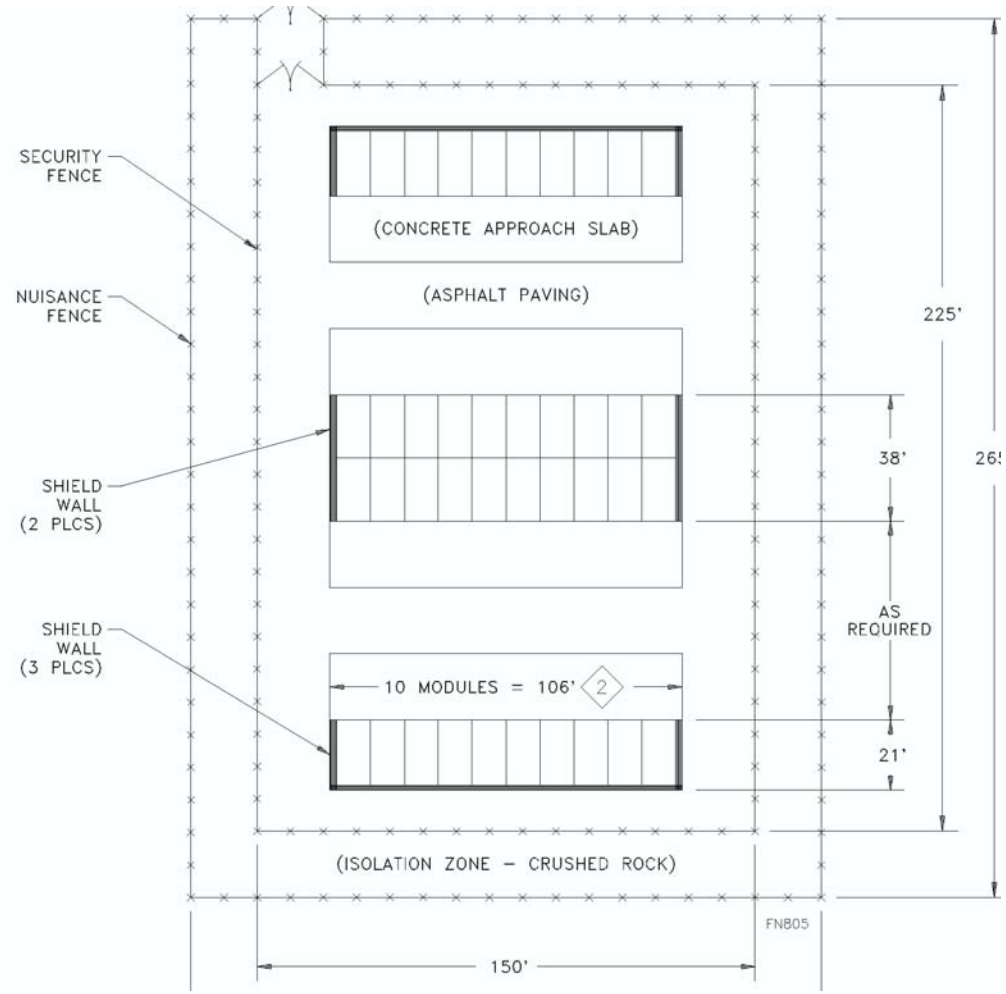


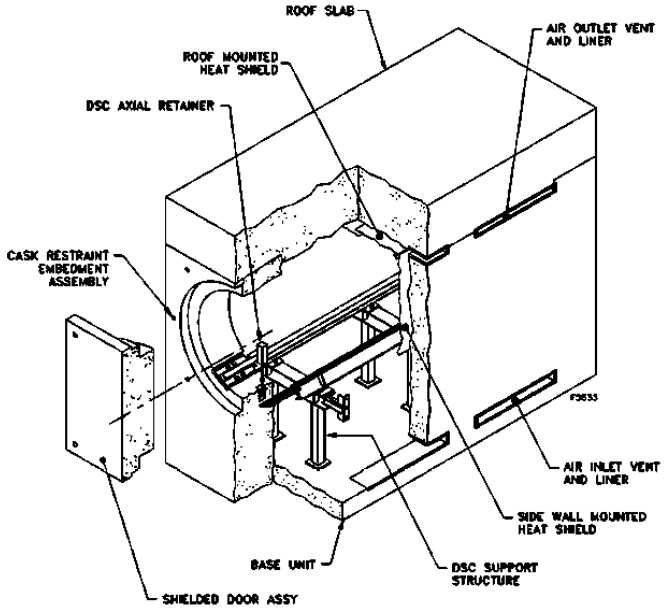






Horizontal Rectangular Cask



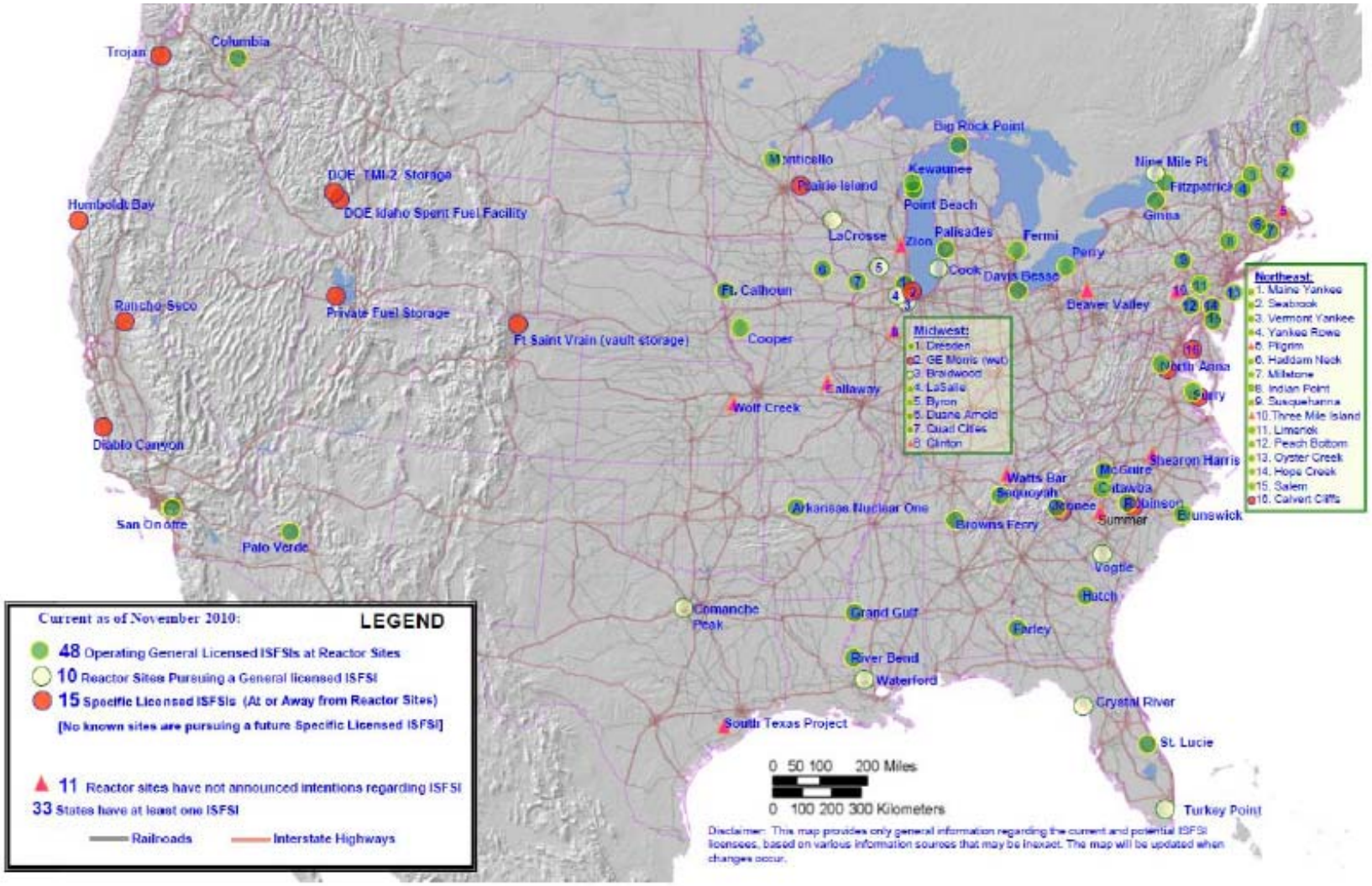


Why Dry Cask Storage?

Sandia National Laboratories

- Dry storage of spent fuel above ground has become an accepted “repository” alternative by installing DCSS at Independent Spent Fuel Storage Installations (ISFSI).
- As of 2010:
  - There were 63 independent spent fuel storage installations (ISFSI) in operation in the United States in 33 different states.
  - More than 1400 spent nuclear fuel dry storage casks in use.
- With 104 operating nuclear power plants in the US and the defunding of the high level waste storage repository at Yucca Mountain in 2011, the use of dry cask storage is likely to increase in years to come.

ISFSIs in the United States



Why Free-Standing Casks?

Sandia National Laboratories

- Free standing cask storage offers financial benefits in the form of reduced implementation and future decommissioning costs.

- Free standing cask storage also results in reduced regulatory burden for ISFSI operators.

- However, there are safety concerns related to the performance of the casks in the event of earthquake induced ground shaking.
  - Cask rocking, sliding, toppling, and/or cask-to-cask pounding.

Parametric Analysis Overview

Sandia National Laboratories

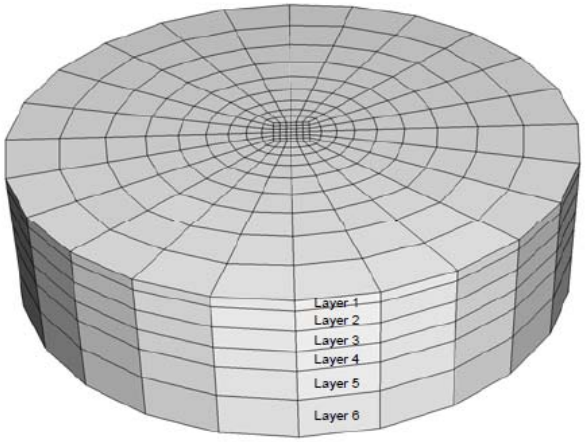
- SNL was contracted by the US NRC to investigate the seismic behavior of dry cask storage systems.
- First phase involved three site-specific/cask-specific analyses.
  - Three-module rectangular Transnuclear West module/cask
  - HI-STORM 100 casks at the Hatch Nuclear Power Station
  - HI-STORM 100 casks at the Private Fuel Storage Facility
- Second phase involved a parametric evaluation aimed at quantifying the sensitivity of calculated cask response characteristics to input parameters such as.
  - Cask design, earthquake ground motion, foundation soil characteristics, and cask-to-pad coefficients of friction.

Coupled Analysis Methodology

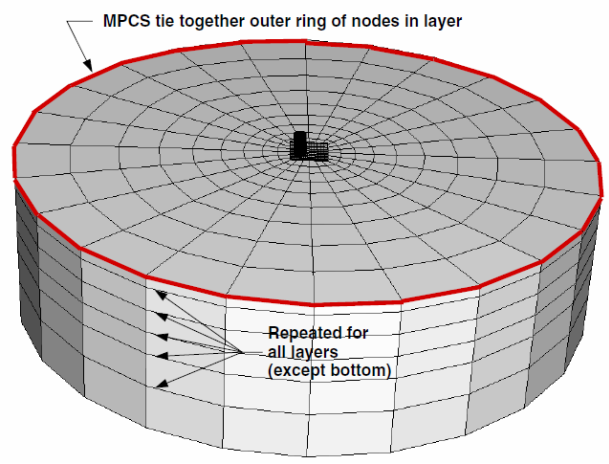
Sandia National Laboratories

- Simple Coupled Model
  - Includes explicit representations of cask, pad, and supporting soil column.
  - Simple → Enables parametric evaluation.
- ABAQUS Explicit Code
  - Explicit formulation was chosen in order to arrive at a converged solution set for the highly nonlinear (sliding contact) problem.
- Ground Motions Applied at Base of Soil Column
  - Selection of a limited set of earthquake records to serve as inputs for ground motion generation.
  - Frequency and amplitude scaling of selected input earthquake records to match various earthquake response spectra.
  - Conversion of surface-defined ground motions to soil-column-base motions through deconvolution analysis.

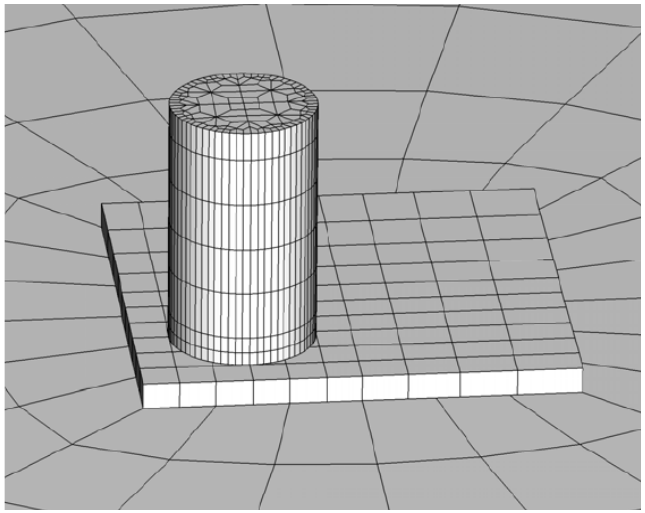
Coupled Model



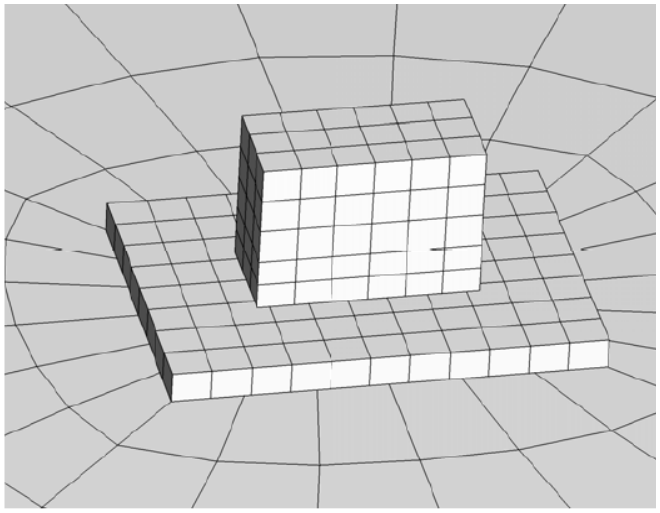
Soil Column Layers



Soil Column Multi-Point Constraints

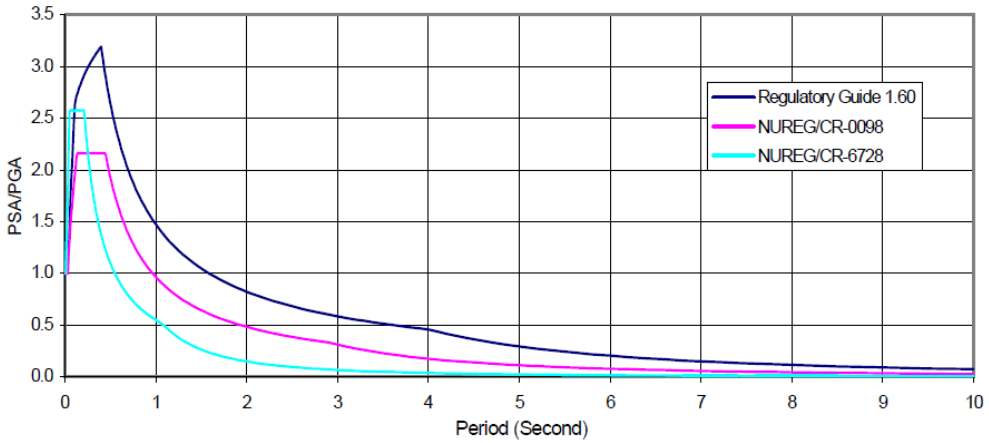


Cylindrical Cask

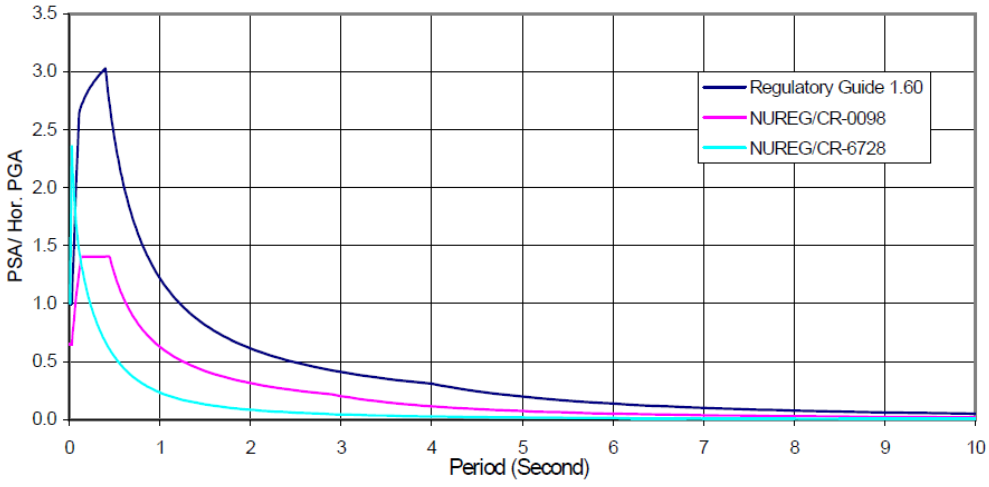


Rectangular Cask

Spectral Shapes



Horizontal Component



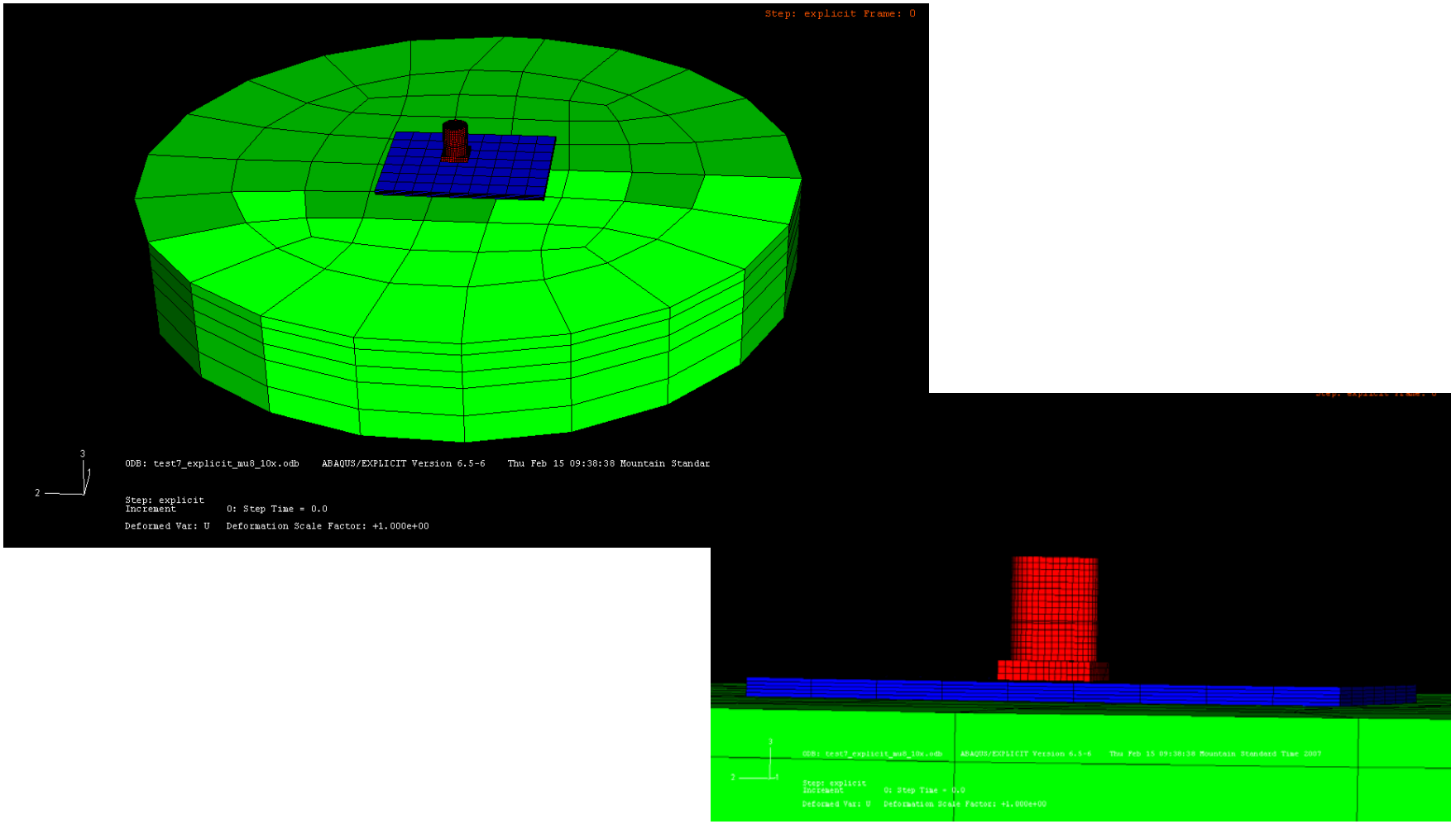
Vertical Component

Scope of Parametric Analysis

Sandia National Laboratories

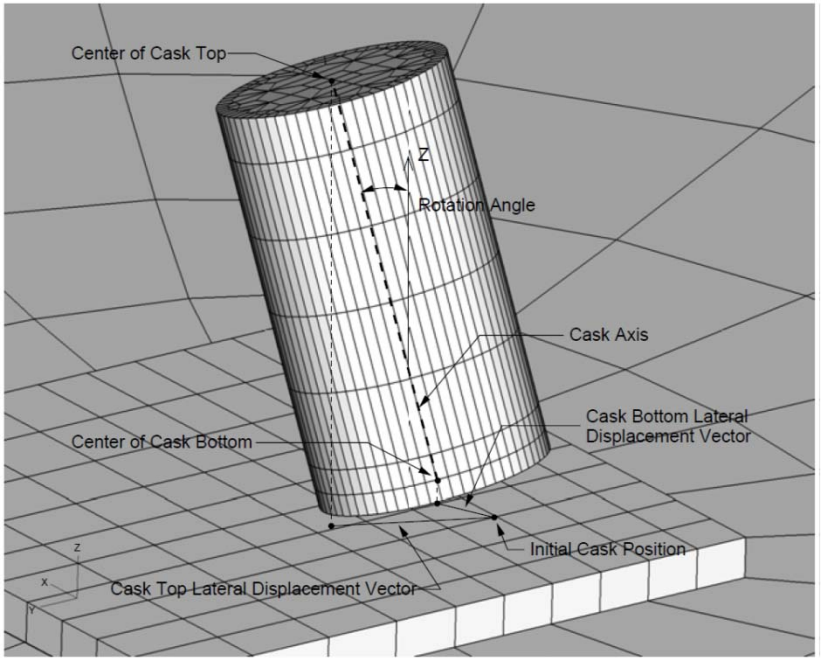
Input Parameters	Description	Details
Finite Element Model	Cask Design	Cylindrical Cask Rectangular Cask
	Foundation Type	Soft Soil Stiff Soil Rock
	Pad-to-Cask Coefficient of Friction	0.20, 0.55, 0.80
Seismic Ground Motions	Spectral Shape	NUREG/CR-0098 Regulatory Guide 1.60 NUREG/CR-6728
	Earthquake Record	NUREG/CR-0098 and Regulatory Guide 1.60 1) 1978 Iran Tabas 2) 1999 Taiwan Chi-Chi 3) 1992 Landers 4) 1994 Northridge 5) 1979 Imperial Valley
		NUREG/CR-6728 a) 1985 Nahanni b) 1988 Saguenay c) 1979 Imperial Valley d) 1989 Loma Prieta e) 1994 Northridge
	Peak Ground Accelerations (PGA)	0.25g, 0.60g, 1.00g, 1.25g

Movie - Example

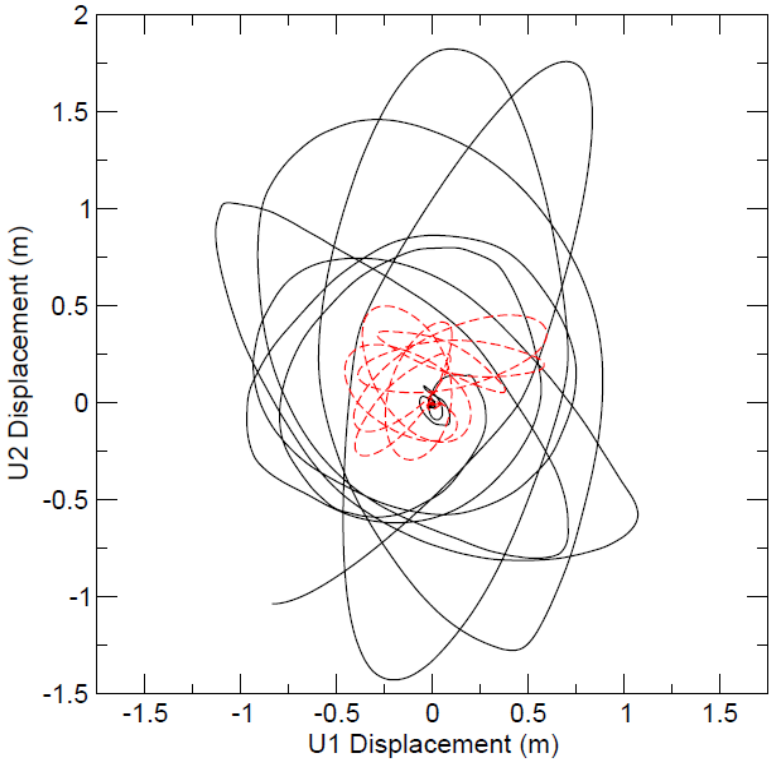


Response Parameters

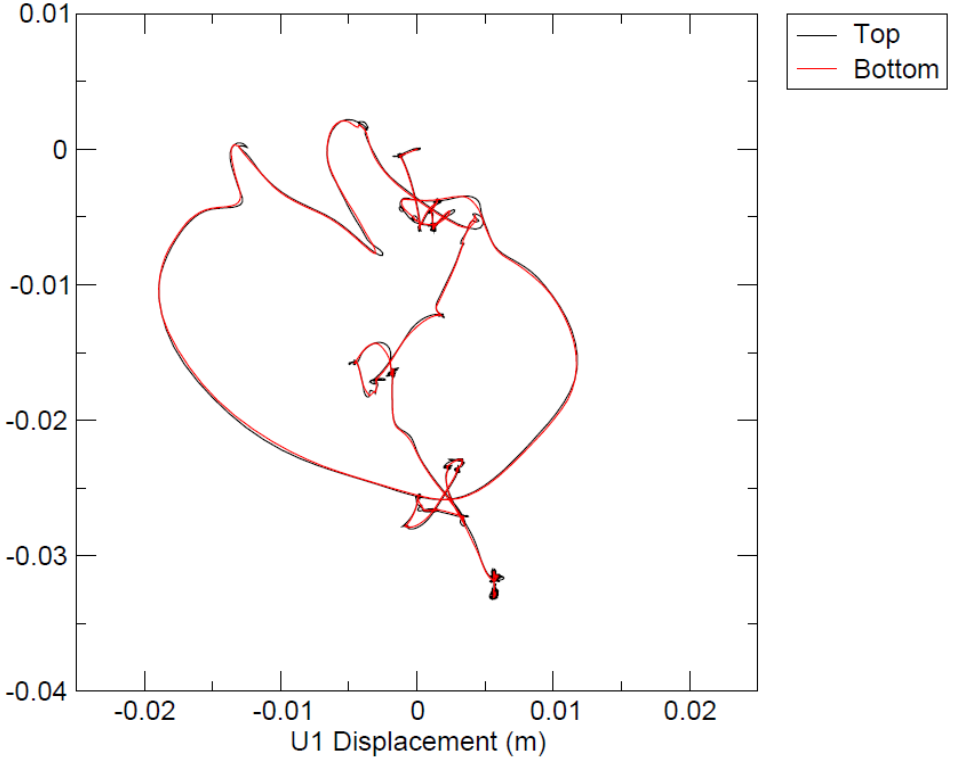
- Three response parameters were used to characterize the cask:
  - Lateral displacement of the cask at its base relative to the concrete pad (cask sliding)
  - Angular rotation of the cask centerline with respect to the vertical coordinate axis (cask tipping angle)
  - Lateral displacement of the top of the cask relative to the concrete pad (combined cask tipping and sliding).



Displacement Trajectory Plots



Cylindrical Cask



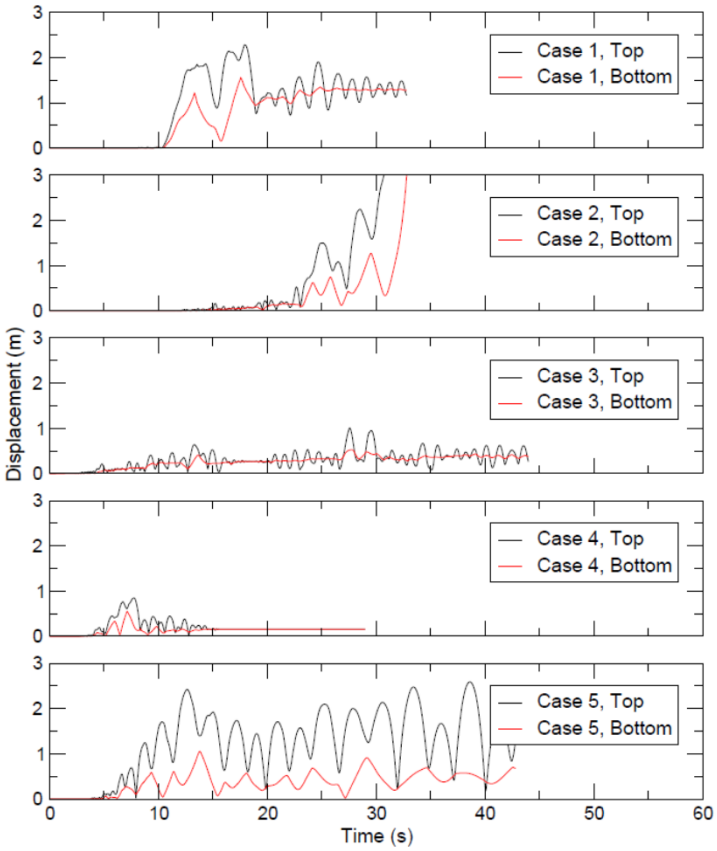
Rectangular Cask

Top and Bottom Displacement Trajectories, Cask-to-Pad μ=0.55, NUREG/CR-0098 Earthquakes, PGA=1.0g, Stiff Soil Foundation

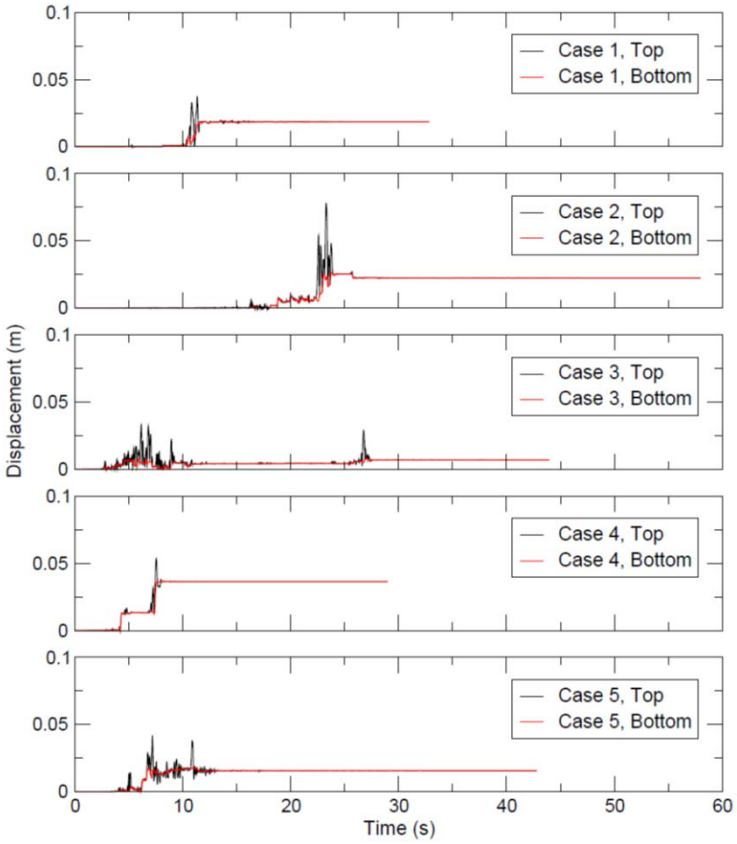
Displacement Time-Histories

Sandia National Laboratories

Cylindrical Cask

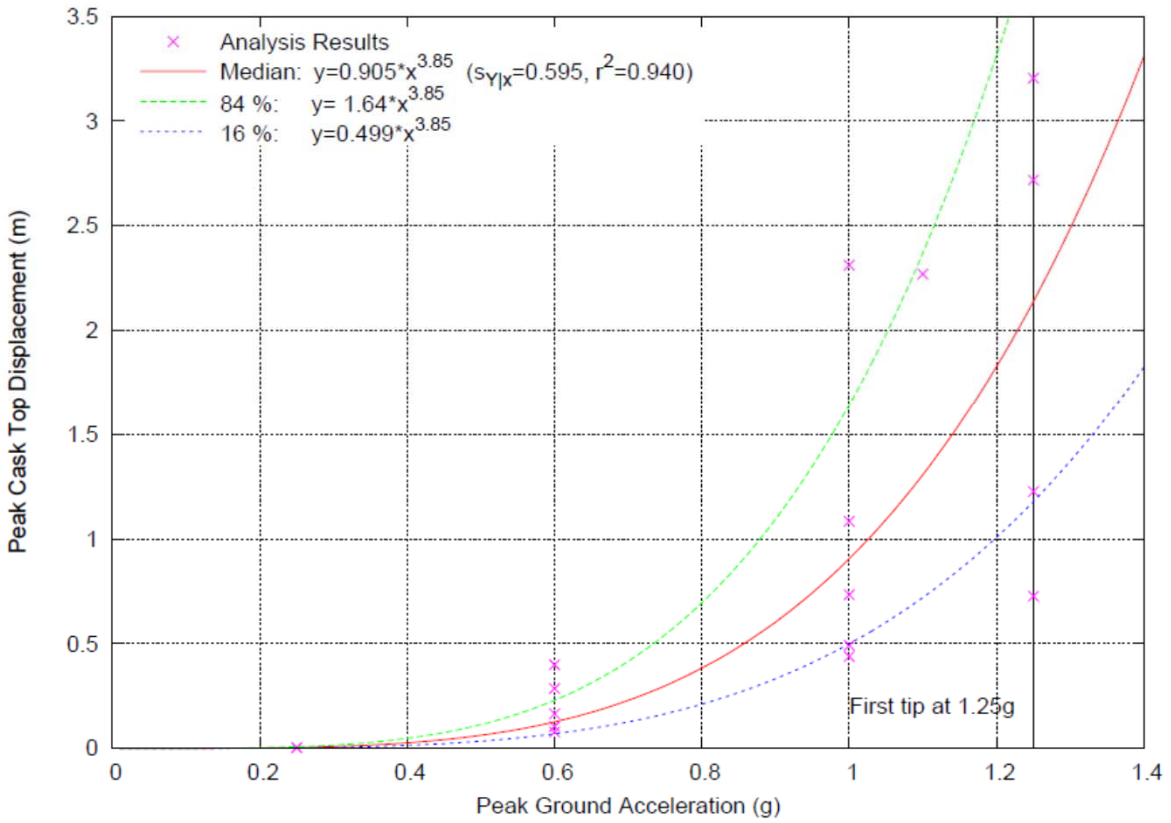


Rectangular Cask



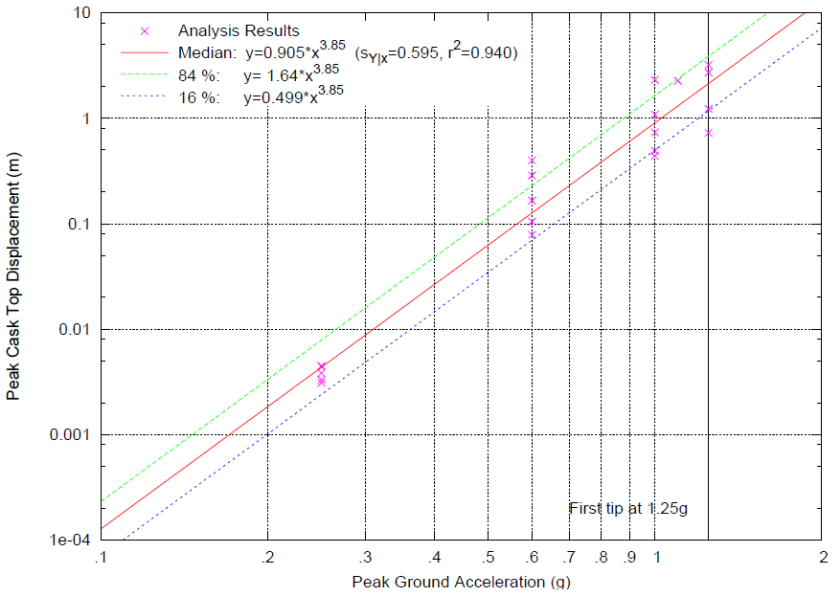
Top and Bottom Displacement Versus Time, Cask-to-Pad μ=0.80, NUREG/CR-0098 Earthquakes, PGA=1.0g, Stiff Soil Foundation

Regression Analyses

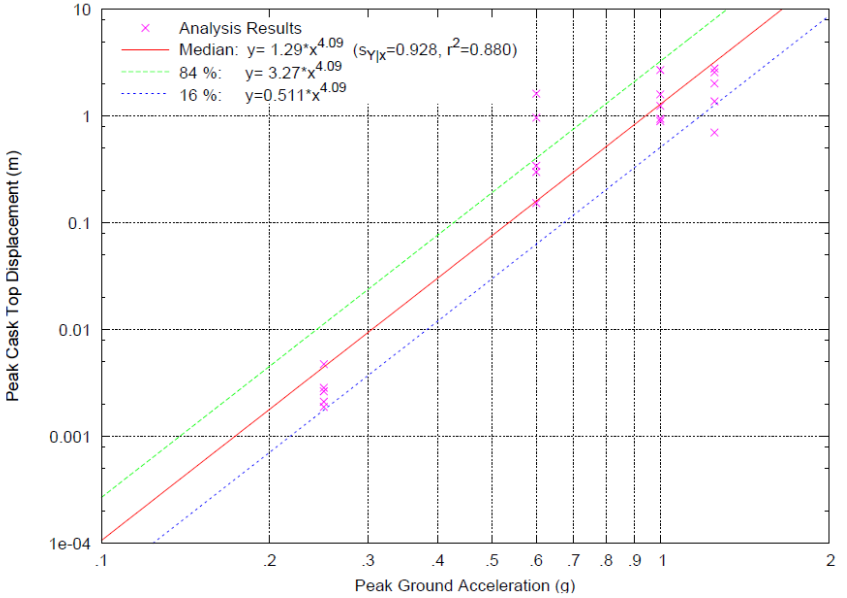


Peak Top Displacement, Cylindrical Cask, NUREG/CR-0098 Earthquakes, Cask-to-Pad μ=0.55, Soft Soil Profiles.

Foundation Type Dependence



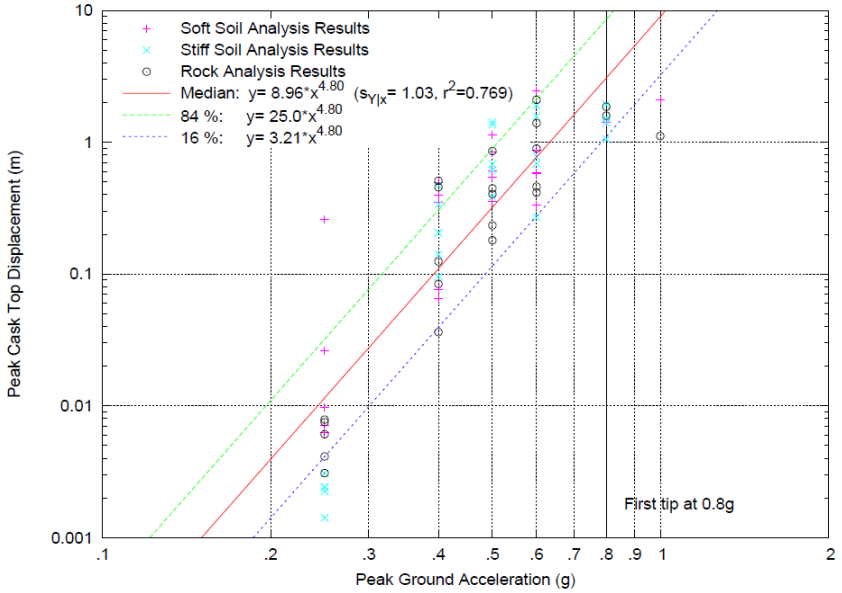
Soft Soil



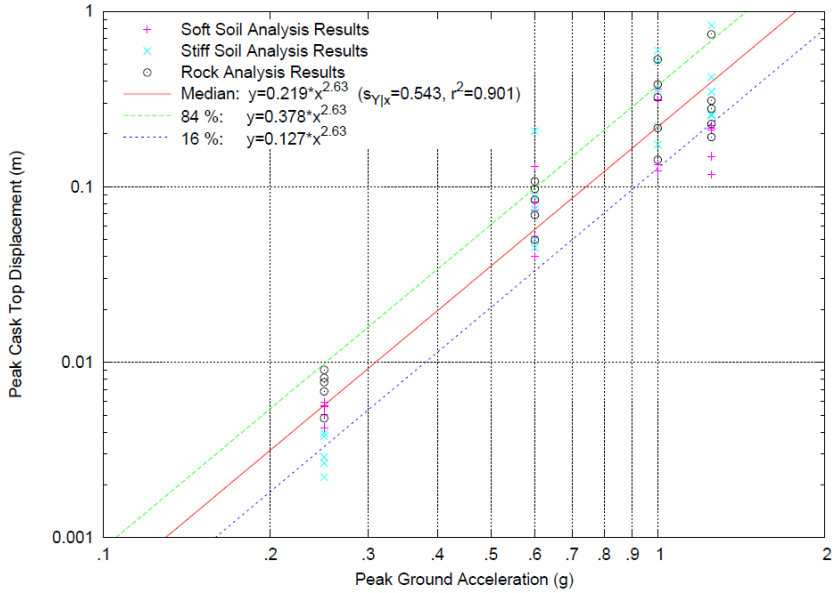
Rock

Peak Top Displacement, Cylindrical Cask, NUREG/CR-0098 Earthquakes, Cask-to-Pad μ=0.55, Soft Soil and Rock Profiles

Spectral Shape Dependence



Regulatory Guide 1.60 Earthquakes



NUREG/CR-6728 Earthquakes

Peak Top Displacement, Cylindrical Cask, Cask-to-Pad μ=0.55, All Foundation Profiles

Summary and Conclusions (1/2)

Sandia National Laboratories

- Cask response exhibited a large amount of scatter.
- Cask response did tend to increase with increasing ground motion intensity; however, in some instances cask response was lower for higher levels of ground shaking.
  - Magnitude of cask response is sensitive to the phasing of ground motion pulses with respect to the timing of the response of the cask.
  - Important to consider a number of different earthquakes when determining expected cask response to ground shaking.
- At low coefficients of friction between the cask and pad, both the cylindrical and rectangular casks tended to slide without rocking, at higher coefficients of friction the casks tended to rock with and without sliding.

Summary and Conclusions (2/2)

Sandia National Laboratories

- The cylindrical casks experienced significantly larger responses in comparison to the rectangular casks, with the cylindrical casks experiencing larger top of cask displacements, larger cask rotations (rocking), and a greater number of occurrences of cask toppling (the rectangular casks never toppled).
- The cylindrical casks were susceptible to rolling once rocking had been initiated, a behavior not observed in the rectangular cask.
- Cask response was not overlying sensitive to foundation type, but was significantly dependent on the response spectrum employed.