The Possible Influence of ISFSI Pad Flexibility on the Sliding Response of Casks at North Anna due to the Earthquake of August 23, 2011

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Outline

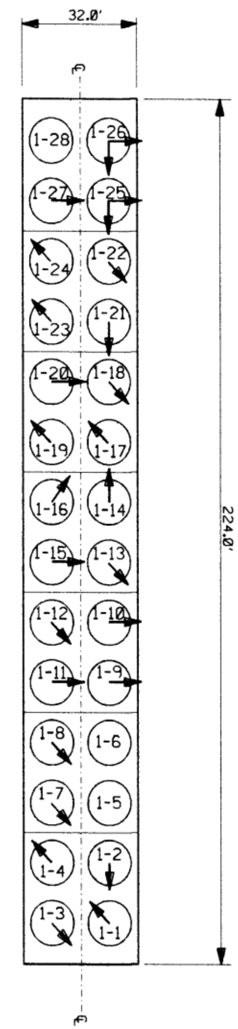
- Distribution of Sliding Response
- Recorded Ground Motion
- Total Movement of the Casks
- ISFSI Pad Flexibility Parametric Study
- Preliminary Observations

The information provided herein constitutes a preliminary evaluation, which is subject to change based on analyses and assessments to be made by the licensee.

Sliding Response of the TN-32 Storage Casks

TABLE OF CASK MOVEMENT DUE TO EARTHQUAKE

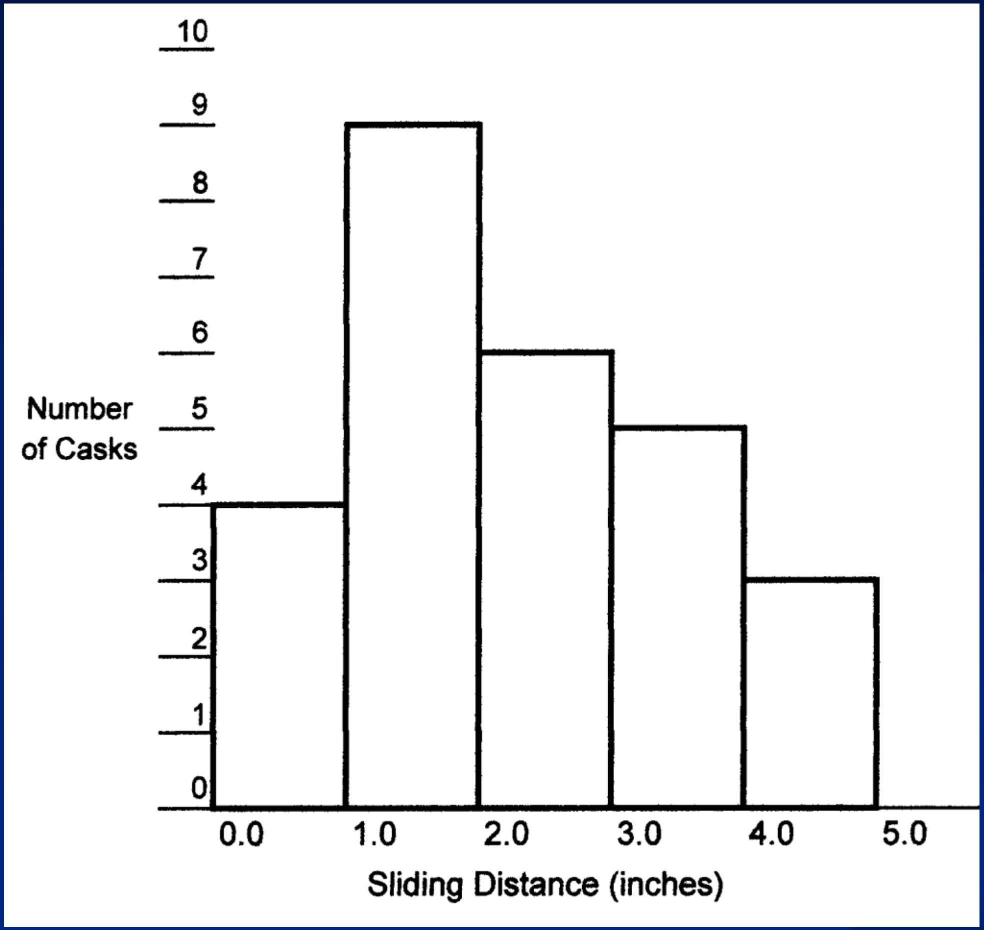
EMPTY	TN-32.49 - E 2" & S 2.5"
TN-32.45 - E 1.5"	TN-32.43 - E 2.5" & S 2.5"
TN-32.38 - NW 1"	TN-32.37 - SE 3"
TN-32.36 - NW 4"	TN-32.29 - S 2"
TN-32.20 - E 1"	TN-32.23 - SE 3.5"
TN-32.14 - NW 0.75"	TN-32.16 - NW 3.5"
TN-32.12 - NE 0.5"	TN-32.13 - N 1"
TN-32.06 - E 1.5"	TN-32.10 - SE 2.5"
TN-32.21 - SE 4.5"	TN-32.19 - E 2.25"
TN-32.24 - E 3"	TN-32.26 - E 1.25"
TN-32.32 - SE 1.5"	TN-32.30 NO MOVEMENT
TN-32.42 - SE 1.5"	TN-32.41 NO MOVEMENT
TN-32.48 - NW 2"	TN-32.47 - S 1"
TN-32.53 - SE 2.5"	TN-32.52 - NW 2"



PLAN - PAD #1

Distribution of Sliding Response

- What may have been one of the factors that contributed to the differences in magnitude of the sliding response of the casks?



Distribution of Coefficient of Friction Between Steel and Concrete

- The distribution of sliding response to some extent reflects the variability of the Coefficient of Friction between the cask's steel base and the concrete pad.

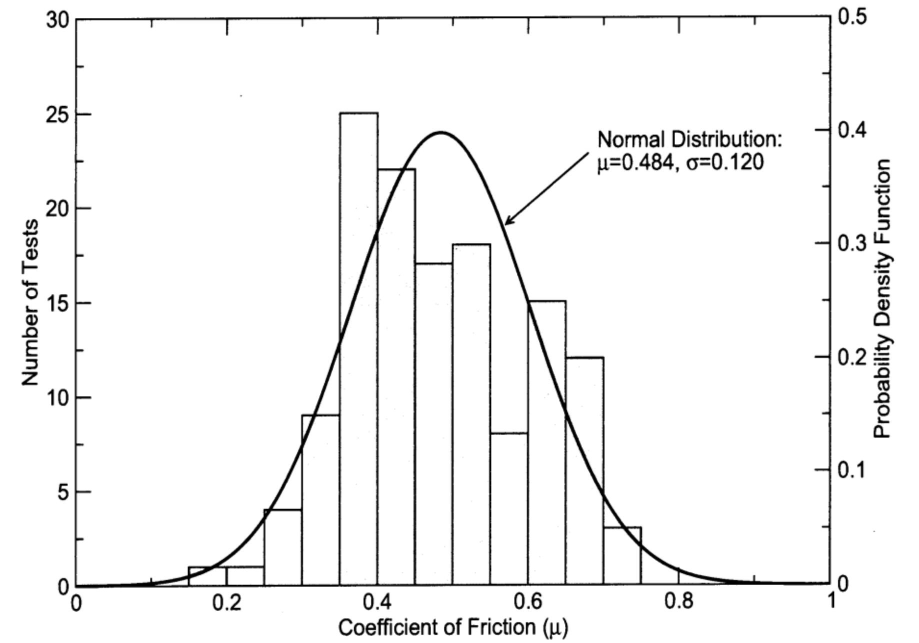
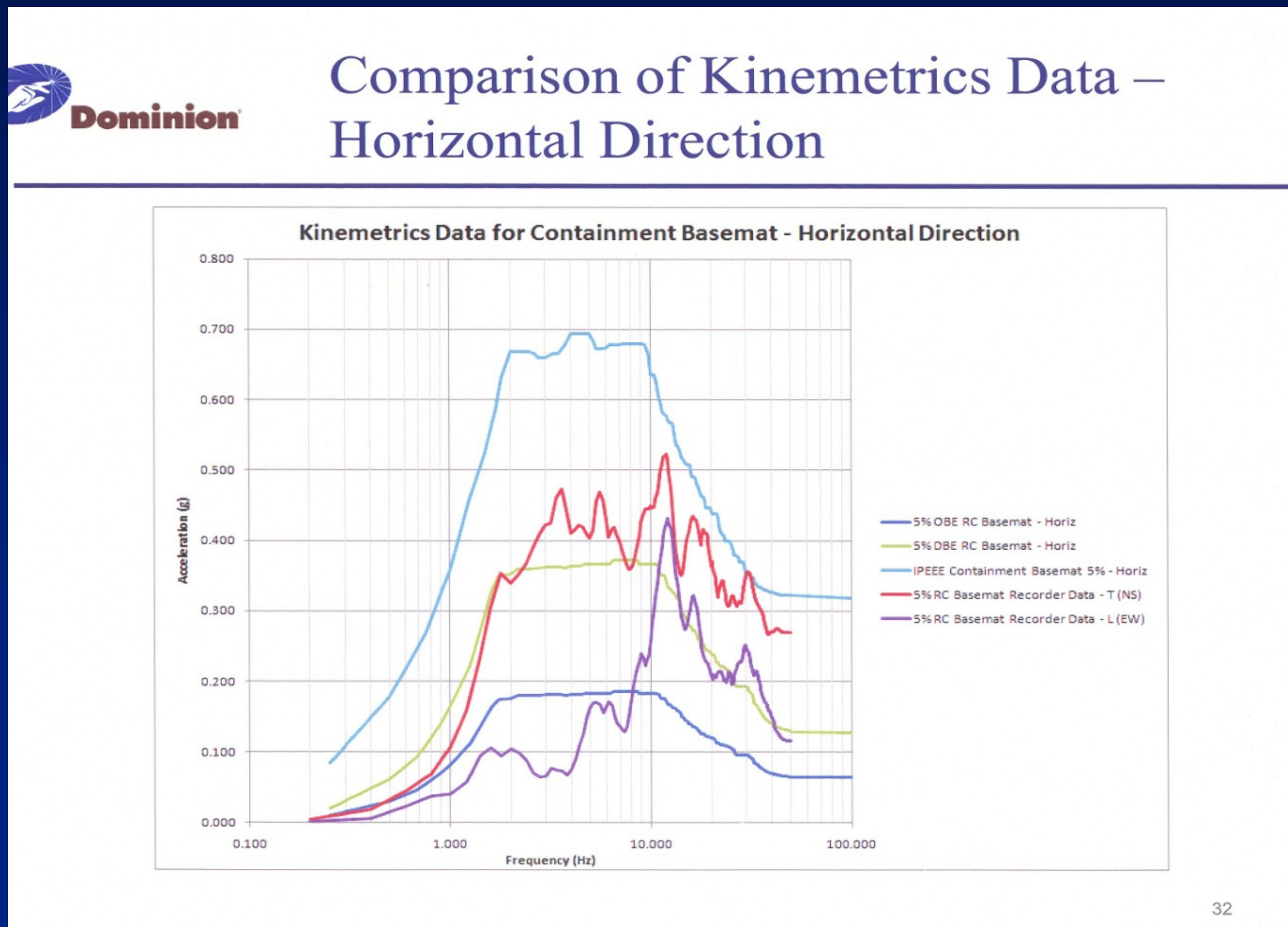


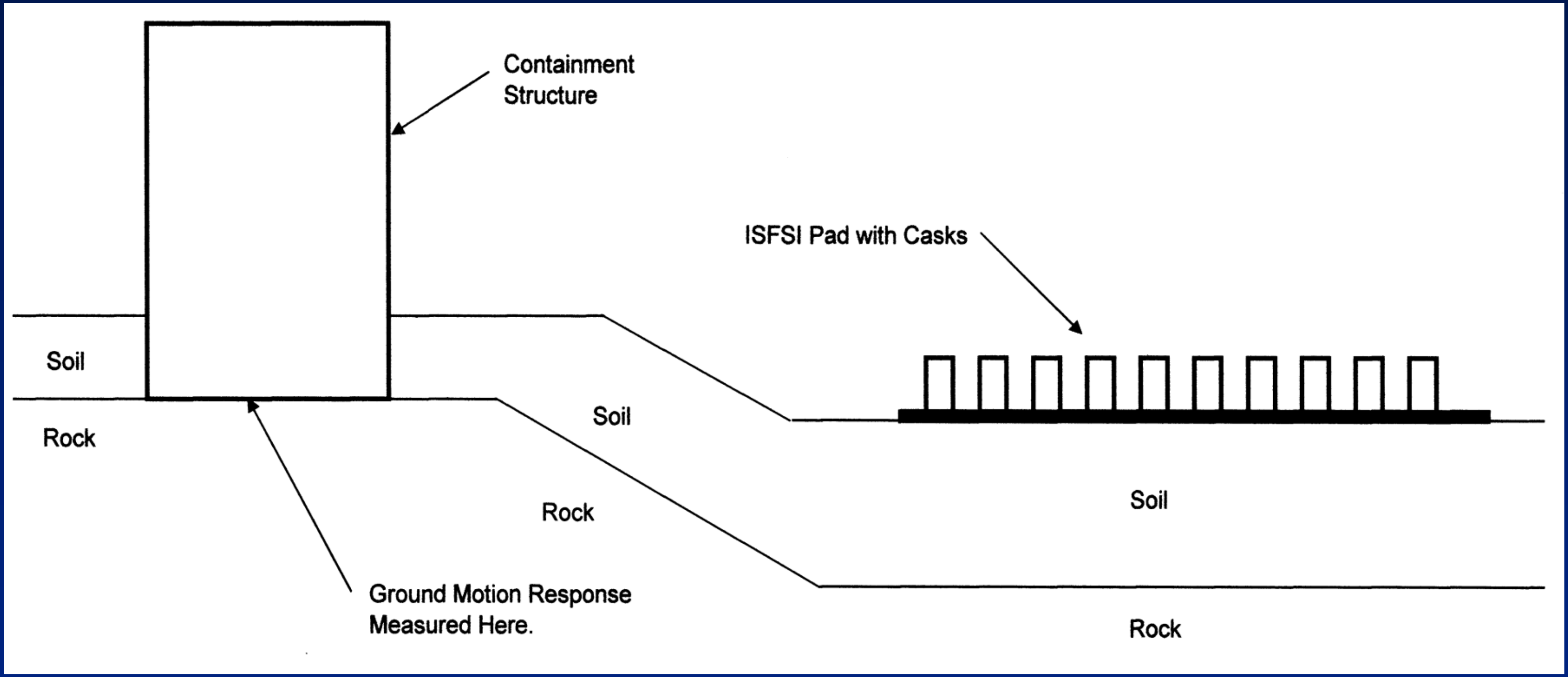
Figure 4.5: Histogram of Steel/Concrete Coefficient of Friction Test Results

Recorded Ground Motion

- The Ground Acceleration recorded at the containment basemat in the N-S direction (long direction of the pad) is much higher than in the E-W direction (short direction of the pad).



Idealized Rock/Soil Profile



Earthquake motion at the ISFSI Pad Surface

- It is reasonable to assume that as the earthquake motion propagated from the bedrock up through the soil to the ISFSI pad that the relative relationship between the strength of the earthquake motion in the N-S direction and E-W direction would be approximately the same.

- That is, the response spectrum in the N-S and E-W directions at the pad surface would be expected to be proportionally the same as they were at the bedrock level, although some frequencies could be amplified and others deamplified.

- So, if the motion of the ISFSI pad is expected to be stronger in the N-S direction than in the E-W direction, one would reasonably expect more sliding in the N-S direction than in the E-W direction.

Sliding Response of the Casks

- Total Movement of all casks in the N-S direction = 32.14”
- Total Movement of all casks in the E-W direction = 38.14”

- So, if the motion of the ISFSI pad is expected to be greater in the N-S direction, why is the total sliding movement in the E-W direction almost 20% greater?

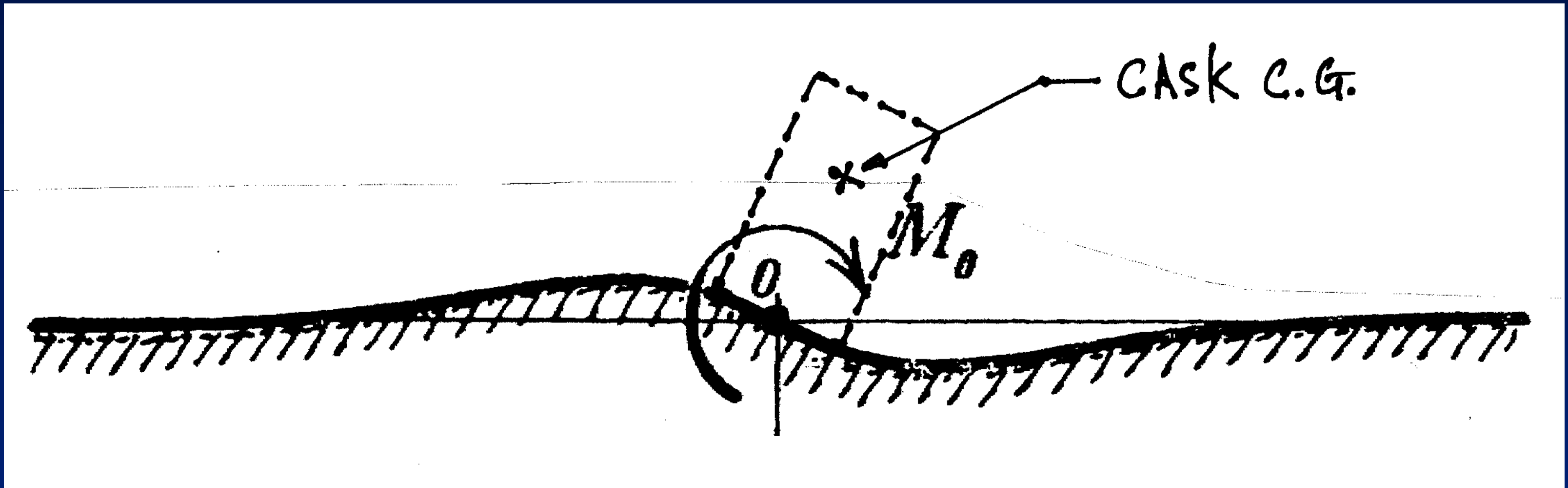
- What may have helped contribute to this result?

Plant Hatch ISFSI SSI Analysis

- While performing the seismic soil-structure interaction (SSI) analysis of the Plant Hatch ISFSI, we discovered that of all the site parameters the flexibility of the ISFSI concrete pad was the most significant contributor to the seismic response of free-standing storage casks (see reference below).

- Moore, D.P., Bjorkman, G.S., and Kennedy, R.P., "Seismic Analysis of Plant Hatch ISFSI Pad and Stability Assessment of Dry Casks," *Proceedings, 8th International Conference on Nuclear Engineering*, Baltimore, MD, April 2-6, 2000.

ISFSI Pad Flexibility



Accelerations at the cask center of gravity (c.g.) can be significantly greater than at the base. It is the acceleration at the cask's c.g. that determines the cask's stability (e.g., initiation of sliding)

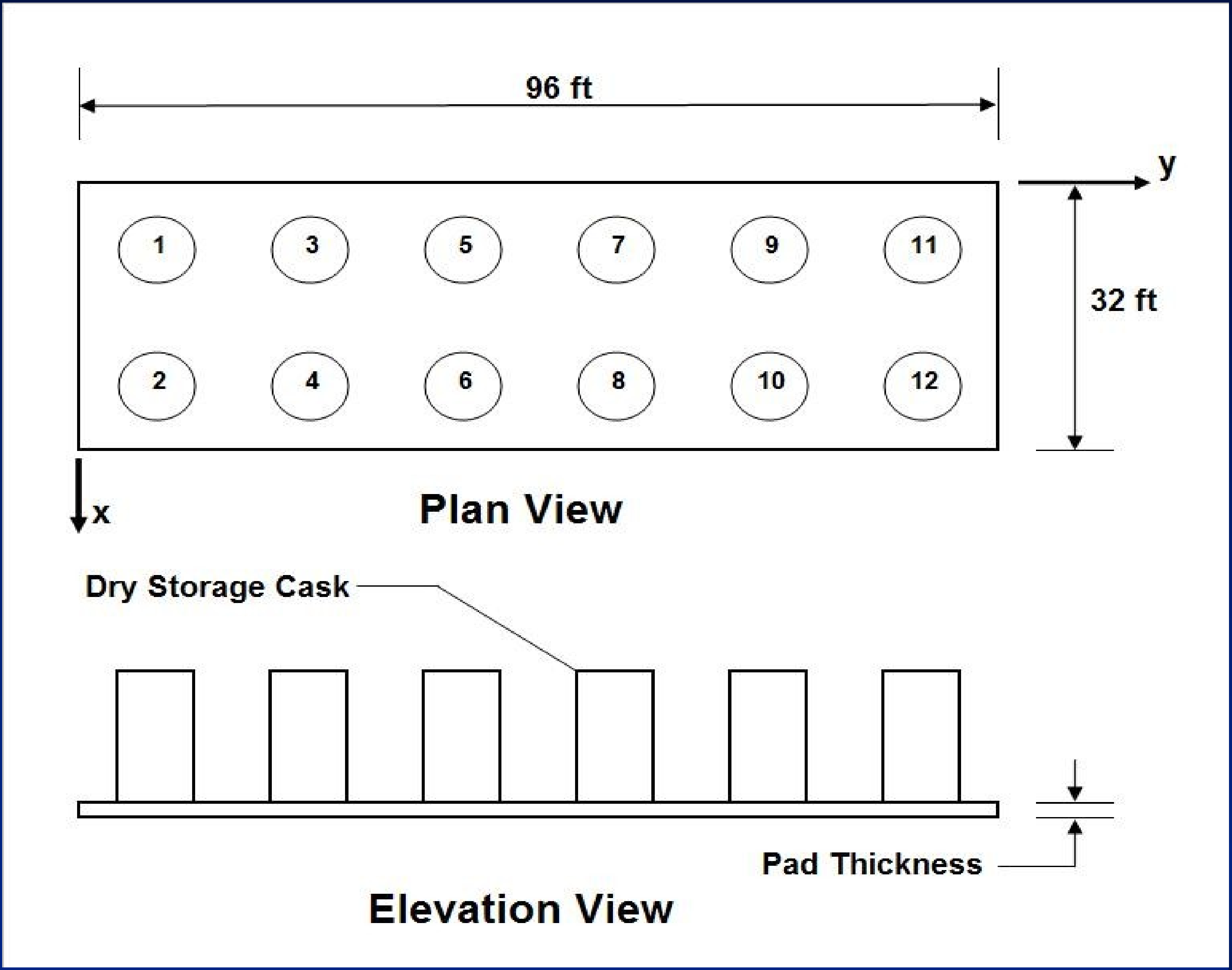
Parametric Study

- Shortly after completing the Hatch ISFSI I performed a parametric investigation to evaluate the influence on cask response of ISFSI pad flexibility (pad concrete thickness), soil stiffness (shear wave velocity) and the arrangement of casks on the pad.

- Bjorkman, G.S., et.al., “Influence of ISFSI Design Parameters on the Seismic Response of Dry Storage Casks,” Structural Mechanics in Reactor Technology Conference, Washington DC, August 2001.

- Bjorkman, G.S., “Influence of ISFSI Design Parameters on the Seismic Response of Dry Storage Casks,” *Proceedings of the Packaging and Transport of Radioactive Materials Conference*, London, October 2010.

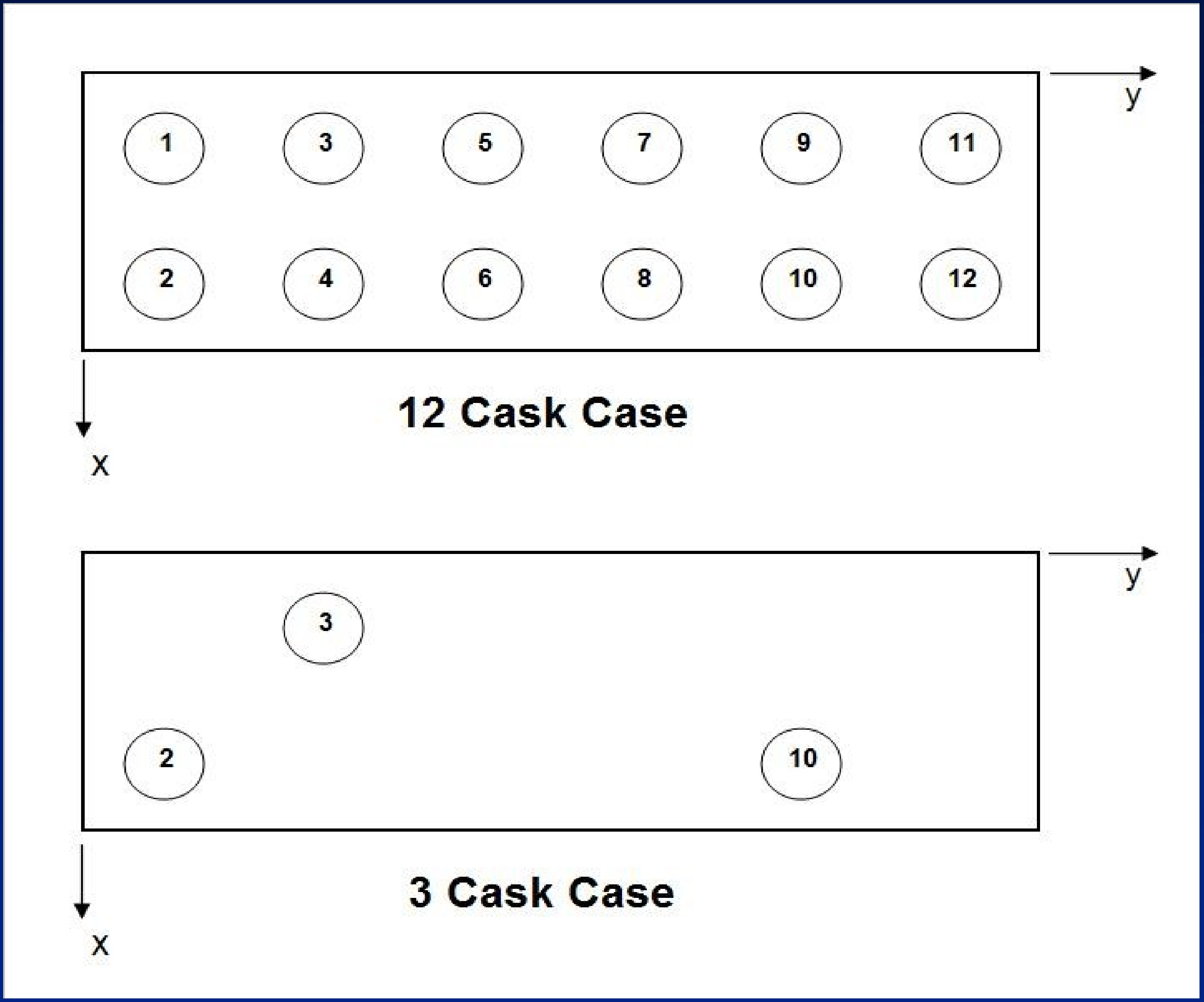
ISFSI Pad and Cask Layout



ISFSI Pad Design Parameters Considered

Three Parameters	Number of Cases	Range of Values
(1) Pad Thickness (Uncracked Concrete Properties)	4	1.5 to 4.0 feet
(2) Soil Shear Wave Velocity (Uniform 100 ft. Depth)	6	500 to 1700 fps
(3) Cask Arrangements	2	3 Casks, 12 Casks

Cask Cases Considered

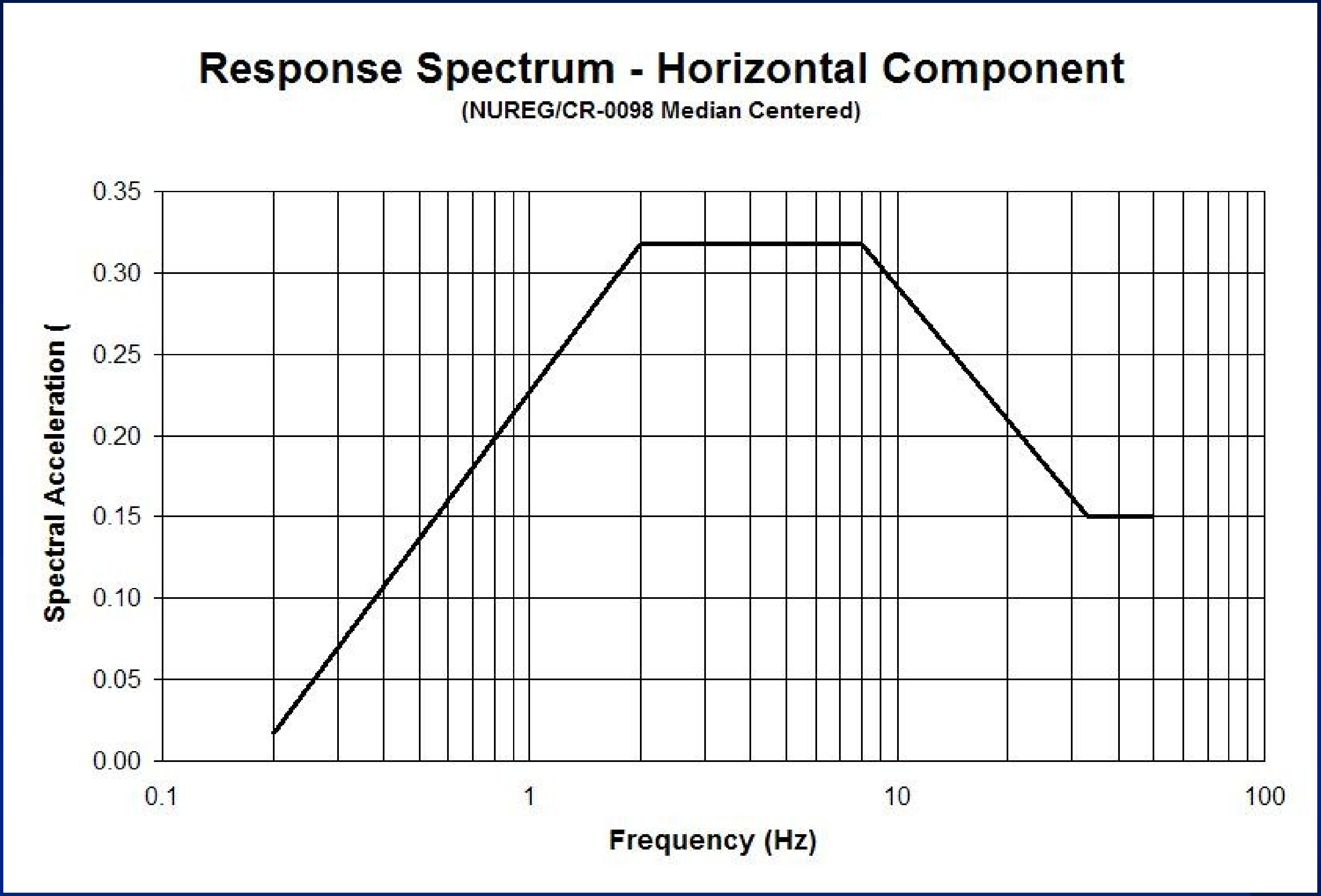


Cases Analyzed

3 Cask Case		Soil Shear Wave Velocity (fps)					
		500	700	900	1100	1300	1700
Concrete Pad Thickness (feet)	1.5						
	2						
	3						
	4						

12 Cask Case		Soil Shear Wave Velocity (fps)					
		500	700	900	1100	1300	1700
Concrete Pad Thickness (feet)	1.5						
	2						
	3						
	4						

Response Spectrum



SSI Analysis Program

- **SASSI**
  - A System for Analysis of Soil-Structure Interaction
  - Details of the SASSI Model are in the Paper

About the Parametric Study Results

- Maximum amplification at the cask base (top-of-pad) of any cask is 1.05 above the Peak Ground Acceleration (PGA) and occurred for the 12 cask case.

- The Amplification Factor is equal to the maximum acceleration at the cask c.g. divided by the PGA. [AF = Acc. at Cask c.g. / PGA]

Amplification Factor vs. Pad Thickness

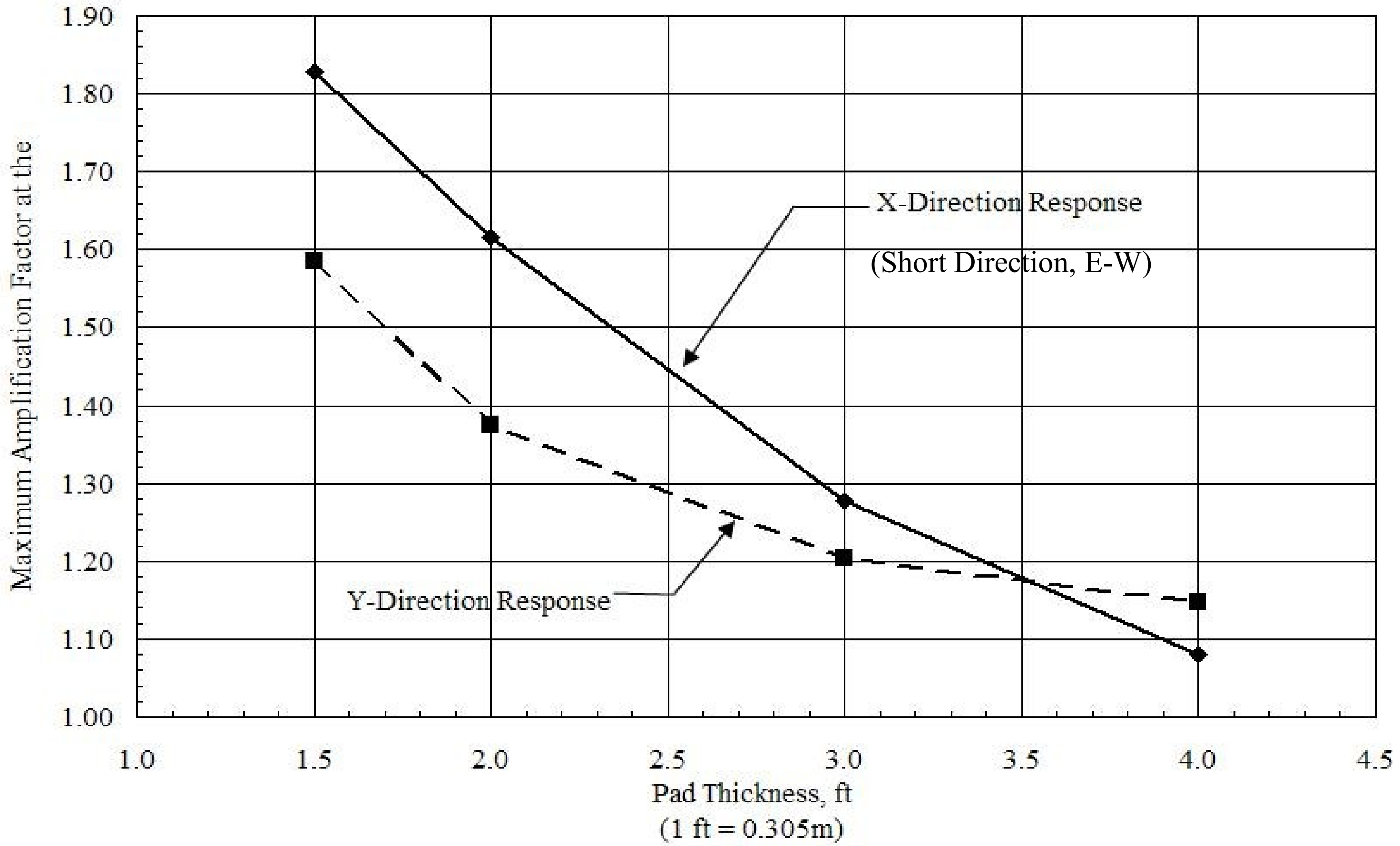


Figure 5: Amplification Factor vs Pad Thickness for the 3-Cask Case for a Shear Wave Velocity of 1100 fps (335 mps)

Amplification Factor vs. Pad Thickness

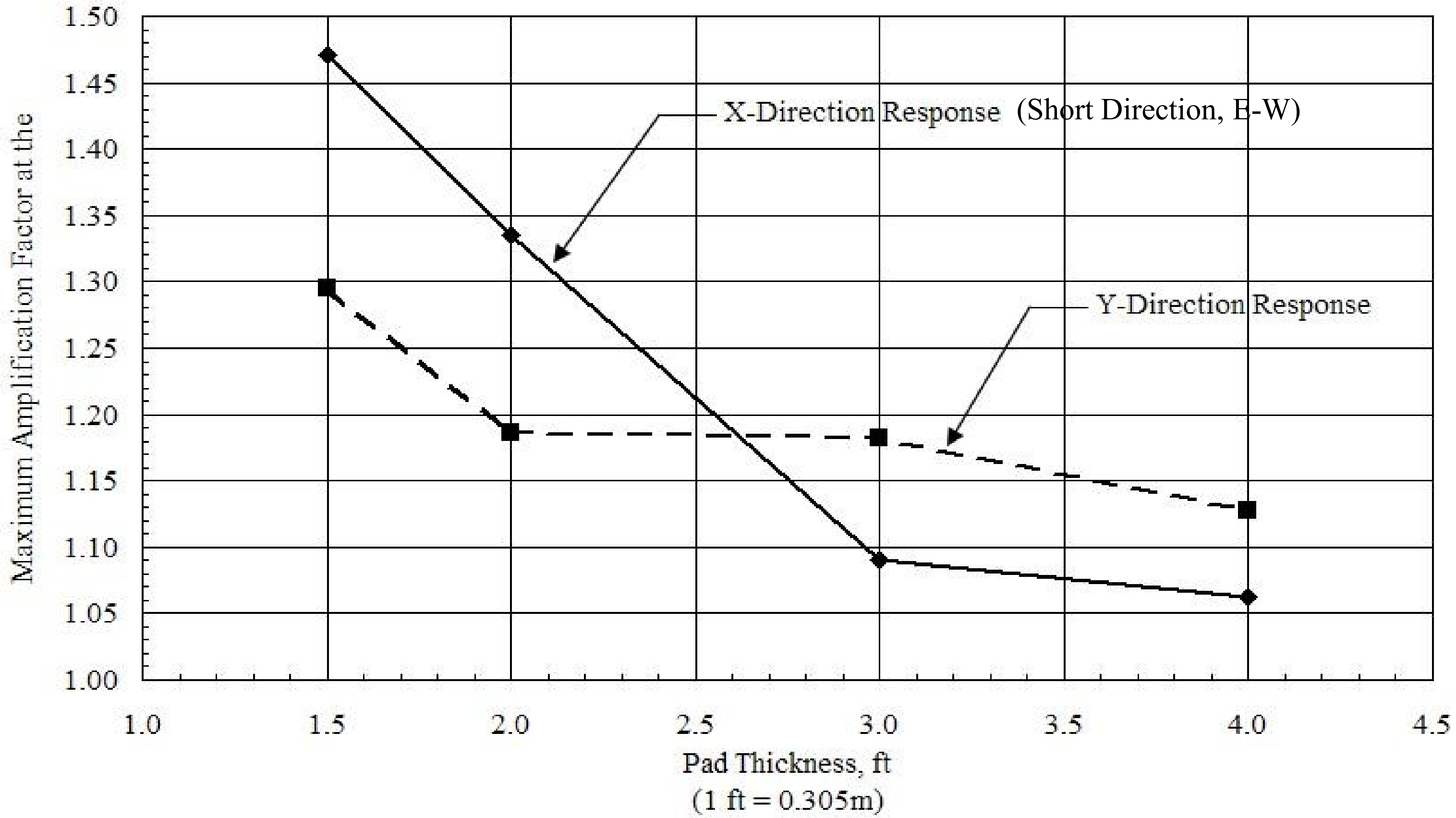


Figure 7: Amplification Factor vs Pad Thickness for the 12-Cask Case for a Shear Wave Velovity of 1700 fps (522mps)

Preliminary Observations

- Based on publically available information, it was observed that the total sliding response of the casks in the E-W direction of the pad was 20% greater than the total sliding response in the N-S direction, even though the ground motion in the N-S direction was observed to be greater than in the E-W direction.

- As demonstrated in the studies cited previously, pad flexibility can significantly increase the acceleration response at the cask center of gravity, and these studies showed that for long rectangular pads of approximately 2 foot thickness, as exists at North Anna, the amplification of the ground motion at the cask center of gravity is greater in the short direction (E-W) of the pad than it is in the long direction (N-S) for the same ground motion input.

- Preliminarily linking these two observations would potentially suggest that pad flexibility may have played an important role in the sliding response of the casks.