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Mr. John Goshen
c/o Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

November 22, 2011

Subject: Technical Information Exchange Meeting on the stability analysis of freestanding stack-up configurations – re-transmittal of Technical Memo.

References:
[1] USNRC Docket No. 72-1014, TAC No. L24476
[2] Holtec Letter 5014730, dated November 14, 2011

Dear Mr. Goshen:

On November 1, 2011, NRC hosted a technical information exchange on stability analysis of freestanding stack-up configurations between industry representatives and members of its Staff. On November 14, 2011 [2] Holtec transmitted to the NRC Technical Memo TM-SF-117 to summarize key observations from the meeting. Regretfully, we have found a typographical error in the original technical memo. This letter transmits Revision 1 of the technical memo and should be considered a complete replacement for Holtec letter 5014730 [2]. Holtec requests letter 5014730 and its attachments be removed from the NRC Agencywide Documents Access Management System (ADAMS).

Attachment #	Content	Proprietary Status	Number of Pages
1	Holtec Memo TM-SF-117R1	Proprietary	7
2	Holtec Memo TM-SF-117R1-NP	Non-Proprietary	7

Attachment 3 is an affidavit requesting the information in Attachment 1 be withheld from the public in accordance with 10 CFR 2.390 due to its proprietary nature.

If you have any questions regarding this transmittal, please do not hesitate to contact me at 856-797-0900 x3687.

Sincerely,

Tammy S. Morin
Licensing Manager
Holtec Technical Services, Holtec International

cc: Mr. Douglas Weaver, USNRC
Holtec Group 1 (w/o attachments)

Technical Memo TM-SF-117-NP*

[Holtec Proprietary Text Removed]

Date: November 22, 2011 (Rev. 1)

Subject: Stability Analysis of Freestanding Stack-up

Keywords: Stack-up; Damping; SRP 3.7.1

On November 1, 2011, the NRC hosted a technical information exchange on stability analysis of freestanding stack-up configurations between industry representatives and members of its staff. The purpose of the meeting was to discuss methodologies for conducting analysis of the freestanding stack-up configuration during vertical dry cask spent fuel loading operations. During the meeting, presentations were given by the NRC (Dr. Gordon Bjorkman), NAC International (Mike Yaksh), Comanche Peak (Bruce Henley), and Holtec (Chuck Bullard).

The meeting was very valuable insomuch as it provided important insight into the NRC's concerns and expectations relative to freestanding stack-up analysis, and it provided a venue for plant personnel and cask vendors to share their experiences and recommendations with the NRC staff. The NRC is working towards the development of a guidance document on performing stability analysis of freestanding stack-up configurations.

Below I have summarized my key observations from the meeting [Holtec Proprietary Text Removed].

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*[Holtec Proprietary Text Removed]

A. Minimum Safety Factor Against Overturning

The NRC in its presentation quantified what they consider to be an acceptable margin of safety against overturning. Specifically, Dr. Bjorkman indicated that a stack-up configuration would be considered stable if the 84th percentile non-exceedance (mean plus one standard deviation) displacement of the stack-up (based on a minimum of five non-linear time history simulations) is less than the critical angle by a factor of 2 or greater. This is a positive development from Holtec's point of view because:

i) it gives clarity to NRC's previous mandate to "preclude overturning of the freestanding stack-up configuration with an extremely high level of certainty" [1], and;

[Holtec Proprietary Text Removed]

B. Synthetic vs. Real Recorded Time Histories

Dr. Bjorkman emphasized in his presentation the difficulties associated with simulating the response of rigid structures to ground motion, which is highly sensitive to initial conditions and the "details" of the ground motion. Because of these factors, the NRC expects real recorded ground motions to be used when performing non-linear time history analysis of stack-up configurations (which is also consistent with the guidance from NUREG-0800, Section 3.7.1 [2]).

[Holtec Proprietary Text Removed]...we plan to perform a sensitivity analysis using modified real recorded time histories to measure the difference in results between Holtec generated synthetic time histories and modified real recorded time histories. Our aim is to show that the peak displacement obtained using 5 sets of synthetic time histories is equal to or greater than the 84th percentile displacement using 5 sets of real recorded time histories. If this cannot be demonstrated, then the results from the sensitivity analysis will be used to establish/recommend an increased factor of safety (greater than 2) against overturning for stability analyses performed using synthetic time histories. [Holtec Proprietary Text Removed].

C. Rigid Body Impact Damping

In his presentation, Dr. Bjorkman noted that two types of damping exist in the rocking of a solid (non-rigid) body: material damping and "rigid body impact damping". He described rigid body impact damping as resulting "solely from considering the conservation of momentum of a rocking rigid body". More importantly he posited that "only material damping shall be used in the time history rocking analysis, since impact damping is already accounted for in the rocking of a rigid body". This assertion seems to be based in part on the paper authored by Yim et. al. [3], which derives the following equation for the kinetic energy ratio, r, for the rocking response of a rigid block:

$$r = \left[1 - \frac{W}{g}\frac{R^2}{I_o}\left(1 - \cos 2\theta_c\right)\right]^2$$

Note that the above equation depends only on the size and mass of the block, not its material. This implies that if a rigid body (with zero material damping) is tipped upwards and then allowed to rock back and forth due to gravity that it will eventually come to rest. This in turn would lead to the following conclusion. If a non-linear time history analysis is performed to predict the rocking response of a rigid block, wherein the rigid block is explicitly modeled as a freestanding body having the proper size and mass, then the analyst should not specify any additional damping (i.e., rigid body impact damping is already accounted for in the solution based on the physics of the problem).

After careful consideration of Dr. Bjorkman's remarks and a closer review of [3], we believe that an important assumption in [3] may have been overlooked, which would affect the conclusion with regards to damping. Specifically, in order to derive the above equation for 'r', the authors of [3] assumed that the impact between the rigid block and the rigid base is "such that there is no bouncing of the block." In other words, the local impacts at the centers of rotation (points O and O' in Figure 1 of [3]) are assumed to be inelastic. It is noted that the same equation is also derived in [5], in which the author writes:

> "If the impact is assumed to be inelastic (no bouncing), the rotation continues smoothly about the point O' and the moment of momentum about point O' is conserved."

Without this assumption, the above equation cannot be derived (see Appendix 1 for derivation). This simplifying assumption is what causes energy to be dissipated from the rocking rigid body, leading to a coefficient of restitution less than one.

Of course, in a non-linear time history analysis, no assumptions are made regarding the bouncing behavior of the rigid body (i.e., stack-up). The only mechanisms to remove energy from the system are through material damping and friction. To illustrate this point, we simulated in LS-DYNA an essentially rigid cylinder rocking on a rigid foundation under gravity, with zero material damping and a coefficient of friction of 1.0 at the foundation interface. While the cylinder does eventually come to rest, it is solely because of the frictional energy losses. This is evident from the time history plots of the system potential energy versus the frictional energy losses. The rigid cylinder comes to rest at the exact time instant when the accumulated frictional energy losses equal the initial potential energy of the cylinder at time zero. There are no energy losses due to "rigid body impact damping". Incidentally, it should be noted that the COR equation derived in [3] (and also in Appendix 1 to this memo) does not include energy losses due to friction at the contact interface.

In the recent stack-up analyses performed by Holtec [Holtec Proprietary Text Removed], we determined the coefficient of restitution of the stack-up by performing a series of LS-DYNA runs in which a deformable stack-up, with a specified initial angular velocity, impacts a concrete foundation [Holtec Proprietary Text Removed]. The minimum coefficient of restitution obtained from LS-DYNA was then converted into an equivalent damping percentage and assigned to the contact elements at the stack-up/ground interface in the ANSYS finite element model. [Holtec Proprietary Text Removed]

D. HI-TRAC/MPC Modeling

The NRC confirmed during the meeting that the canister (MPC) and the transfer cask (HI-TRAC) can be modeled as a single rigid body, for stability analysis purposes, when the nominal radial gap between them is small (< ½”). This accords with the stack-up analysis model implemented by Holtec, which combines the MPC and HI-TRAC into one solid cylinder. It is noted that the nominal radial gap between the MPC and the HI-TRAC is only 3/16”.

References

[1] USNRC Letter from V. Ordaz to R. McCullum, June 30, 2011.

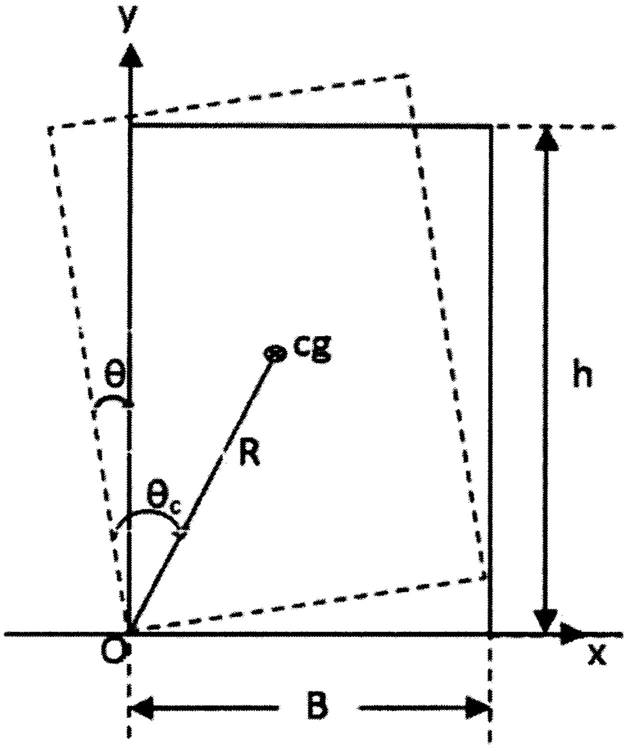
[2] NUREG-0800, Section 3.7.1, Revision 3.

[3] Yim, C., Chopra, A.K., and Penzien, J., “Rocking Response of Rigid Blocks to Earthquakes”, Earthquake Engineering and Structural Dynamics, Vol. 8, 565-587 (1980).

[Holtec Proprietary Text Removed]

[5] Housner, G.W., “The Behavior of inverted Pendulum Structures During Earthquakes”, Bulletin of the Seismological Society of America, Vol. 53, No. 2, pp. 403-417, February 1963.

Consider a rigid block of height h and width B (as shown in the figure below) which is initially displaced by an angle θ about point O and subsequently is allowed to rock.



The motion of the rocking block is governed by the Lagrangian Equation:

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{q}_i}\right] - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = \overline{Q}_i$$

Where: T = Kinetic Energy

V= Potential Energy

Q_i = Generalized Non-Conservative Force

Integrating Lagrangian Equation over the interval t ~ t+τ

$$\int_t^{t+\tau} \frac{d}{dt}\left[\frac{\partial T}{\partial \dot{q}_i}\right] dt - \int_t^{t+\tau} \frac{\partial T}{\partial q_i} dt + \int_t^{t+\tau} \frac{\partial V}{\partial q_i} dt = \int_t^{t+\tau} \overline{Q}_i dt$$

Since $\frac{\partial T}{\partial q_i}$ and $\frac{\partial V}{\partial q_i}$ remain finite during impact and τ could be arbitrarily small, the last two terms on the left hand side of the above equation can be ignored, i.e.,

$$\Delta\left[\frac{\partial T}{\partial \dot{q}_\iota}\right] = \left[\frac{\partial T}{\partial \dot{q}_\iota}\right]_{t+\tau} - \left[\frac{\partial T}{\partial \dot{q}_\iota}\right]_t = \int_t^{t+\tau} \bar{Q}_\iota dt$$

or

$$\Delta\left[\frac{\partial T}{\partial \dot{q}_\iota}\right] = P_i \text{ (Generalized Impulse)} \qquad (1)$$

Apply Equation (1) to the problem for $\dot{x}, \dot{y}\ and \dot{\theta}$, for the kinetic energy of

$$T = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}m\dot{y}^2 + \frac{1}{2}I_{cg}\dot{\theta}^2 \qquad (2)$$

At the time of impact, $\theta = 0$ and subscripts 1 and 2 in the following equations represent the state just before and just after impact.

$$\Delta\left[\frac{\partial T}{\partial \dot{x}}\right] = m(\dot{x_2} - \dot{x_1}) = P_x \qquad (3)$$

$$\Delta\left[\frac{\partial T}{\partial \dot{y}}\right] = m(\dot{y_2} - \dot{y_1}) = P_y \qquad (4)$$

$$\Delta\left[\frac{\partial T}{\partial \dot{\theta}}\right] = I_{cg}(\dot{\theta_2} - \dot{\theta_1}) = \frac{P_y B}{2} - P_x y_{cg} \qquad (5)$$

Assume no bouncing of the block, i.e., rotation continues smoothly about the impact point O, the following relationship holds

$$\frac{B}{2}\dot{\theta_2} + \dot{y_2} = 0 \qquad (6)$$

Substituting Equation (6) in Equation (4)

$$P_y = m\left(-\frac{B}{2}\dot{\theta_2} - \frac{B}{2}\dot{\theta_1}\right) \qquad (7)$$

Using the geometric relationship at pivot point O, Equation (3) can be rewritten as

$$P_x = m(y_{cg}\dot{\theta_2} - y_{cg}\dot{\theta_1}) \qquad (8)$$

Substituting Equations (7) and (8) in Equation (5)

$$I_{cg}\left(\dot{\theta}_2 - \dot{\theta}_1\right) = \frac{B}{2}m\left(-\frac{B}{2}\dot{\theta}_2 - \frac{B}{2}\dot{\theta}_1\right) - y_{cg}m\left(y_{cg}\dot{\theta}_2 - y_{cg}\dot{\theta}_1\right), \text{ or}$$

$$\left[I_{cg} + m\left(\frac{B}{2}\right)^2 + my_{cg}{}^2\right]\dot{\theta}_2 = \left[I_{cg} - m\left(\frac{B}{2}\right)^2 + my_{cg}{}^2\right]\dot{\theta}_1 \tag{10}$$

Note that

$$I_o = I_{cg} + m\left(\frac{B}{2}\right)^2 + my_{cg}{}^2$$

Therefore, Equation (10) can be rewritten as

$$I_o\dot{\theta}_2 = I_o\dot{\theta}_1 - 2m\left(\frac{B}{2}\right)^2\dot{\theta}_1 \tag{11}$$

Since $\frac{B}{2} = R\sin\theta_c$, Equation (11) can also be written as

$$I_o\dot{\theta}_1 - mRB\dot{\theta}_1\sin\theta_c = I_o\dot{\theta}_2 \tag{12}$$

Equation (12) is same as Equation (6) from [3]. The kinetic energy ratio, r, can be calculated per Equation (11) as

$$r = \left(\frac{\dot{\theta}_2}{\dot{\theta}_1}\right)^2 = \left[1 - \frac{B^2}{2}\frac{m}{I_o}\right]^2, \text{ or}$$

$$r = \left(\frac{\dot{\theta}_2}{\dot{\theta}_1}\right)^2 = \left[1 - \frac{mR^2}{I_o}(1 - cos2\theta_c)\right]^2 \tag{13}$$

[illegible]

Presented by

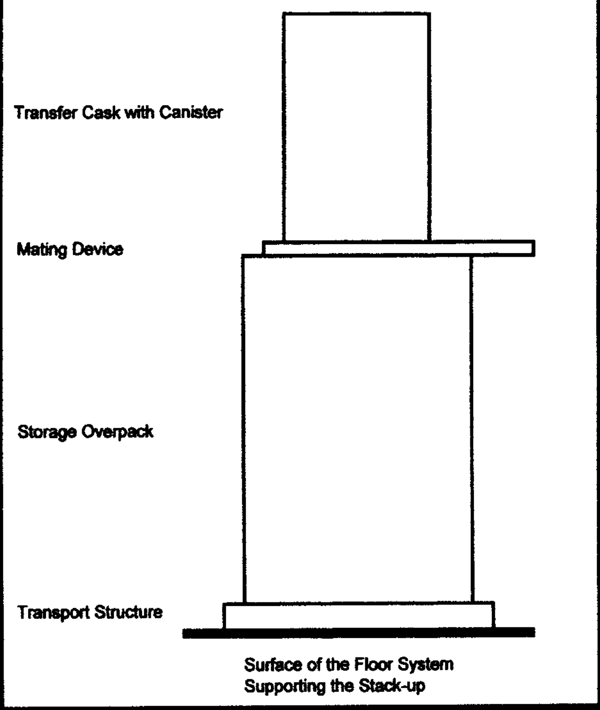
Gordon S. Bjorkman, Jr.
Senior Technical Advisor, Structural Mechanics
Spent Fuel Storage and Transportation Division
November 1, 2011

- Unique Aspects of Stack-up
- Some Definitions
- Rocking Behavior of a Rigid Body
- ASCE Standard 43-05 Appendix A Methodology and its Acceptability
- Key Elements of a draft NRC Guidance Document

[illegible]

- <u>Unique Aspects of Stack-up</u>

- Multiple rigid bodies
- Significant Mass
- High Slenderness Ratio (high center of gravity)
- Most Prone to Rocking



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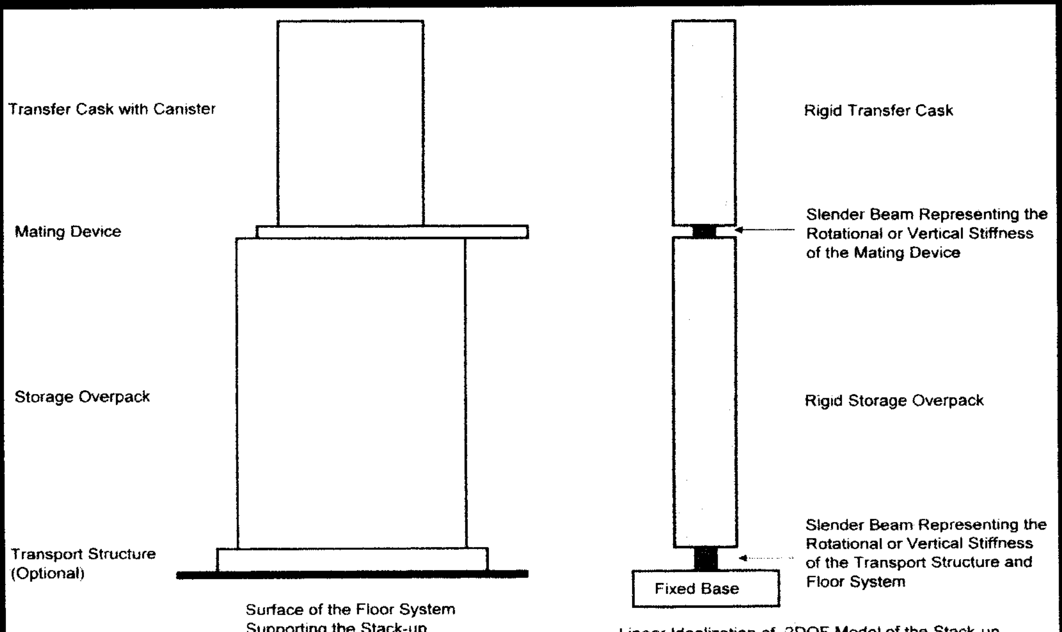
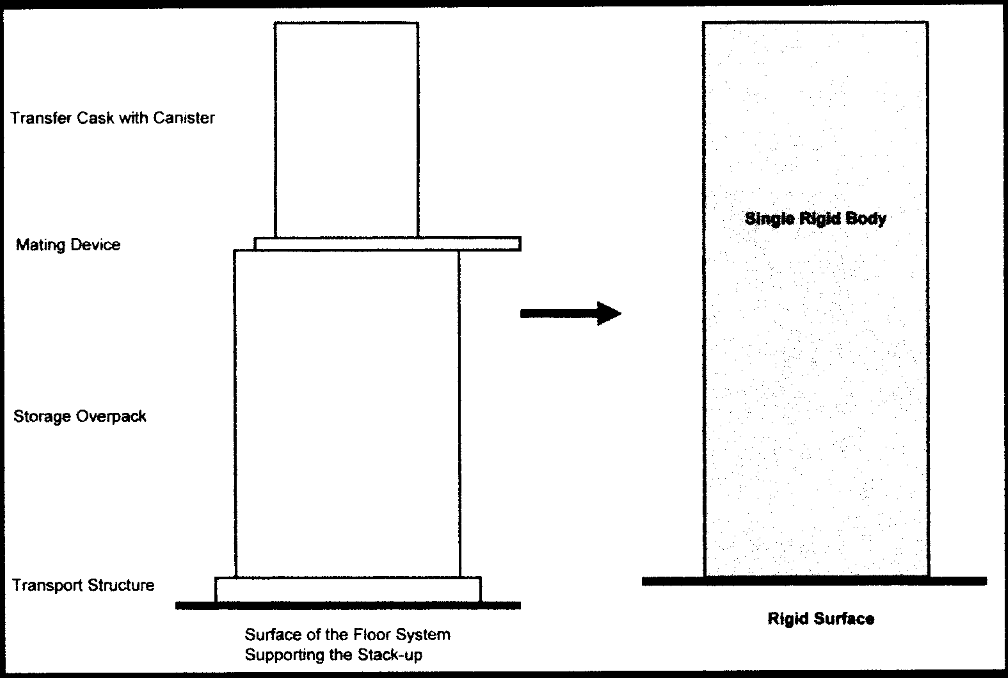
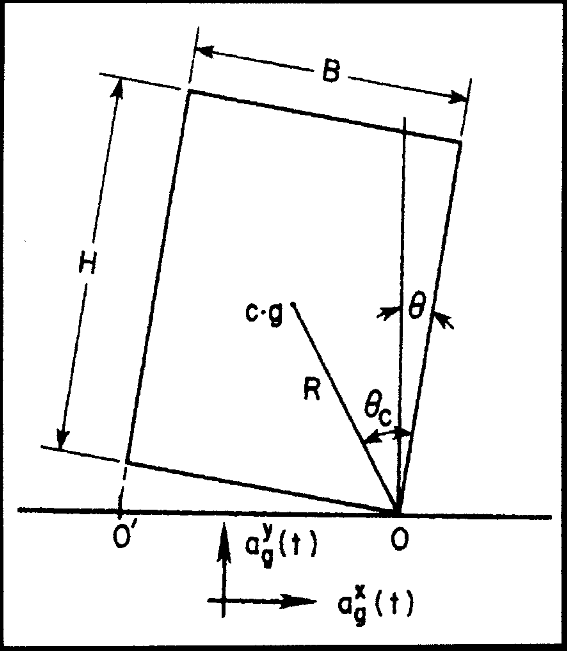


Linear Idealization of 2DOF Model of the Stack-up (Vertical and Horizontal Response are Uncoupled)



- What do we do as Engineers?
- What do we know about Earthquakes?
- Codes, Standards and Regulations will change. The Physics of the Problem does not change.
- Good Guidance begins with an understanding of the Physics of the problem.

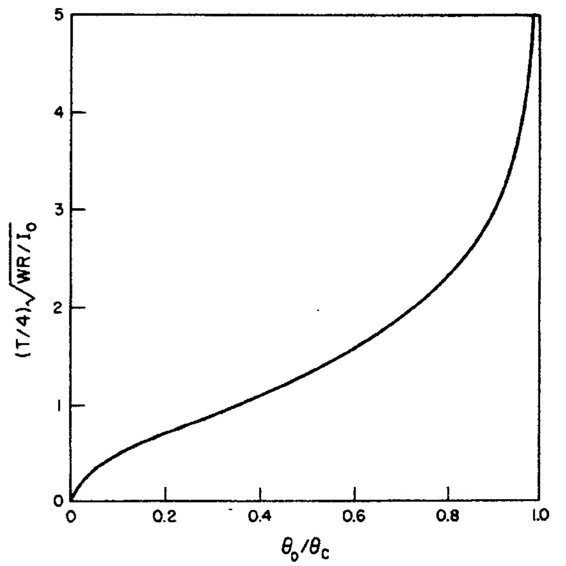
- Slenderness Ratio = H/B
- Size = R
- Rocking Angle =
- Critical Angle =



- "the response of a rigid block is very sensitive to small changes in its size and slenderness ratio and to the details of the ground motion. <u>Systematic trends are not apparent</u>;" (Yim, Chorpa and Penzien, 1980)
- "In an attempt to understand the nonlinear and poorly conditioned phenomena of the response of rigid structures to ground motion, these structures are idealized as rigid blocks. Despite this idealization, the problem of simulating the response of rigid blocks is still <u>a very difficult problem in solid mechanics</u>." (Lucero and Ross, 2003)

- What are some of the behavioral characteristics that make rigid body rocking such a difficult problem?
- Answer: It is highly nonlinear in almost every aspect of its behavior and sensitive to initial conditions.

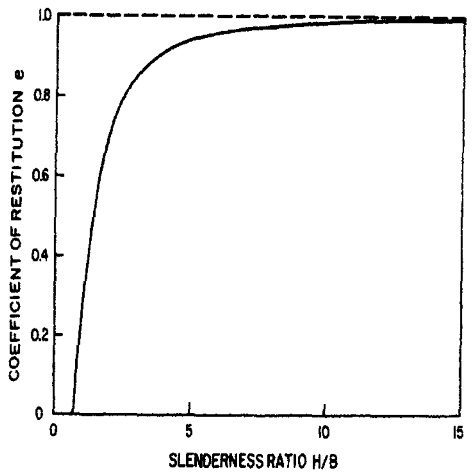
- Non-dimensional Period of Vibration, T, vs. Rocking Amplitude,
- Frequency = 1/T



Free vibration period *T* of block rocking with amplitude θ_0 (Reference 6)

- Variation of the Coefficient of Restitution, based on the conservation of angular momentum, with slenderness ratio.

- For a typical Stack-up, H/B = 3 to 3.3
- For a typical storage cask, H/B = 1.5 to 1.8



Variation of coefficient of restitution, based on conservation of angular momentum, with slenderness ratio

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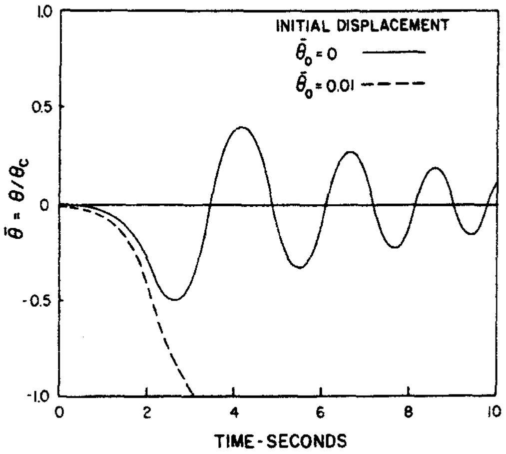
- Rocking Sensitivity to Initial Conditions.



Response of a block (R = 10 ft, $H/B = 4$) to a rectangular pulse of acceleration = 0·26 g and duration = 2·1 s

- Very Sensitive to the Details of the Ground Motion

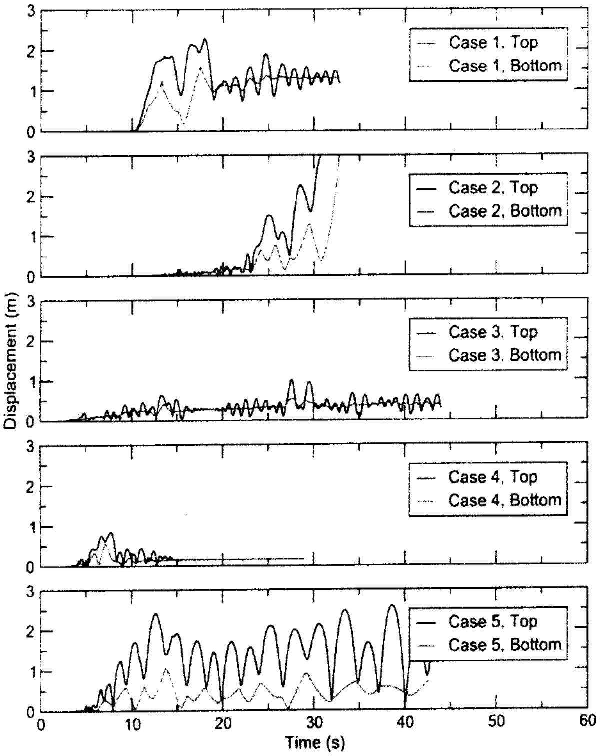


Figure 5.12: Time Histories of Cask Displacement Relative to Pad for Cylindrical Cask, Stiff Soil Profile, Cask/Pad μ=0.8, All 5 Earthquakes, NUREG/CR-0098 Spectral Shape, PGA=1.0 g

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- The rocking response of a rigid block is very sensitive to small changes in its size and slenderness ratio and to details of the ground motion.
- The stability of a block subjected to a particular ground motion does not necessarily increase with increasing size or decreasing slenderness ratio.
- Overturning of a block by a ground motion of particular intensity does not imply that the block will necessarily overturn under the action of more intense ground motion.
- Vertical ground motion significantly affects the rocking response of a rigid block, although in no apparently systematic way.
- In contrast, systematic trends are observed when the rocking response of rigid blocks is studied from a probabilistic point of view.

- Early Summer 2011: A draft guidance document was sent to SFST, NRO and NRR staff for review and comment.
- An important element of the draft guidance was the use of the ASCE Standard 43-05 Appendix A methodology.
- Of the comments received, two would require a significant effort to resolve.

- ASCE Standard 43-05 Appendix A only considers the rocking mode. It does not consider the sliding-rocking mode. Does the sliding-rocking mode produce greater rocking than rocking alone?
- What is the NRC staff's basis for accepting the ASCE Standard 43-05 Appendix A methodology? (NUREG/CR-6926 specifically states that "the application of such methods should be reviewed on a case-by-case basis.")

- NUREG/CR-6926, "Evaluation of the Seismic Design Criteria in ASCE/SEI Standard 43-05 for Application to Nuclear Power Plants," Brookhaven National Laboratory, March 2007.

- The most expeditious way to resolve these two questions would be to use the results presented in NUREG/CR-6865.

- NUREG/CR-6865, "Parametric Evaluation of Seismic Behavior of Freestanding Spent Fuel Dry Cask Storage Systems," Sandia National Laboratories, February 2005

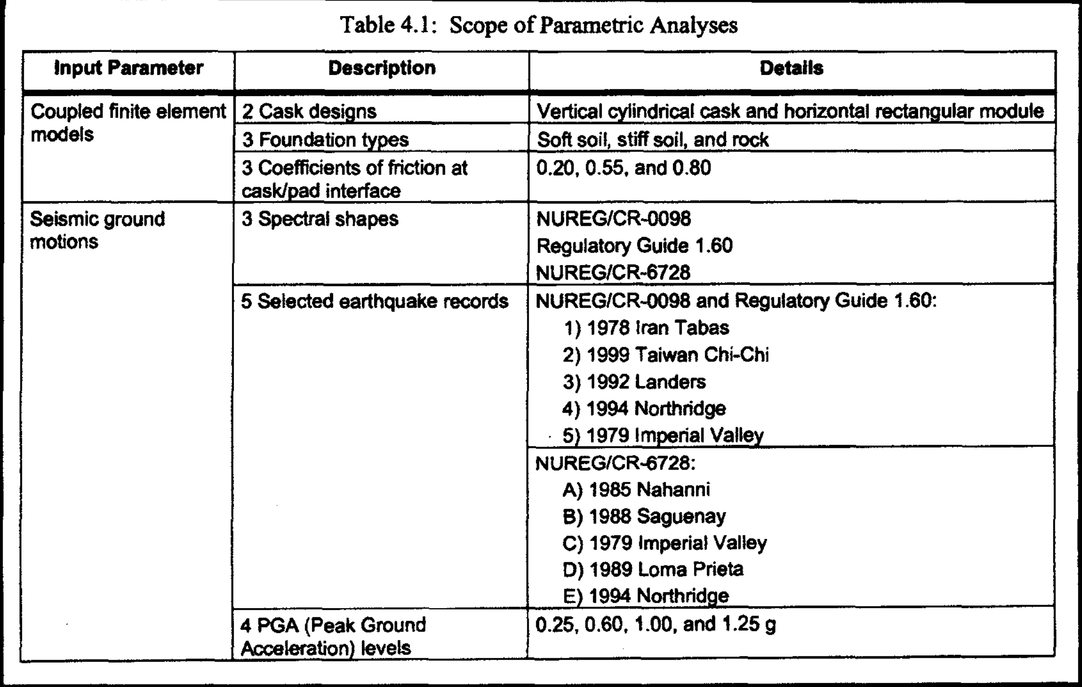


Table 4.1: Scope of Parametric Analyses

Input Parameter	Description	Details
Coupled finite element models	2 Cask designs	Vertical cylindrical cask and horizontal rectangular module
	3 Foundation types	Soft soil, stiff soil, and rock
	3 Coefficients of friction at cask/pad interface	0.20, 0.55, and 0.80
Seismic ground motions	3 Spectral shapes	NUREG/CR-0098 Regulatory Guide 1.60 NUREG/CR-6728
	5 Selected earthquake records	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
	4 PGA (Peak Ground Acceleration) levels	0.25, 0.60, 1.00, and 1.25 g

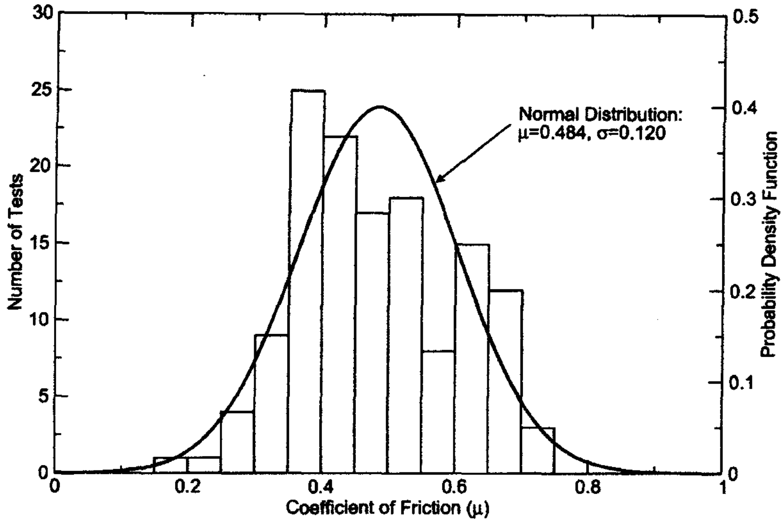
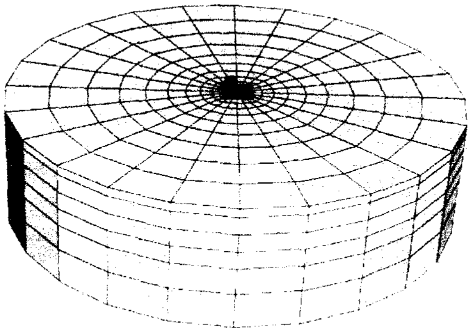
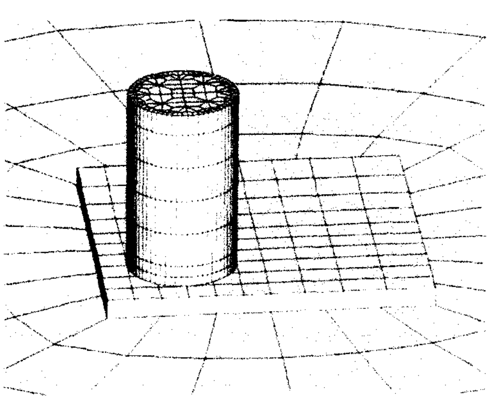


Figure 4.5: Histogram of Steel/Concrete Coefficient of Friction Test Results



(a) Overall Model



(b) Detailed View of Region of Model with Cask and Pad

Figure 3.6: Finite Element Model of Cylindrical Cask, Pad, and Foundation

Sliding-Rocking Evaluation

Based on NUREG/CR-6865

RG 1.60 Spectra, All Soil Profiles

	$\mu = 0.20$	$\mu = 0.55$	$\mu = 0.80$
PGA	Median Peak Cask Rotation (Degrees)		
0.25	0.01	0.09	0.12
0.40	0.02	0.84	1.23
0.60	0.03	5.64	9.14
1.00	0.07	62.50	114.00

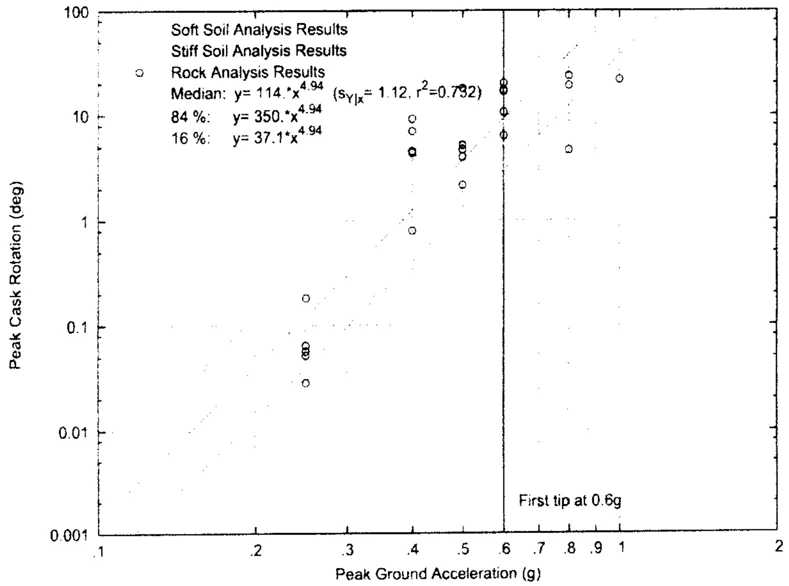


Figure VI.24: Peak Rotation Regression Fit, Cylindrical Cask, Regulatory Guide 1.60 Earthquakes, Cask/Pad μ=0.8, All Soil Profiles

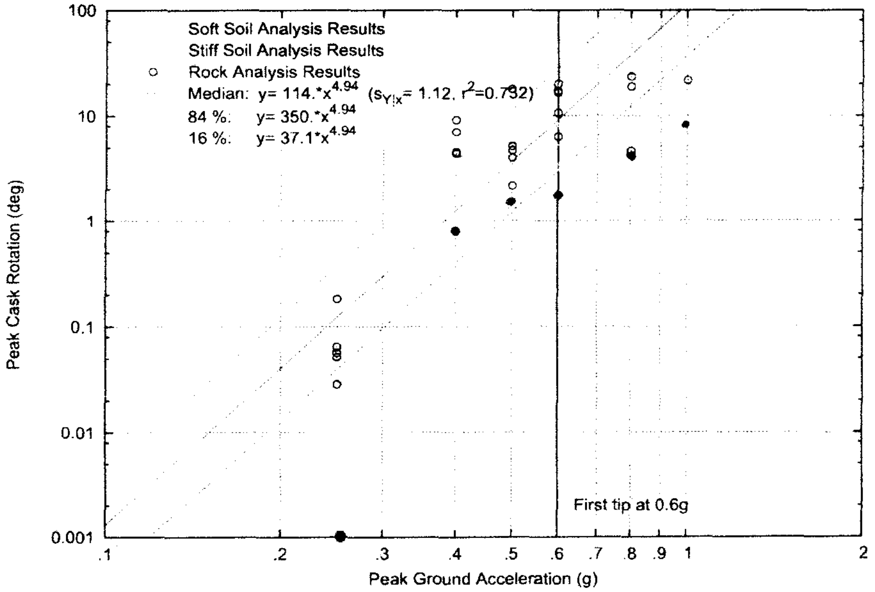


Figure VI.24: Peak Rotation Regression Fit, Cylindrical Cask, Regulatory Guide 1.60 Earthquakes, Cask/Pad μ=0.8, All Soil Profiles

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Comparison of ASCE 43-05 Appendix A Results with NUREG/CR-6865 Time History Results

$\mu = 0.80$, RG 1.60, All Soil Profiles
Critical Angle = 29.2 degrees

	Median Peak Cask Rotation (Degrees)	
PGA	NUREG/CR-6865 Median	ASCE 43-05 App. A, 10% Damping
0.25	0.1	0
0.40	1.2	0.8
0.50	3.7	1.4
0.60	9.1	2.1
0.80	37.9	4.4
1.00	114.0	7.9

Pre-Decisional Information

- For low levels of floor motion intensity, the stack-up configuration may be evaluated using linear elastic dynamic analysis methods (e.g., response spectrum analysis). If such an analysis shows that insipient tipping will take place, then nonlinear time history analysis methods shall be used.

[illegible]

- The transfer cask shall be attached to the mating device and the mating device shall be attached to the storage overpack by positive mechanical connections. The connections and mating device shall be designed to resist DL, LL and SSE without exceeding the Level D Stress Limits of the ASME B&PV Code Section III, Division 1, Subsection NF.

- DL = Dead Load; LL = Live Load; SSE = Safe Shutdown Earthquake

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[illegible]

- To determine the rotational stiffness of the mating device a detailed finite element model incorporating the effects of prying action may be required. Given the possible asymmetry of the mating device about the horizontal rotational axes, the stiffness about a horizontal axis in one direction may be different about the same axis in the other direction. Because of the sensitivity of rocking to small changes in initial conditions, analyses shall be performed using both stiffnesses. However, if the rocking frequency of the transfer cask using the lower of the two frequencies is greater than the frequency at the ZPA of the floor spectra, the entire stack-up may be considered to respond as a single rigid body.

- At this time the staff has no basis for accepting the rocking methodology of ASCE Standard 43-05 Appendix A.

- When performing nonlinear time history analyses of the stack-up configuration, multiple sets of floor motion time histories should be used to represent the floor motion. Each set of floor motion time histories shall be selected from real recorded ground motions. The staff suggests that the five ground motion time histories used to envelope the RG 1.60 ground spectrum in NUREG/CR-6865 be used. The amplitude of these ground motions may be scaled but the phasing of the Fourier components must be maintained.
- The mean plus one standard deviation of the calculated responses shall be an estimate of the maximum rocking angle. This estimate multiplied by a safety factor of 2.0 shall not exceed the critical angle for tip-over.

Pre-Decisional Information

- When the nominal radial gap between the canister and transfer cask is small (<1/2") the canister and transfer cask may be considered to respond together as a rigid body.

Pre-Decisional Information

- Two distinctly different types of damping exist in the rocking of a solid (non-rigid) body.
- The first type of damping is rigid body impact damping, which results solely from considering the conservation of momentum of a rocking rigid body, and is not related to material, or hysteretic damping.
- The second type of damping is material damping, which results from energy dissipation within the material itself. The damping values given in RG 1.61 shall be used for material damping.
- Only material damping shall be used in the time history rocking analysis, since impact damping is already accounted for in the rocking of a rigid body.

- The supporting structure (floor system or combined transport structure and floor system) shall be designed to support the concentrated load of the stack-up configuration in a slightly tipped condition. The flexibility of the supporting structure shall be modeled in the dynamic analysis.

[illegible]

- When the transfer cask is supported and held by the main crane, the stack-up configuration shall be considered stable.

- Questions