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ADDITIONAL CASK ANALYSES FOR THE PFSF

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PFSF

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- All significant assumptions are stated.
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REVISION LOG

Revision 0 – Original Issue

EXECUTIVE SUMMARY

The HI-STORM 100 storage overpack, containing a loaded MPC, resides on a series of ISFSI pads at the PFSF. Each ISFSI pad supports one (1) to eight (8) casks in a 2 x 4 array. The array of casks has previously been analyzed for dynamic response under a series of "design basis" and "beyond design basis" seismic events; the current design basis is a 2,000 year return period event. During the Atomic Safety Licensing Board (ASLB) hearings (April 29, 2002-May 11, 2002), and in prefiled direct testimony, several issues were raised by the State of Utah that are addressed in this report to support rebuttal testimony by PFS.

This report contains analyses on three seismic stability issues:

1. The validity of the Altran dynamic simulation results using SAP2000.
2. The effect of the soil cement between adjacent pads insofar as it potentially affects the dynamic response of the pads.
3. The sensitivity of the dynamic response to contact stiffness and damping values.

TABLE OF CONTENTS

1.0 INTRODUCTION AND SCOPE

Loaded HI-STORM 100s are to be placed on the PFS ISFSI pad. The pad is assumed driven by three components of linear acceleration corresponding to a "design basis" 2,000-year return period earthquake ground motion. In their prefiled testimony and during the NRC licensing hearings in Salt Lake City (April 29, 2002-May 11, 2002), some issues were raised by the State's witnesses that will be addressed herein. In this report, the formulation and results of additional calculations and simulations performed are presented. The key issues addressed by analysis in this report are:

<u>Key Issues</u>

1. The validity of the Altran dynamic simulation using SAP2000 [1].
2. The effect of the five-foot (5') span of the soil cement layer between adjacent pads, insofar as it acts as a connecting stiffness element that potentially affects the dynamic response of adjacent pads and casks.

In addition, VN simulations were performed to evaluate the sensitivity of the VN results to changes in cask-to-pad contact stiffness and damping.

2.0 METHODOLOGY

The objectives of this report are satisfied by performing dynamic analyses using the Visual Nastran (VN) simulation model that has been previously employed on this project [2, 3]. The dynamic analysis employs a three-dimensional model with contact between each overpack and the top surface of the ISFSI concrete pad. As applicable, underlying soil-cement/soil is included in the analyses by means of appropriately defined soil springs consistent with the input seismic motion. The dynamic analysis computer code Visual Nastran [4] is capable of solving the appropriate equilibrium equations including large deflection and orientation changes, should they occur.

3.0 GENERAL ASSUMPTIONS

In the dynamic VisualNastran (VN) analyses, the HI-STORM 100 overpack and the internal loaded MPC are modeled as a single rigid body. This is consistent with the response frequencies associated with the event and with the lowest elastic frequencies associated with the bodies. The simulation of the HI-STORM and the MPC by a single homogeneous cylinder is conservative as it neglects any energy lost through internal contact of the MPC with the overpack.

In the dynamic VN simulations, the interface contact between the base of the overpack and the concrete pad is modeled by compression-only elements. These are realistic assumptions that appropriately model the expected interface behavior. Frictional behavior at the contact locations is included with the maximum net horizontal resisting force proportional to the instantaneous normal force at the contact location.

The coefficient of friction at the interface of the ISFSI pad and the base of the HI-STORM 100 overpack in all simulations is conservatively set to 0.8 to maximize the likelihood of the cask to overturn.

Since multiple analyses are performed in this report, other assumptions are introduced as necessary when discussing a particular analysis.

4.0 INPUT DATA

4.1 General Input for Key Issues 1 and 2

The bounding weights for the loaded HI-STORM 100 and for the MPC are used in the analysis. Table 3.2.1 of [6] lists these bounding weights as:

Bounding Weight of Empty HI-STORM = 270,000 lb.
Bounding Weight of Loaded MPC = 90,000 lb.

The 2, 000-year return period seismic inputs for the dynamic analyses have been provided to Holtec in the form of three components of linear acceleration time histories (30 sec. duration) acting at the top of the soil cement [5]. The effect of the soil substrate and the soil-cement were included in the development of this time history set.

A custom contact model in VisualNastran (VN) simulates the resistance of the ISFSI concrete pad to the HI-STORM 100 resting on the pad where each facet point on the contact interface between HI-STORM and the ISFSI pad top surface is simulated by a compression-only spring with a force-deformation relation of the form:

$$F = -k\delta - c\dot{\delta}$$

where "F" is the force developed in the spring, "k" is the contact spring constant, "c" is the damping coefficient, and "δ" is the local penetration at the contact point. The springs, along with appropriate friction elements, are located around the periphery of the overpack.

4.2 Specific Input Data for Key Issue #1 Analyses

Input data for the VN simulation simulating the Altran model (Key Issue #1) is presented in Table 1. Note that the reduction in the number of contact points used by Altran is only a rough approximation to the real behavior of a circular contact interface.

Table 1 – Key Input Data - VN Model Used to Evaluate Altran Dynamic Analysis	
Cask Weight (lb)	360,000
Number of Cask-to-Ground Contact Locations	8 (at 45 degrees)
Vertical Contact Stiffness per Contact Location (lb/inch)	125,000
Contact Damping	1% of Critical
Coefficient of Friction at Each Contact Location	0.8

4.3 Specific Input Data for Key Issue #2 Analyses

A summary of the input data for the VN simulations involving multiple casks on adjacent pads (Key Issue #2) is summarized in Table 2 below; this set of data is identical to the data set used for the simulation in Case 1 of [3], except for the last three items in the table that reflect the new parameters required to simulate the sliding pad and the soil cement between the pads.

Table 2 – Input Data for Cask Contact		
Item	Value	Reference (unless noted reference is to Ref. [3], (Holtec report HI-2022854))
Cask mass (lbm)	360,000	P.12, Figure 8
Cask height (inch)	231.5	HI-STORM FSAR
Cask radius (inch)	66.25	HI-STORM FSAR
Pad length/width/thickness (ft)	67/30/3	Appendix C, p. C-1
Pad mass (lbm)	934700	Figure 8
Cask contact stiffness per facet (lbf/inch)	1179030	Figure 7 and Appendix A, p A-1
Cask Contact damping per facet (lbf *sec/inch)	4549.05	Appendix A, p A-2
Cask-Pad Coefficient of Friction	0.8	
Number of facets per cask	16	Appendix A, p. A-1
Soil Spring and Damper Data		
Kx (lbf/in)	9,512,000	Appendix D
Cx (lbm/sec)	9.249×10^7	"
Ky (lbf/in)	9,037,000	"
Cy (lbm/sec)	8.789×10^7	"
Kz (lbf/in)	12,040,000	"
Cz (lbm/sec)	1.727×10^8	"
Kxx (lbf-in/deg)	2.423×10^{10}	"
Cxx (lbf in sec/deg)	3.812×10^8	"
Kyy (lbf-in/deg)	8.137×10^9	"
Cyy (lbf in sec/deg)	8.427×10^7	"
Kzz (lbf in/deg)	2.226×10^{10}	"
Czz (lbf in sec/deg)	1.556×10^8	"
Seismic Input (2k event)	3 input files	Geomatrix
Coefficient of Friction Between Pad and Substrate for Sliding Pad Simulation	0.31	Stone and Webster
Elastic Modulus for Soil-Cement Between Pads (ksi)	1,000	Stone and Webster
Geometry of Soil-Cement Between Pads	30' wide x 2'-4" deep x 5' long	Stone and Webster

5.0 COMPUTER CODES

The main section of this report is written using Microsoft Word (Office 2002), while the calculation appendix is prepared using MathCad (Version 2000).

The following analysis code has been used (see Appendix B for approved computer code list):

VisualNastran 2001, R2, MSC Corporation

VisualNastran 2001 (formerly known as Working Model 4-D) has been independently validated in accordance with Holtec QA requirements.

6.0 ANALYSES

6.1 Key Issue #1 - Evaluation of Altran Simulation

Reference [1] presents a summary of analyses performed by a State witness; the general tenor of that report is that the DYNAMO and VN simulation results are very sensitive to the choice of contact stiffness and damping inputs; hence, the results of PFS's analyses cannot be relied upon. The analyses in [1] use the finite element computer code SAP2000; in particular, in Table 3 of that report, results (Case 3) are presented that suggest that a cask will lift-off approximately 2' and move horizontally approximately 30' when the following parameters are used:

Cask weight "W"= 360,000 lb.
Total Vertical Contact Stiffness "K" (sum of 8 locations) = 1,000,000 lb/in
Damping "C" = 1% of Critical

The conclusions of the State's witness are that, while the parameters he used are not necessarily a meaningful data set, the results obtained using them demonstrate that the analysis is very sensitive to the input parameters chosen (i.e., vertical contact stiffness and damping). The State's witness acknowledges that SAP2000 is a "small deflection" program, but claims that this limitation does not affect the validity of his results.

To test these claims by the State' witness, Holtec has conducted two VN dynamic analyses using the same input parameters listed above. The VN program, as previously discussed, is capable of accounting for large cask movements.

In the first analysis, the Altran model was reproduced in VisualNastran by modeling a single rigid cask on a pad driven by the three components of the design basis seismic event. Figure 1 shows the VN cask model. To duplicate the contact model simulated in

[1], contact between cask and pad (around the periphery of the cask) is restricted to eight specific locations by embedding eight (8) small spheres (negligible mass compared to the cask mass) in the base of the cask, and rigidly attaching the spheres to the cask. Cask-to-pad contact was simulated by defining the following contact parameters: vertical stiffness = 125,000 lb./inch and coefficient of friction =0.8 between sphere and pad at each of the 8 locations. The 1% damping parameter at each location is assigned by computing the damping constant from the equation

$$C = (1/8) \times 0.01 \times 2((W/g) \times K)^{1/2}$$

and incorporating a damper in parallel with the vertical contact stiffness. To match the Altran model, the soil springs were removed from the model and the pad was driven directly by the three input seismic accelerations.

The second VN simulation was performed using the eight-cask model from [3] (Case 1). As in the first case, the soil springs were removed from the model and the pad was driven directly by the 2k return period seismic event. To assess the effect of using only eight cask-to-pad contact locations, this run employed sixteen contact points between cask and pad. The contact stiffness and damping are chosen to produce a total stiffness of 1,000,000 lb./inch and 1% of critical damping so as to exactly reproduce a 0.36" static deflection of the pad prior to the initiation of the seismic event. Since the pad is driven only by translational acceleration time histories, the cask responses should be decoupled and the response of cask #1 provides a direct comparison with the simulation in [1], the only differences being the use of more cask-to-pad contact points than in the Altran model and the number of casks in the simulation.

6.2 *Key Issue #2 - Evaluation of Effects of Pad-to-Pad Interaction*

To evaluate the potential effects of pad-to-pad interaction, Holtec conducted two sets of analyses. The first set was to respond to the claim by the State's witnesses that if two pads are loaded with different number of casks, the different total mass associated with adjacent pads could cause out-of-phase motion and a transmittal of additional forces between pads. To determine whether this contention raises a credible concern, VN dynamic models were constructed to include the effect of the stiffness coupling due to soil cement between adjacent pads. Figure 2 shows a simulation model with two pads; one pad is fully populated with 8 casks, while the adjacent pad contains only a single cask placed in a likely location for a "first cask on a pad". The soil cement between the pads is modeled by two springs connecting the two pads. In one simulation, the springs are assumed linear and support tension and compression forces between pads, while in a companion simulation the springs are assumed non-linear and do not support any tension forces between pads. The substrate under each pad is modeled by the set of six linear springs associated with the lower bound values consistent with the design basis 2000-year return period seismic event. The base of the soil spring set under each of the two pads is fixed and both pads and all of the nine casks are driven by appropriate inertial force time histories.

Figure 3 shows the configuration for the second analysis. This analysis utilizes a simulation model developed to study what happens if a pad slides and impacts the adjacent soil cement. The purpose of this simulation is to evaluate the effect of potential impact forces on cask stability should the presence of gaps in the soil cement between adjacent pads lead to non-linear contact and asymmetrical pad loading. The State's witnesses have suggested in their testimony that this is an unanalyzed condition not necessarily bounded by previous simulations performed by PFS.

For this simulation, a single eight-cask pad is modeled but the pad is assumed to be able to slide on the substrate if the pad-to-substrate friction coefficient exceeds 0.31. To accomplish this representation, the linear soil springs between pad and ground are removed from the simulation. To provide the appropriate pad-to-ground contact, eight spheres (with negligible mass compared to the pad mass) are embedded in the pad and rigidly attached to it. These "contact" spheres are positioned under each of the centerlines of the eight casks. Contact between each sphere and the ground is defined at each sphere-substrate interface by a vertical contact stiffness and a damper whose values are 1/8th of the value previously associated with the total vertical linear stiffness and damping between pad and substrate (see Appendix C for Case 1 input parameters). The coefficient of friction between sphere and ground at each of the eight contact locations is set to 0.31. Both pad sliding and pad liftoff are permitted. A fixed, rigid frame surrounds the entire pad with a clearance gap of approximately 0.6" to all edges of the moving pad.

Appendix A contains supporting calculation details for these two sets of simulations.

6.3 *Other Analyses*

In addition to the analyses conducted to address the two key issues described above, VN simulations were also performed to evaluate the effect of varying certain input parameters to the VN analysis. In particular, Holtec evaluated decreasing the cask-to-pad contact damping to a conservative 5% (reduced from the realistic value of 40% used in previous VN analyses (Case 12 of [3]) and the effect of decreasing the total contact stiffness between cask and pad to 4,760,000 lb./inch (reduced from the value of approximately 40,000 kip./inch). These analyses are intended to test the sensitivity of the our solutions to changes in these parameters, in response to the State's claim that the PFS analyses are highly sensitive to the choice of these input parameters. The VN model used for these simulations is the same as used for Case 1 in [3], except for the changes noted above. For each simulation, the pad is fully populated, the soil springs are the lower bound design basis set, and the initial static deflection of the casks relative to the pad, is matched to the appropriate total stiffness.

7.0 COMPUTER FILES

All relevant computer files associated with this calculation package are archived on the Holtec Server. A directory listing of computer files is given below:

The seismic zip files contain individual simulation results

\PROJECTS\70651\HI2022878AIS\ANALYSIS

Name ▲	Size	Type	Date Modified
Khan 8 point 5-31-02.zip	33,988 KB	WinZip File	5/31/2002 8:02 PM
Miscellaneous.zip	67,569 KB	WinZip File	6/3/2002 3:48 PM
pfs 2k 4-29-02 5% contact damp -design basis lower bound cof=.8.zip	144,522 KB	WinZip File	4/29/2002 7:01 AM
pfs 2k 5million contact 4-26-02 lb soil cof=.8.zip	183,545 KB	WinZip File	4/27/2002 8:14 AM
pfs 2k 6-03-02 true 40, 40% cof=.8.zip	114,093 KB	WinZip File	6/3/2002 11:09 AM
PFS 2k 5-20-02 2 pads tens-comp connection cof=.8 soil elastic.zip	151,012 KB	WinZip File	5/22/2002 9:19 AM
PFS 2k 5-21-02 2 pads comp only connection cof=.8 soil elastic.zip	151,085 KB	WinZip File	5/22/2002 8:59 AM
PFS 2k 6-03-02 conv 8 casks kahn table 3 case 3 lower bound soil co...	104,426 KB	visualNastran Deskt...	6/3/2002 3:36 PM
PFS 2k 6-03-02 conv 8 casks kahn table 3 case 3 lower bound soil co...	65,145 KB	WinZip File	6/3/2002 3:50 PM
PFS 2k 6-03-02 true 40k, 40% cof=.8.WM3	181,310 KB	visualNastran Deskt...	6/3/2002 7:44 AM
pfs 6-02-02 40k, 5%.zip	216,893 KB	WinZip File	6/2/2002 6:56 AM
pfs -final5% 6-01-02 with net d plotted.WM3	159,288 KB	visualNastran Deskt...	6/1/2002 11:49 PM
pfs -final5% 6-01-02 with net d plotted.zip	101,581 KB	WinZip File	6/3/2002 3:52 PM
PFS final 2k 5-05 8 casks cof=.8 gap=.6 sliding cof=.31.zip	83,452 KB	WinZip File	5/7/2002 12:35 PM

\PROJECTS\70651\HI2022878AIS\REPORT

Name	Size	Type	Date Modified
Appendix A.mcd	53 KB	Mathcad Document	5/29/2002 12:53 PM
HI2022878.doc	6,080 KB	Microsoft Word Doc...	6/3/2002 3:35 PM
Report HI-2022878.zip	5,142 KB	WinZip File	6/3/2002 3:54 PM

\PROJECTS\70651\HI2022878AIS\AVI Files

Name	Size	Type	Date Modified
khan 5-31-02 convergence.avi	17,744 KB	AVI Video	5/31/2002 5:51 PM
PFS 2k 5-20-02 2 PADS Tens-Comp 30sec.avi	18,537 KB	AVI Video	5/24/2002 9:12 AM
PFS 2k 5-21-02 2 PADS Comp. Only 30sec.avi	18,464 KB	AVI Video	5/24/2002 9:05 AM
PFS 2k 4-26-02 8 casks 5 million k lower bound soil cof=.8 30sec.avi	20,278 KB	AVI Video	5/30/2002 3:34 PM
PFS 2k 4-29-02 8 casks kahn table 3 case 3 -holtec model 30sec.avi	17,825 KB	AVI Video	5/30/2002 3:44 PM
PFS final 2k 5-05 8 casks cof=.8 gap=.6 sliding cof=.31 30sec.avi	19,093 KB	AVI Video	5/30/2002 3:50 PM

8.0 RESULTS OF ANALYSES

8.1 Key Issue #1 - Evaluation of Altran Simulation

8.1.1 Analytical Considerations

It can be shown that the low stiffness and damping values used by the State witness in the evaluation reported in [1] do not reflect the physical reality of the contact between a steel cask and a concrete pad.

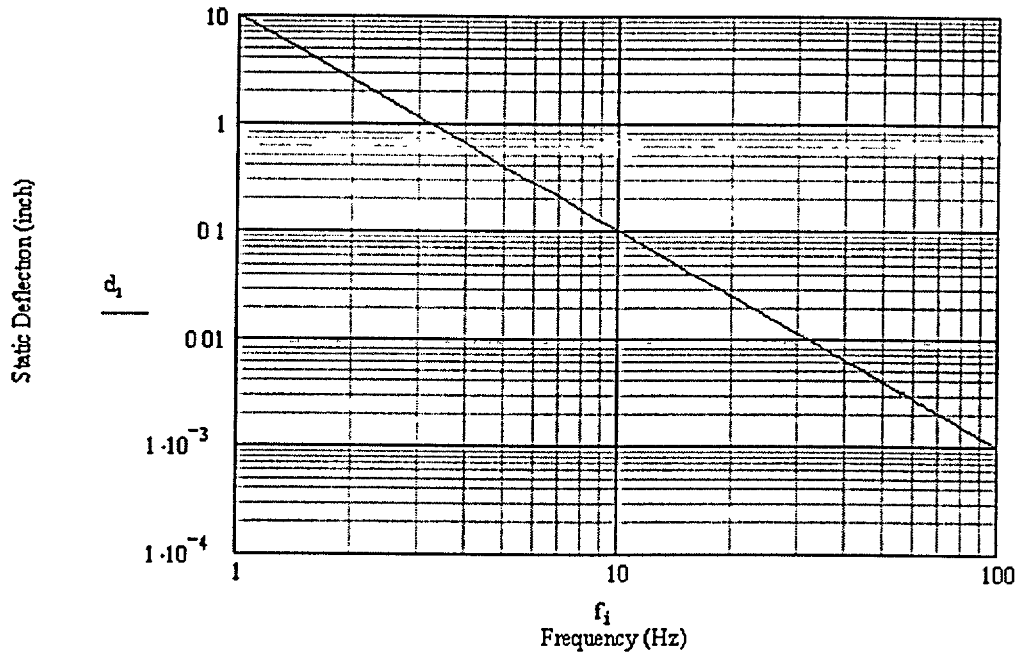
For a cask weight, "W", a total vertical contact stiffness of "K" corresponds to a natural frequency of linear vibration of the cask, relative to the pad, of magnitude:

$$f = \frac{1}{2\pi}\sqrt{\frac{Kg}{W}} = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}}$$

where $\delta = W/K$ is the static deflection of the cask. Solving for the static deflection, δ, gives:

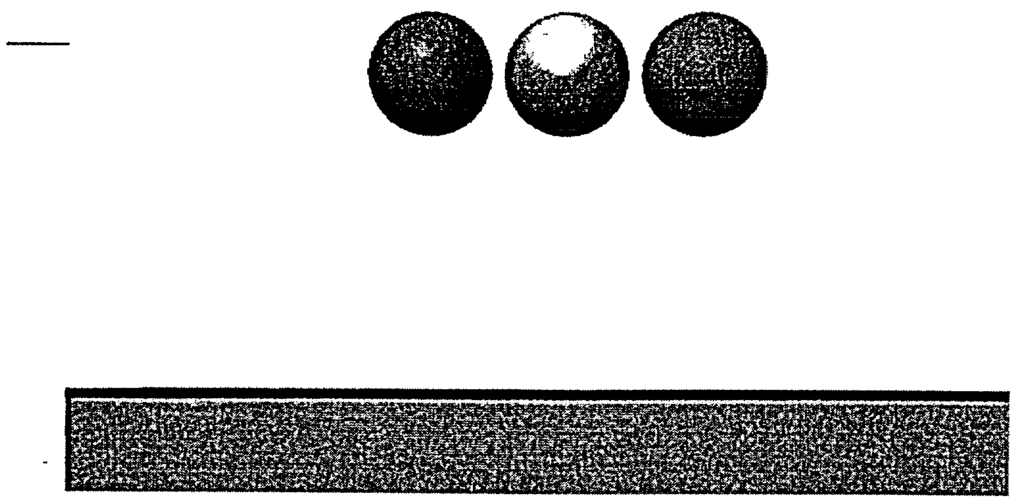
$$\delta = g \Big/ (2\pi f)^2$$

This relation is plotted below on a log-log scale (static deflection in inches vs. natural frequency in Hz (cycles per second)). As the figure demonstrates, the natural frequency of vibration of the cask is inversely proportional to the static deflection and directly proportional to the contact stiffness.



Using a cask weight of W=360,000 lb., and assuming (as the State witness does) that an appropriate vertical stiffness is K=1,000,000 lb./inch, the natural frequency is computed to be 5.214 Hz. From the curve, the static deflection of the cask, corresponding to a natural frequency of 5.214 Hz, is 0.36" into the concrete. Such a deflection is not credible for a concrete pad. In other words, a 0.36" penetration of the cask into the concrete under a dead weight load, and a corresponding 5.2 Hz natural frequency simulating such contact behavior, are not consistent with "real life" expectation of a cask resting on a concrete surface.

The State's witness appears to suggest that 1% of critical damping is an appropriate value for contact damping and that the value of 40% used by PFSF is too large. To address this assertion, consider the simple experiment indicated in the sketch below that shows three identical spheres, each having the same mass, and each located a height H=18" above a target surface.



If the spheres are dropped under gravitational force only, they each acquire a downward speed, "V", at the instant of impact, where

$$V = (2gH)^{1/2}$$

Subsequent to the impact, each sphere has an initial upward speed

$$V_1 = eV$$

"e" is commonly known as the "coefficient of restitution" and ranges in value from 0.0 to 1.0. The lower limit indicates a "perfectly plastic" collision (all kinetic energy dissipated), while the upper limit represents a "perfectly elastic" collision (no kinetic energy dissipated). The coefficient of restitution is a function of the materials, local shape of the contacting bodies at the contact region, and surface finish of the two contacting bodies, and can be computed from a simple experiment matched to the theoretical solution. The choice of body shape for this numerical experiment is immaterial since the coefficient of restitution is specified.

Consider the response of the spheres after multiple contacts. Due to the effect of gravity and the smaller upward speed subsequent to the initial contact, the bodies rise to a height less than the original 18" height; subsequent motion of the spheres with the attendant contacts is repeated until the spheres come to rest on the target surface. It can be shown that there is a direct mathematical relationship between the "coefficient of restitution" and the "percent of critical damping".

After "n" bounces on the target, the relation between the initial starting height, H, the height H_n to which the spheres return after bounce "n", and the coefficient of restitution, e, is:

$H_n/H = e^{2n}$

For $H_n/H = 0.01$ (i.e. 0.18"/18", for example), the results for different "e" values are:

e=0.969 -> n=73 (1% of critical damping)
e=0.854 -> n=14 (5% of critical damping)
e=0.254 -> n=2 (40% of critical damping)

The above results show that 40% damping reflects reality (the spheres come to rest after 2 bounces), 5% damping is a conservative choice (the spheres come to rest after 14 bounces), and 1% damping is unrealistically small (the spheres come to rest after 73 bounces). A movie file has been produced for this "experiment" and dramatically illustrates the unrealistic response produced by the assumption of 1% of critical damping.

8.1.2 Evaluation Results

The VN simulation of the Altran Case 3 in Table 3(in Ref. [1]) was performed using contact spring constant and damping values of 1,000,000 lb./inch and 1% of critical damping, respectively, in order to establish whether the choice of contact stiffness and damping influences the results to the significant extent suggested by Altran [1].

Figure 4 shows the results of the first dynamic analysis for Key Issue #1 in which Holtec reproduced the Altran Model using the VN program. The results from this evaluation are given in the form of plots of the displacement of the top center point of the cask vs. time, the displacement of the cask mass center vs. time, and the rotations of the cask from the vertical vs. time. The VN solution produces the following key results:

Maximum Cask Excursion (x or y direction) for Altran Contact Parameters – 8 point Cask Contact			
Total Contact Stiffness (lb./in)	% of Critical Damping at Contact Location	Max. Excursion of Top of Cask From Location at Start of Run (inch)	Maximum Peak-to-Peak Displacement of Top of Cask (inch)
1,000,000	1%	11.0	21.0

These results demonstrate that the assumed low values of contact stiffness and damping have some impact on the calculated cask motions. However, the large cask excursions (approximately 30' in one of the horizontal directions) predicted by Altran appear to be due to the utilization of the SAP2000 Code beyond the range of its applicability. However, from the results given above, it cannot be determined how much of the increase in response is caused by the number of contact locations chosen and how much of the increase is due to the use of unrealistic input parameters.

To assess the effect of using only eight contact locations around the cask periphery, a simulation is performed using the standard Holtec model where the cask has sixteen contact locations around the periphery but the contact parameters are chosen to be equivalent to a static deflection of 0.36" (corresponding to 1,000,000 lb./inch total vertical stiffness) and a damping of 1% of critical.

Figure 5 shows the results of the second dynamic analysis for Key Issue #1. The table below summarizes the results for Cask #1.

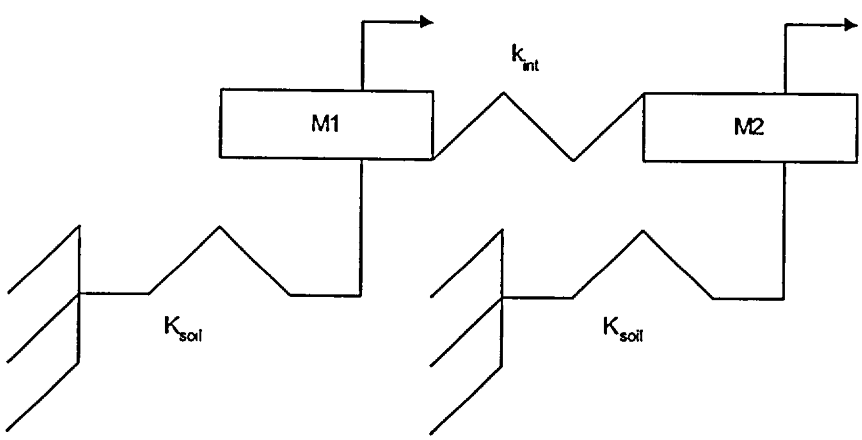
Maximum Cask Excursion (net displacement) for Altran Parameters – VN Analysis with 16 point Cask Contact			
Total Vertical Contact Stiffness (lb /in)	% of Critical Damping at Contact Location	Max. Excursion of Top of Cask From Location at Start of Run (inch)	Maximum Peak-to-Peak Net Displacement of Top of Cask (inch)
1,000,000	1%	19.3	32

It can be concluded from these two sets of simulations that even using unrealistic low values for contact stiffness and damping does not alter the conclusions of the earlier Holtec studies; that is, that cask stability is maintained under the 2k year return period design basis ground motion. Comparison of the two analyses shows that the choice of number of contact locations does influence the results.

8.2 Key Issue #2 - Evaluation of Effects of Pad-to-Pad Interaction

8.2.1 Analytical Considerations

The State witnesses contend that the dynamic response of a pad could be affected by "coupling" with adjacent pads due to out-of-phase motion between them. To explore this concern analytically, consider the following simple 2-degree of freedom (2-DOF) mass-spring system.



The soil spring constant (K_{soil}) is known and the soil-cement spring constant (k_{int}) between the two loaded pads (masses M1 and M2) can be computed. The natural frequencies of vibration, "f", of this classic 2-degree of freedom linear model can be computed by solving the quadratic equation:

$$f^2 - bf + c = 0$$

Appendix A contains the details of the calculation of the spring constant for the soil cement and the solution of the quadratic equation. Three cases are considered, all with one pad fully loaded: (1) the adjacent pad is empty, (2) the adjacent pad is loaded with a single cask, and (3) the adjacent cask is loaded with eight casks. The results of this simple analysis are provided in the following table:

Results from 2-DOF Frequency Analysis		
Pad Loading	1st Natural Frequency (Hz)	2nd Natural Frequency (Hz)
0 casks/8 casks	6.228	47.698
1 cask /8 casks	6.015	41.959
8 casks/8 casks	4.939	29.765

The results of this simple analysis demonstrate that the lowest natural frequency, corresponding to a predominately in-phase motion of the two pads, is near the high-energy input frequency of the 2k return period seismic event. On the other hand, the natural frequency associated with predominately out-of-phase motion of the two pads is a frequency above those associated with the energy of the seismic event, since most of the seismic energy input is at frequencies below 25 Hz. This simple analysis shows that the effect of pad-to-pad interaction should be negligible; the VN results discussed below confirm this assertion.

8.2.2 Evaluation Results

As discussed in Section 6.2, three VN simulations were performed to evaluate the effect of the presence of soil cement between the pads. Cask-to-pad contact parameters were the same as used in [3]. Figures 6-8 show the results from these simulations; a summary of the key results is provided in the table below:

Summary of Key Results from VN Simulations with Pad-to-Pad Interaction						
Case Considered	Maximum Tension Load in Soil Cement Between Pads (lb.)	Maximum Compression Load in Soil Cement Between Pads (lb)	Cask #3 on Pad #1 Max. Excursion from Starting Location (inch)	Cask #3 on Pad #1 Max. Peak-to-Peak Displacement (inch)	Cask #1 on Pad #2 Max. Excursion from Starting Location (inch)	Cask #1 on Pad #2 Max. Peak-to-Peak Displacement (inch)
2-Pads, Elastic Soil-Cement Between Pads (Fig 6)	1,200,000	800,000	5	3.5	3.8	6
2-Pads, Compression Only Soil-Cement Between Pads (Fig 7)	-	1,900,000	3.4	1.7	3.2	5
1 Pad – Compression Only Fixed Soil Cement Surrounding Pad – Initial Gap = 0 6" (Fig 8)	-	2,000,000	-	-	1.28	2.2

Examination of the movie files associated with these runs confirms that excursions of the other casks are of the same order of magnitude as the values reported above. It is seen from the above results that the various postulated pad-to-pad interactions, impart loads on the soil cement between or surrounding the pads, and in the pads themselves. However, they do not provide sufficient forces to materially alter the maximum excursions of the casks on each pad. For example, a 2,000,000 lb. compression impact force developed in the soil cement between the pads does not induce a significant compressive stress in the concrete pad because of the large area (30' x 3') that is available to absorb this load as a compressive pressure. Based on this area, the pad compressive in-plane pressure that arises from the interaction load is only

P = 2,000,000 lb./(30' x 3') = 154.3 psi

The results from the simple analytical model, together with the confirming VN solutions, demonstrate that pad-to-pad interactions under the design basis 2k return period ground motion do not adversely affect the stability of the casks, and show that asymmetrical loading on the pad due to impacts with adjacent soil cement has negligible effect.

8.3 Results From Other Analyses

Finally, Figures 9 and 10 present results of the additional sensitivity analyses discussed in Section 6.3. Both analyses include SSI and have contact stiffness between casks and pad chosen to produce the correct initial static deflection of the cask corresponding to the specified total stiffness. The first of these analyses varied the damping value used in Case 12 from [3] (from 40% to just below 5%), and the second analysis varied the total contact stiffness used in Case 12 of [3] from approximately 40,000 kip./inch to 4,760 kip./inch. Other than these changes, the parameters and methodology for the two sensitivity analyses are identical to those employed in Case 1 of [3] (i.e., the 2k seismic event is the driving excitation, 8 casks are present on the pad, and the lower bound soil properties are employed). The results are summarized below with the results from the design basis analysis in [3] (Case 1) included for reference.

Maximum Cask Excursion for Varying Contact Stiffness and Damping			
Total Contact Stiffness (lb./in)	% of Critical Damping at Contact Location	Max. Excursion of Top of Cask From Location at St art of Run (inch)	Maximum Peak-to-Peak Displacement of Top of Cask (inch)
40,087,024 (Case 12 of [3] with 40% damping and cask frequency of 33 Hz)	40%	3.2 (Cask #1)	4.7 (Cask #1)
38,194,576 (Fig. 9)	4.9%	3.4 (Cask #1) 10.5 (Cask #5)	5.0 (Cask #1) 18.0 (Cask #5)
4,760,000 (Fig. 10)	40%	3.7 (Cask #1)	6.5 (Cask #1)

These results further confirm that the PFSF cask stability analyses are not highly sensitive to either contact stiffness, or % of critical damping (i.e., changes are on the order of inches, not multiples of feet).

9.0 SUMMARY AND CONCLUSIONS

In response to allegations made by witnesses for the State of Utah in the PFS NRC licensing hearings, additional dynamic simulations and other analyses with respect to the seismic performance of the HI-STORM casks and supporting pads at the PFSF. For all dynamic simulations, the driving excitation is the 2000 Year Return Period Ground Motion set of acceleration time histories. The results from this additional work can be summarized as follows:

Key Issue #1 – Analytical considerations and the results of VN runs confirm that the cask remains stable even if unrealistic low values for contact stiffness and damping are chosen. The VN runs also establish that the analytical tools employed by State Consultant Altran are inappropriate since evidently the computer code has been applied beyond its capabilities.

Key Issue #2 – Analytical considerations and VN runs confirm that pad-to-pad interaction does not give rise to force transfer of sufficient magnitude to affect the stability of the casks on the pads. This is true regardless of pad loading and whether a gap is assumed to be present between a pad and the soil cement adjacent to it

Finally, the results from the solutions performed to study the issue of sensitivity of cask excursions to contact stiffness and damping input values show only a small sensitivity to either contact stiffness (as long as the stiffness is "realistic" for the contacting materials) or contact damping.

10.0 REFERENCES

[1] Analytical Study of HI-STORM 100 Cask System for Sliding and Tip-Over Potential During High-Level Seismic Event, Technical Report-01141-TR-001, Rev. 0, Dec. 11, 2001.

[2] Dynamic Response of Free Standing HI-STORM 100 Excited by 10,000 Year Return Earthquake at PFS, HI-2012780, Rev. 1, 11/09/01.

[3] PFSF Beyond Design Basis Scoping Analysis, HI-2022854. Rev. 1, 4/19/02.

[4] VisualNastran Desktop 2001 R2, MSC Software, 2001.

[5] [11.5] A.I. Soler, Multi-Cask Response at PFS ISFSI from 2000-Yr. Seismic Event (Rev.2), HI-2012640, Rev.1, 2001.

11.0 FIGURES

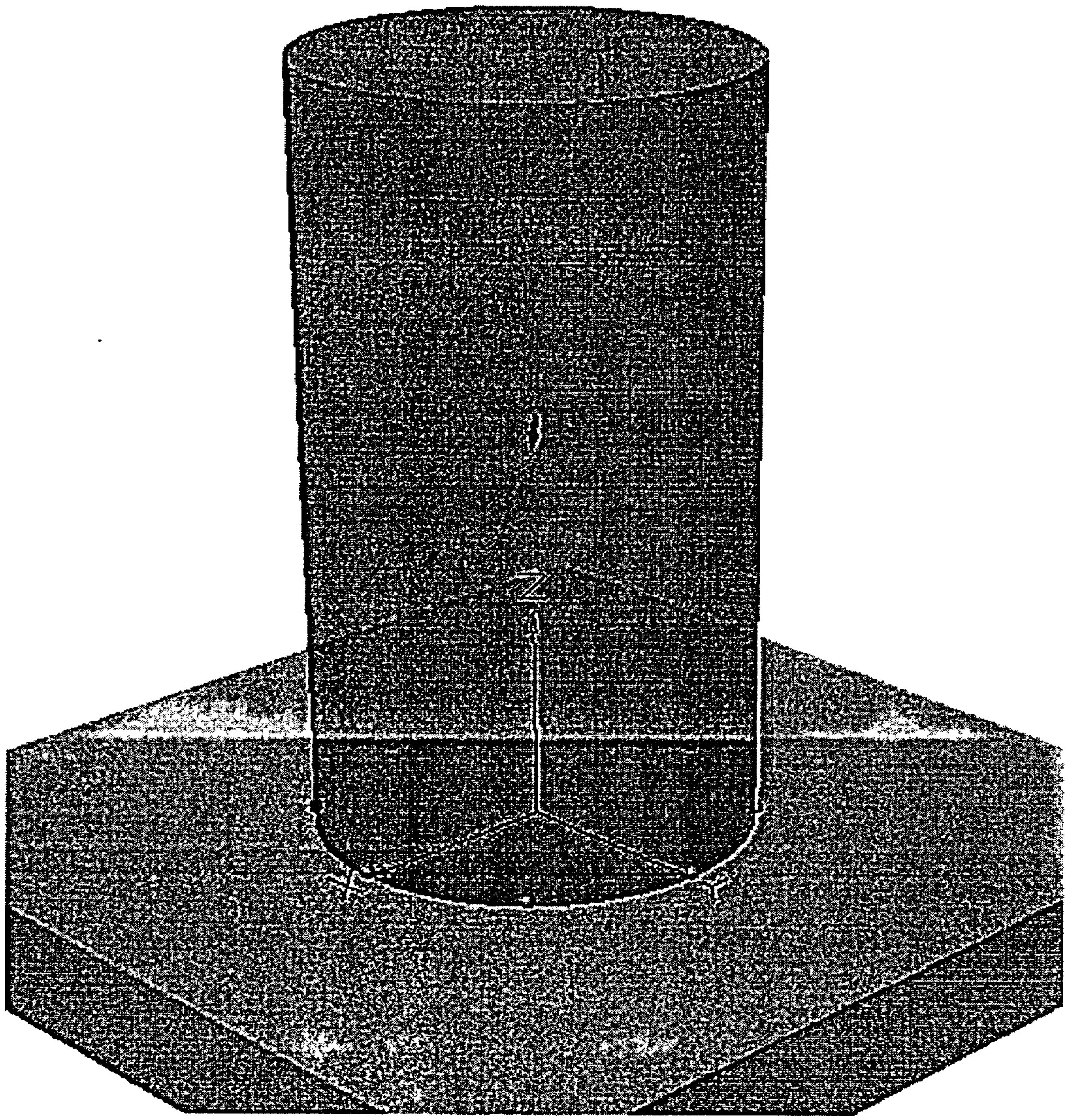


FIGURE 1 – Single Cask Model Replicating that Used in Altran SAP2000 Analysis

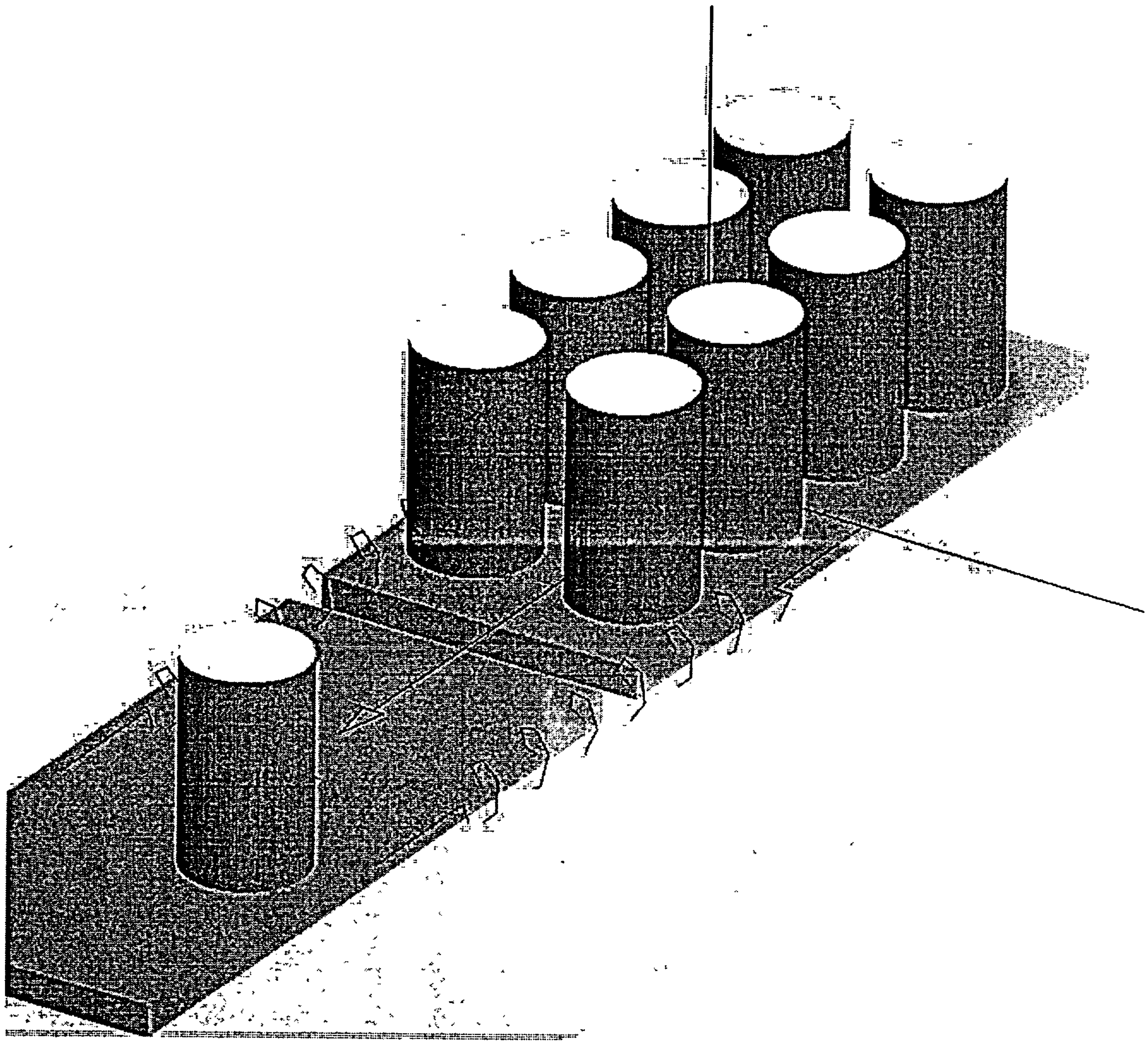


FIGURE 2 - VN Model for Two Adjacent Pads Unequally Loaded and Joined by Soil Cement Layer

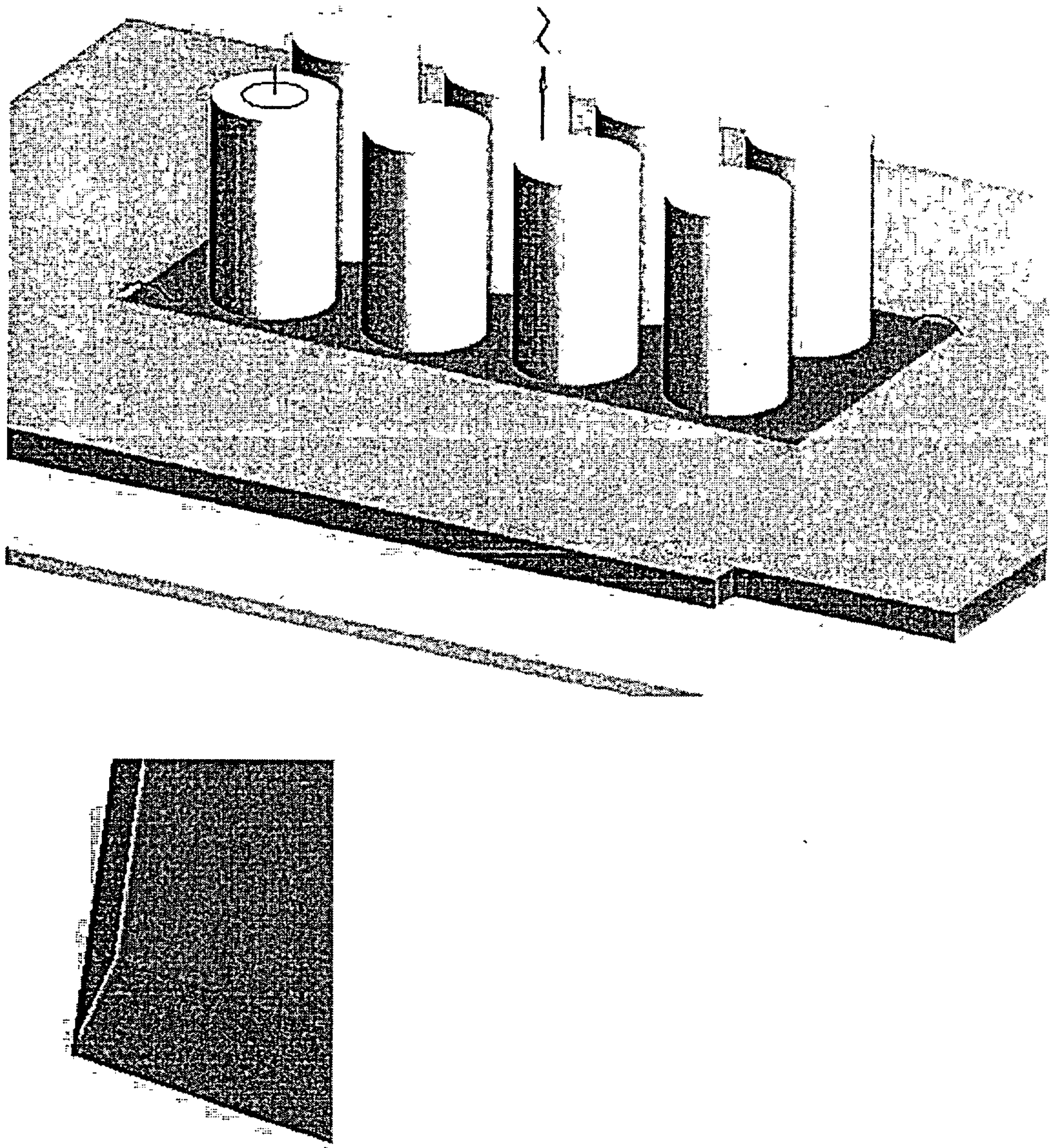


FIGURE 3 - VN Model for Single Pad Surrounded by Soil Cement (with Corner Detail Shown)

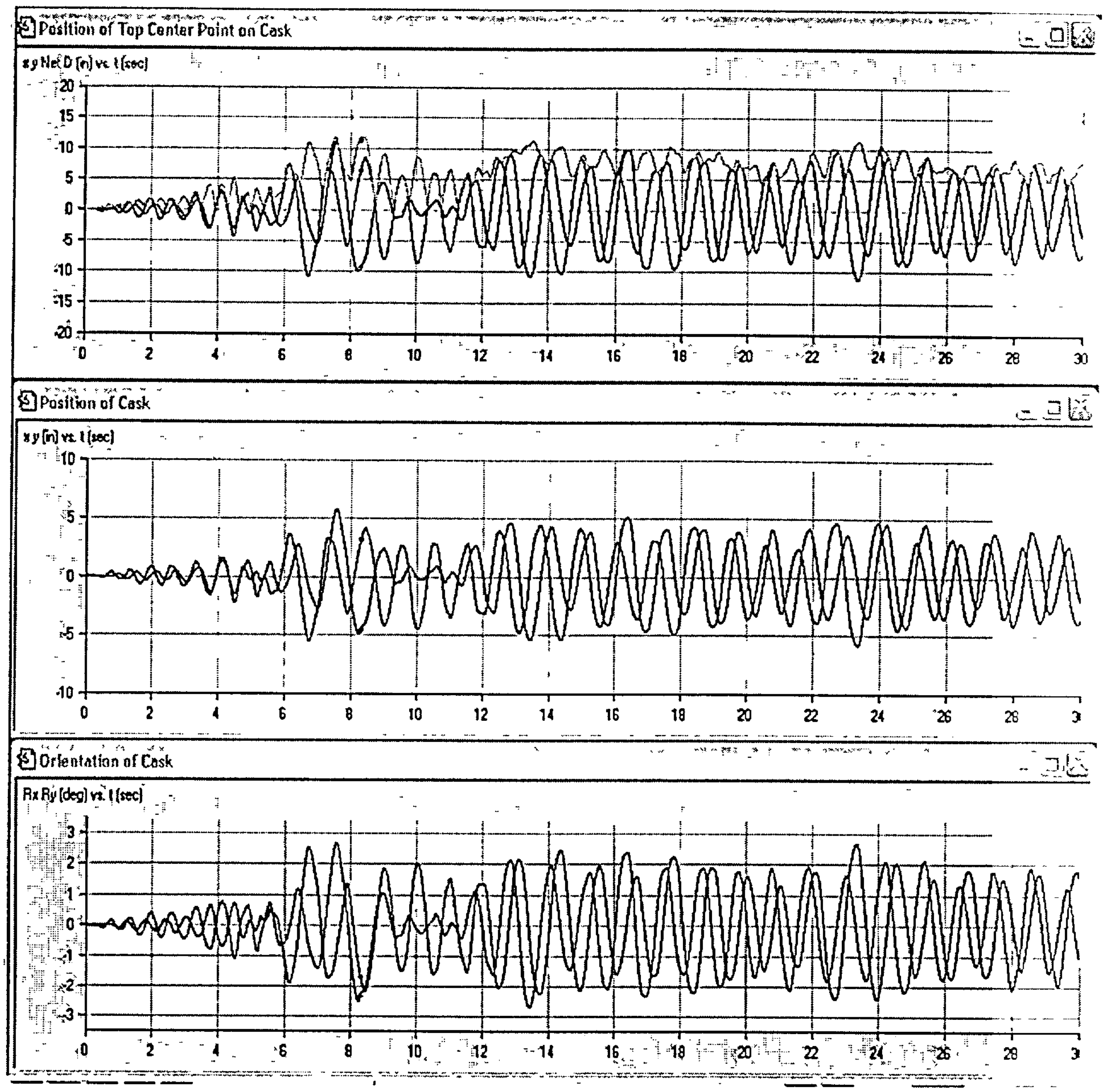


FIGURE 4 – Results From VN Simulation Replicating ALTRAN Table 3, Case 3

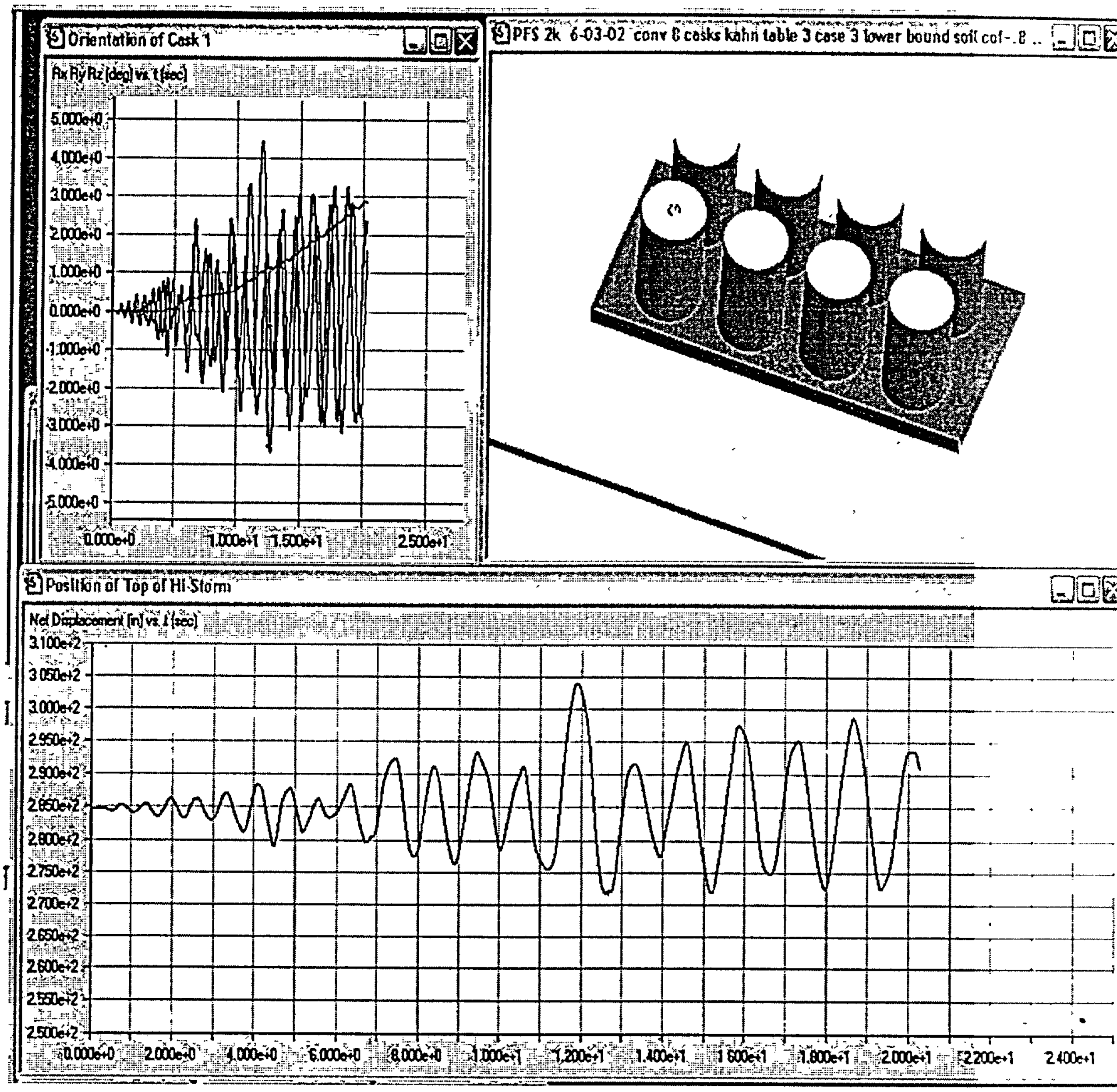


FIGURE 5 - VN Results for Cask 1, 8 Casks on Pad, COF=0.8, No Soil Springs, 2k Seismic Event Driving Pad, Contact Stiffness and Damping = Khan's 1000 kpi and 1% Damping

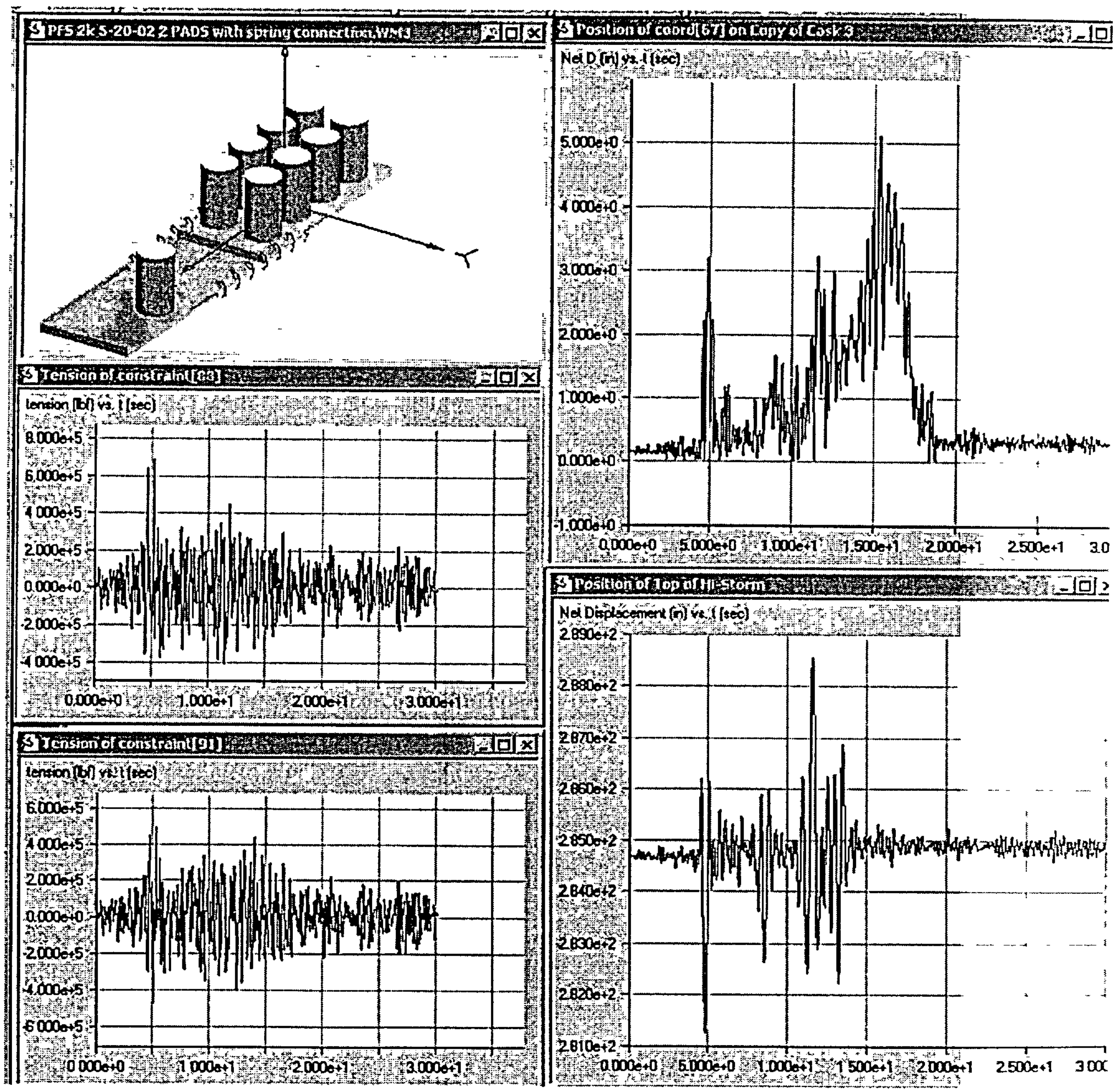


FIGURE 6 – VN Results for Two Unequally Loaded Pads – Elastic Soil With Tension/Compression Springs Simulating Soil Cement Layer

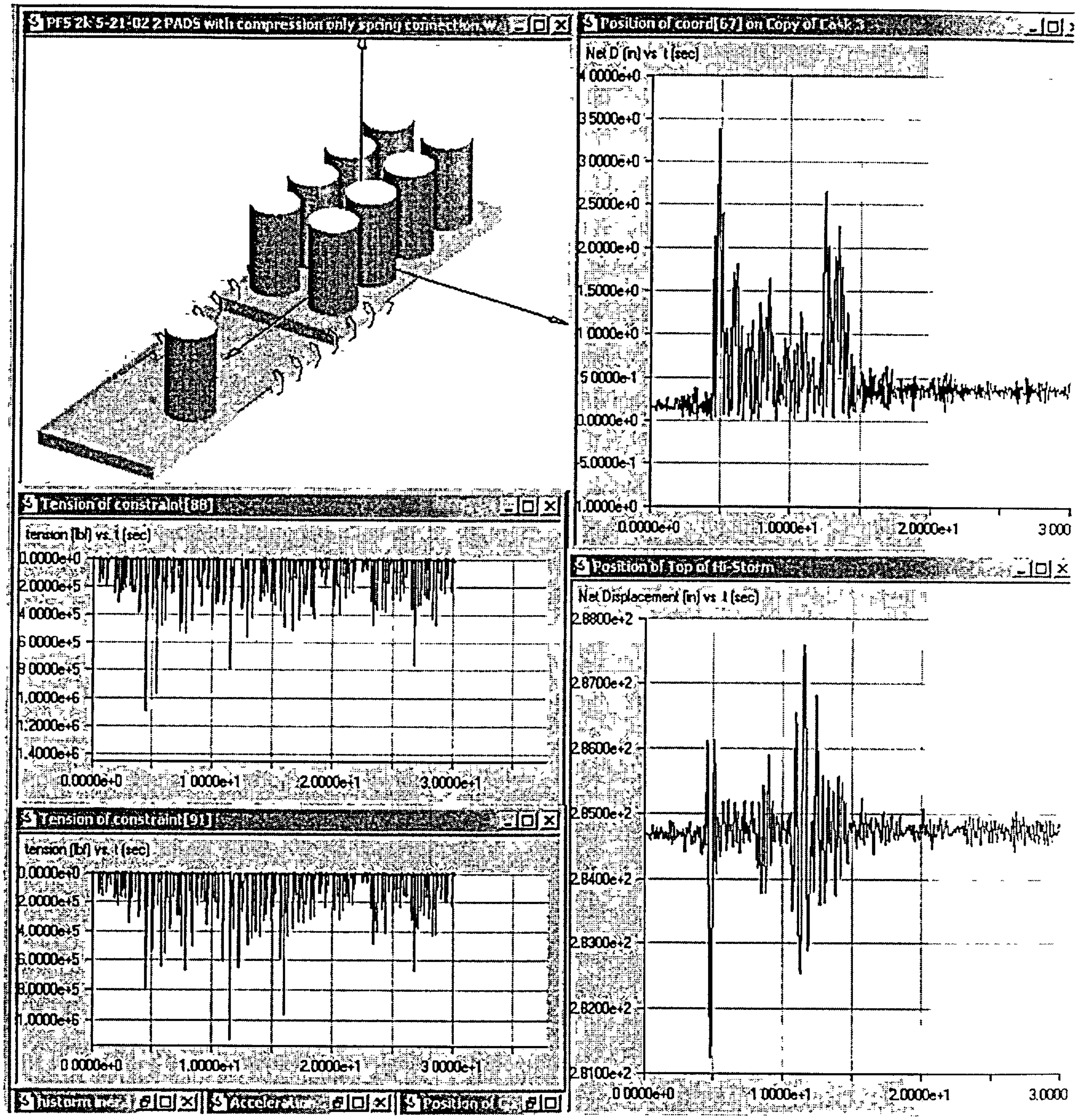


FIGURE 7 - VN Results For Two Unequally Loaded Pads – Soil Cement Between Pads Has Compression Only Resistance form Soil Cement

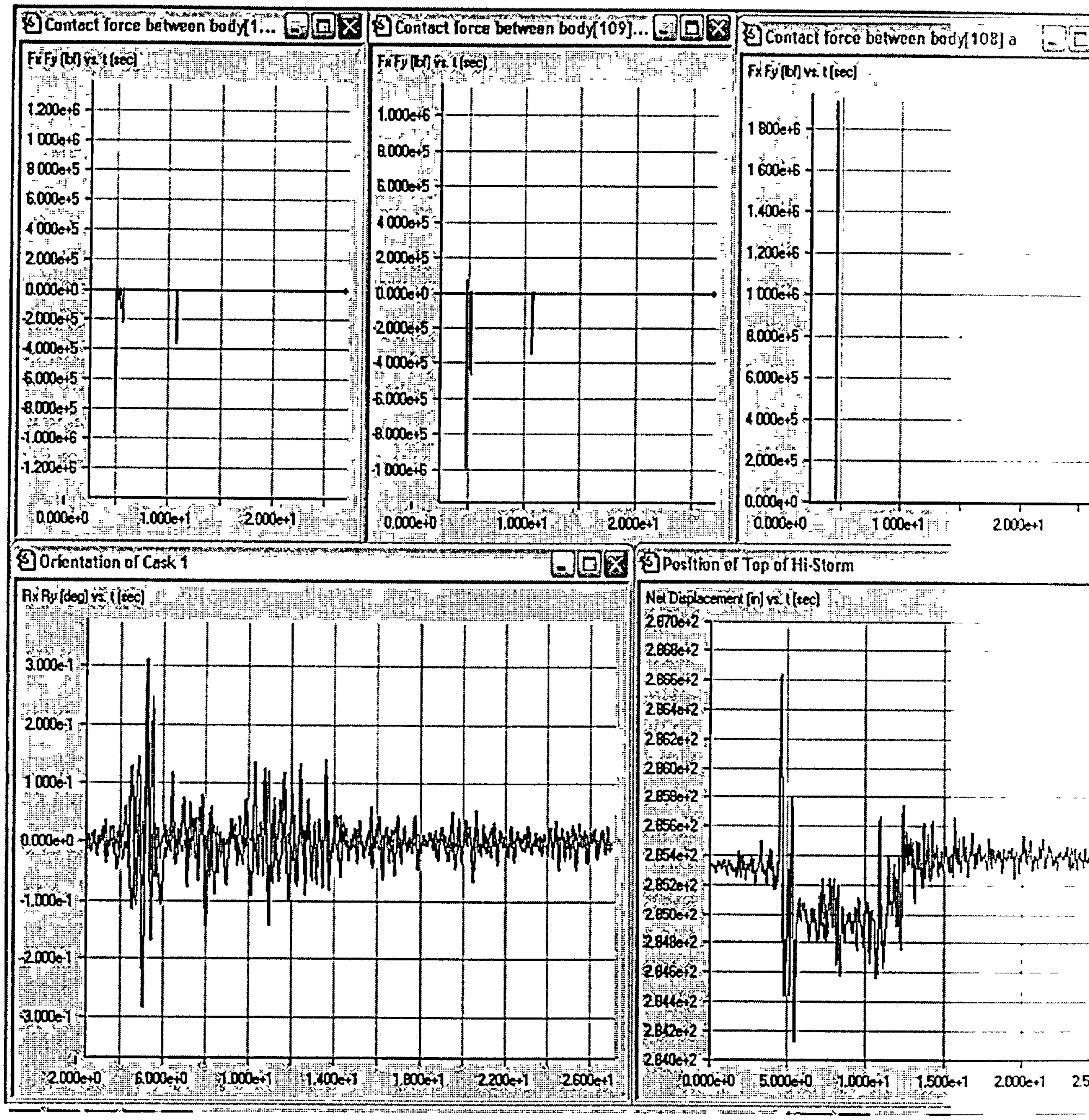


FIGURE 8 - VN Results for Cask 1 From Analysis of Sliding Pad Surrounded by Soil Cement with a 0.6" Gap

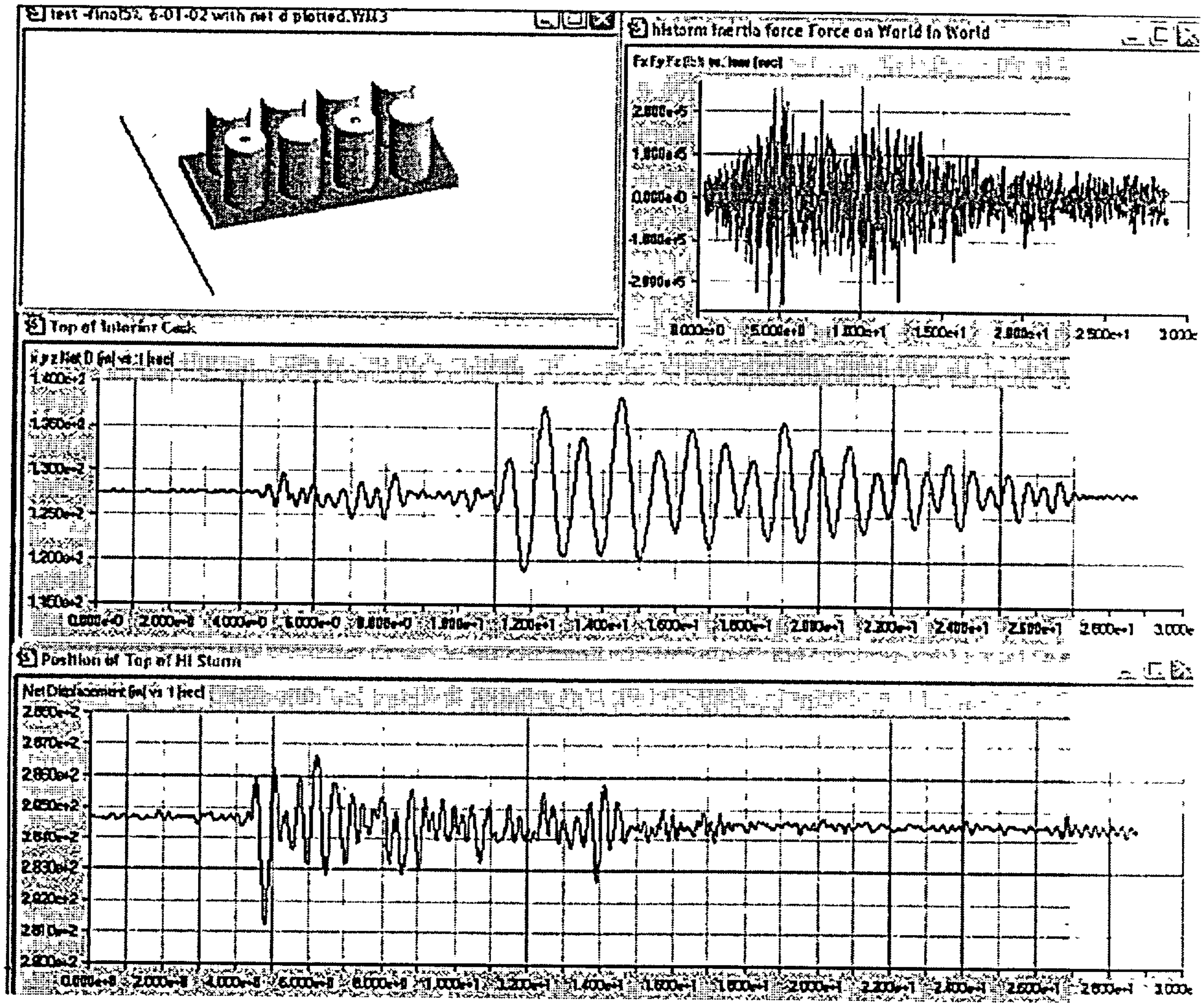


FIGURE 9 - VN Results for Cask 1, 8 Casks on Pad, COF=0.8, Lower Bound Soil Stiffness, 2k Seismic Event, Cask-to-Pad Contact Stiffness and Damping: 40,kpi, 4.9% Critical Damping

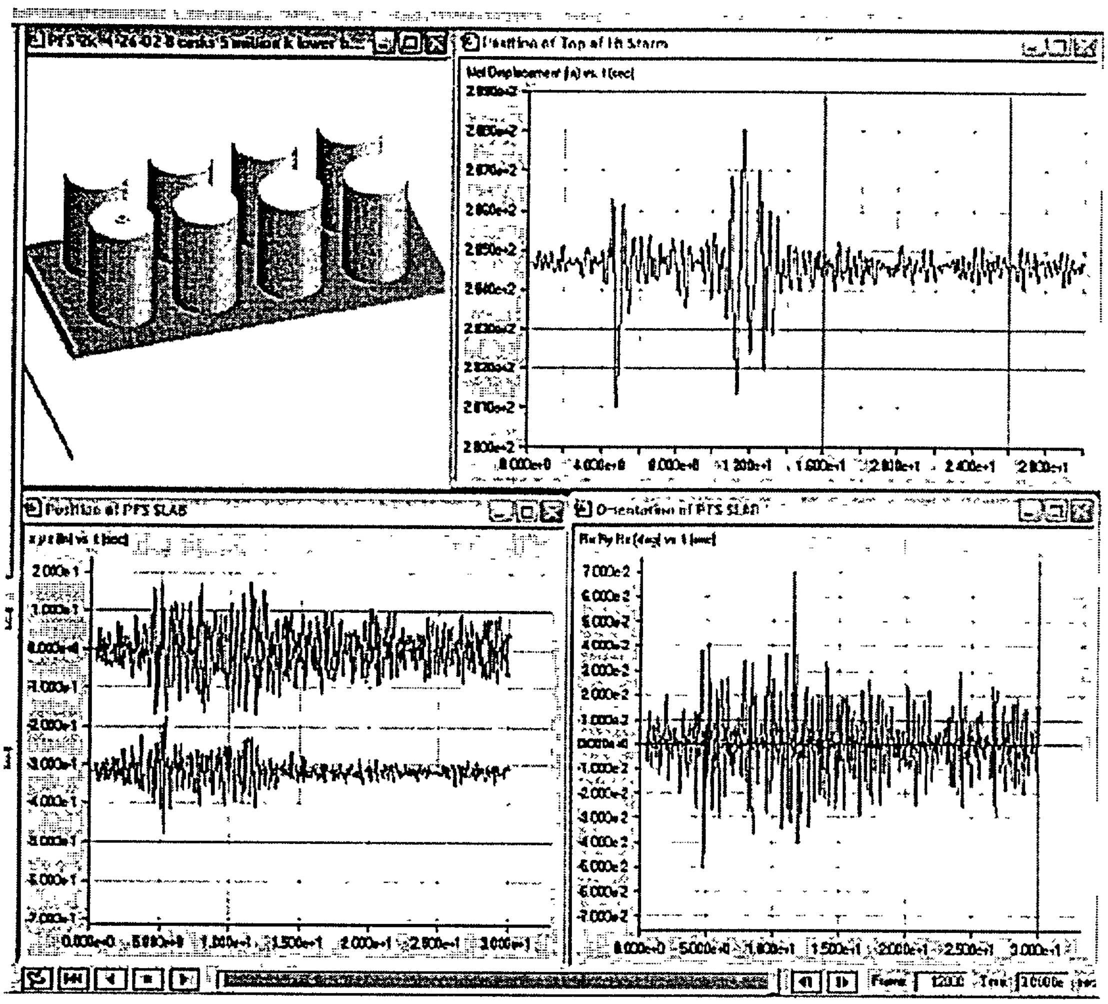


FIGURE 10 - VN Results for Cask 1, 8 Casks on Pad, COF=0.8, Lower Bound Soil Stiffness, 2k Seismic Event, Cask-to-Pad Contact Stiffness and Damping: 4,760 kpi, 40% Critical Damping

12. APPENDICES

Appendix A – Supporting Calculations

Appendix B – Approved Computer Program List (4 pages)

APPENDIX A - Supporting Calculations

Calculations Supporting Key Issue #1

Computation of Parameters for Kahn Simulation

Total Stiffness (vertical)

$K_t := 1000000 \frac{lbf}{in}$

PerCent Critical Damping

$\zeta := .01$

$W := 360000\ lbf$

Number of Contact Locations $n := 8$

At each of eight contact interfaces between sphere and ground, stiffness and dampers are:

$k_t := \frac{K_t}{n}$ $k_t = 1.25 \times 10^5 \frac{lbf}{in}$ $c := \frac{1}{n} \cdot \zeta \cdot \left(2 \cdot \sqrt{\frac{W}{g} \cdot K_t} \right)$ $c = 76.339\, lbf \cdot \frac{sec}{in}$

Calculations Supporting Key Issue #2

Calculation of Soil Cement Spring Stiffness Between Adjacent Pads - 2 pad analysis

$E := 1000000\ psi$ Young's Modulus (Per S&W e-mail)

$L := 5\ ft$ Span Between Pads PFSF TSAR

$A := 28\ in \cdot 30\ ft$ $K := 1. \cdot E \dfrac{A}{L}$ $K = 1.68 \times 10^{8} \dfrac{lbf}{in}$

$\zeta := .00000825$ $\beta := \dfrac{\zeta}{\pi\ 33 \cdot Hz}$ $\beta = 7.958 \times 10^{-8} s$ Negligible Damping Assumed!!

$c := \beta \cdot K$ $c = 13.369 lbf \dfrac{sec}{in}$ $c = 5.162 \times 10^{3} \dfrac{lb}{sec}$

Calculations -1 pad surrounded by soil cement

2k Event

Vertical stiffness pad-to-ground

There are eight contact elements identified by embedded spheres under the center of each cask

$n := 8$

The vertical stiffness and damping associated with the soil is:

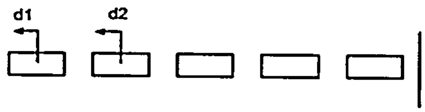
$K_V := 1.204 \cdot 10^{7} \cdot \dfrac{lbf}{in}$ $C_V := 1.727 \cdot 10^{8} \cdot \dfrac{lb}{sec}$

Therefore the individual contact stiffnesses and dampers are:

$k_V := \dfrac{K_V}{n}$ $k_V = 1.505 \times 10^{6} \dfrac{lbf}{in}$

$c_V := \dfrac{C_V}{n}$ $c_V = 5.591 \times 10^{4} lbf \cdot \dfrac{sec}{in}$

The spring rates for the lateral resistance from the soil cement are computed based on the assumption that pads are completely out of phase over the length of 10 pads



$$d_1 - d_5 := F\cdot\left(\frac{1}{k}+\frac{1}{k}+\frac{1}{k}+\frac{1}{k}\right)$$

Therefore, the effective resistance from the intervening soil cement is 25% of the value associated with the soil cement between each pad

$E_{sc} := 1000000\cdot psi$ ref letter from Stone and Webster
(see attachment at end of this appendix)

The span between pads and the frontal area are $A_1 := 30\ ft\cdot 2.33\cdot ft$ $L_1 := 5\cdot ft$

There will be two contact elements along the edge; therefore,

$$K_1 := \left(\frac{E_{sc}\cdot A_1}{L_1}\right)\cdot .25\cdot\left(\frac{1}{2}\right) \qquad K_1 = 2.097\times 10^{7}\ \frac{lbf}{in}$$

In the other direction, $A_1 := 67\cdot ft\cdot 2.33\cdot ft$ $L_1 := 35\cdot ft$

There will be two contact elements along the edge; therefore,

$$K_s := \left(\frac{E_{sc}\cdot A_1}{L_1}\right)\cdot .25\left(\frac{1}{2}\right) \qquad K_s = 6.69\times 10^{6}\ \frac{lbf}{in}$$

Base damping at each location on 5% @ 10Hz Here, use a more reasonable value for damping

$$z := \frac{0.05\ sec}{\pi\cdot 10} \qquad z = 1.592\times 10^{-3}\ s$$

$$C_1 := z\cdot K_1 \qquad C_1 = 3.337\times 10^{4}\ lbf\cdot\frac{sec}{in}$$

$$C_s := z\cdot K_s \qquad C_s = 1.065\times 10^{4}\ lbf\cdot\frac{sec}{in}$$

Results from Classical 2-DOF Linear Vibration Analysis

$K_{soil} := 9.512 \cdot 10^6 \cdot \frac{lbf}{in}$ Ref. App. D, HI-2022854

If adjacent pads are moving out of phase with pad under study, then the intervening soil cement between pads acts as a stiff spring. The spring constant is computed as follows:

$L := 5 \cdot ft$ $E := 1000000\ psi$ Ref. dynamic modulus per e-mail from S&W

$A := 28 \cdot in \cdot 30 \cdot ft$ $k_{int} := E \cdot \frac{A}{L}$ $k_{int} = 1.68 \times 10^8 \frac{lbf}{in}$

CASE 1 - 1 cask on pad 1, 8 casks on pad 2

$W_1 := 1 \cdot 360000 \cdot lbf + 934000\ lbf$ $W_1 = 1.294 \times 10^6\ lbf$

$W_2 := 8 \cdot 360000\ lbf + 934000\ lbf$ $W_2 = 3.814 \times 10^6\ lbf$

Calculate roots of quadratic equation governing eigenvalue problem

$b := \frac{(W_1 + W_2)}{W_1 \cdot W_2} \cdot (K_{soil} + k_{int}) \cdot g$ $b = 7.093 \times 10^4 \frac{1}{s^2}$

$c := \frac{g^2}{W_1 \cdot W_2} \cdot \left[(K_{soil} + k_{int})^2 - k_{int}^2\right]$ $c = 9.926 \times 10^7 \frac{1}{s^4}$

$Z := \left(1 - 4 \frac{c}{b^2}\right)^{.5}$ $Z = 0.96$ $X_1 := .5\ b \cdot (1 - Z)$ $X_2 := .5 \cdot b \cdot (1 + Z)$

$f_1 := \frac{\sqrt{X_1}}{2 \cdot \pi}$ $f_1 = 6.015\,Hz$ $f_2 := \frac{\sqrt{X_2}}{2 \cdot \pi}$ $f_2 = 41.959\,Hz$

CASE 2 pad #1 is empty, pad #2 has 8 casks

$W_1 := 0\ 360000\ lbf + 934000\ lbf$ $W_1 = 9.34 \times 10^5\ lbf$

$W_2 := 8\ 360000 \cdot lbf + 934000\ lbf$ $W_2 = 3.814 \times 10^6\ lbf$

$b := \frac{(W_1 + W_2)}{W_1 \cdot W_2} \cdot (K_{soil} + k_{int}) \cdot g$ $\quad b = 9.135 \times 10^4 \frac{1}{s^2}$

$c := \frac{g^2}{W_1 \cdot W_2} \cdot \left[(K_{soil} + k_{int})^2 - k_{int}^2\right]$ $\quad c = 1.375 \times 10^8 \frac{1}{s^4}$

$Z := \left(1 - 4\frac{c}{b^2}\right)^{.5}$ $\quad Z = 0.966$ $\quad X_1 := .5 \cdot b \cdot (1 - Z)$ $\quad X_2 := .5 \cdot b \cdot (1 + Z)$

$f_1 := \frac{\sqrt{X_1}}{2 \cdot \pi}$ $\quad f_1 = 6.228\,\text{Hz}$ $\quad f_2 := \frac{\sqrt{X_2}}{2 \cdot \pi}$ $\quad f_2 = 47.698\,\text{Hz}$

CASE 3 Both pads have 8 loaded casks

$W_1 := 8 \cdot 360000\,\text{lbf} + 934000 \cdot \text{lbf}$ $\quad W_1 = 3.814 \times 10^6\,\text{lbf}$

$W_2 := 8 \cdot 360000 \cdot \text{lbf} + 934000 \cdot \text{lbf}$ $\quad W_2 = 3.814 \times 10^6\,\text{lbf}$

$b := \frac{(W_1 + W_2)}{W_1 \cdot W_2} \cdot (K_{soil} + k_{int}) \cdot g$ $\quad b = 3.594 \times 10^4 \frac{1}{s^2}$

$c := \frac{g^2}{W_1 \cdot W_2} \cdot \left[(K_{soil} + k_{int})^2 - k_{int}^2\right]$ $\quad c = 3.368 \times 10^7 \frac{1}{s^4}$

$Z := \left(1 - 4 \cdot \frac{c}{b^2}\right)^{.5}$ $\quad Z = 0.946$ $\quad X_1 := .5 \cdot b \cdot (1 - Z)$ $\quad X_2 := .5 \cdot b \cdot (1 + Z)$

$f_1 := \frac{\sqrt{X_1}}{2 \cdot \pi}$ $\quad f_1 = 4.939\,\text{Hz}$ $\quad f_2 := \frac{\sqrt{X_2}}{2 \cdot \pi}$ $\quad f_2 = 29.765\,\text{Hz}$

ATTACHMENT - e-mail from S&W with soil cement recommendations

Subject: PFSF: Profile & Moduli of Elasticities for Holtec's Tipover Analyses Including Soil Cement
To: alan_soler@holtec.com Cc: dlnm01@nspco.com X-Mailer. Lotus Notes Release 5.0.9
November 16, 2001 From: Paul Gaukler@shawpittman com Date: Thu, 25 Apr 2002 14:10 35 -0400
X-MIMETrack: Serialize by Router on DCSMTP1/ShawPittman(Release 5.0.9a |January 7, 2002) at 04/25/2002 02:10.40 PM
Thanks.
Paul Gaukler
ShawPittman LLP
Phone: 202-663-8304
Fax: 202-663-8007
---- Forwarded by Paul Gaukler/SPPT/US on 04/25/2002 02.10 PM ----
paul.trudeau@swe
c.com To. alan_soler@holtec.com
cc: Paul_Gaukler@shawpittman.com, Jerry.Cooper@swec com, thomas.chang@swec.com
03/21/2002 12:16 Subject. PFSF: Profile & Moduli of Elasticities for Holtec's Tipover Analyses
PM Including Soil Cement

Alan,
We've reviewed the modulus of elasticity value applicable for the soil
cement
adjacent to the cask storage pads for use in developing a response to the
State's comments regarding banging of the pads into the soil cement The
email
I sent you on March 2, 2001 (copy below) provided a value of the static
modulus
of elasticity for soil cement (w/unconfined compressive strength of at
least 250
psi) of 350,000 psi. I believe that this number is reasonable for the
large
strains we anticipated in your cask tipover analysis. For the proposed
analysis
of the pad impacting the soil cement, we discussed using a dynamic modulus,
rather than the static or large-strain modulus, to be conservative. I
expect
that for the small strains applicable for the dynamic modulus, this value
should
be two to three times greater than this; therefore, I recommend using an
eleastic modulus value of 1 x 10(superscript: 6) psi for this analysis. If
your
analysis concludes that the strains in the soil cement are comparable to
those
in the vicinity of impact from your tipover analysis, then we can back off
on
this modulus value if necessary.
Paul
---------------- Forwarded by Paul Trudeau/Transportation/SWEC on
03/21/2002 12.02 PM ----------------
From: Paul Trudeau on 03/02/2001 04:19 PM
To: alan_soler@holtec.com

cc: brian_gutherman@holtec.com, max.m.delong@nspco.com, Jerry
Cooper/Mechanical/SWEC@SWEC, John Donnell/Power/SWEC@SWEC,
pjtrudeau@adelphia.net
Subject: PFSF: Profile & Moduli of Elasticities for Holtec's Tipover
Analyses
Including Soil Cement
Alan,
Our best-estimate of the static modulus of elasticity (E(subscript: s)) of
the
soil cement is 350,000 psi, the density is assumed to be 105 pcf, and
Poisson's
ratio is assumed to be ~0.2. We expect to have a minimum of 1 ft of soil
cement
under each of the pads and as much as 4.5 ft under some of the pads. To
account
for potential variations in the field, we feel it is prudent to perform
these
analyses using at least 5 ft of soil cement under the pads. Also note,
that
this maximum amount can be reduced by any increase in the thickness of the
pads
above the present 3 ft thickness. In this case, however, we still need to
provide at least 1 ft of soil cement under all of the pads because of
statements
we made to that effect in the SAR.
The underlying silty clay/clayey silt layers have a cumulative thickness of
~23
ft and are expected to have E(subscript: s) values that do not exceed 6,000
psi,
based on values reported for similar soils in Table 13 of NUREG/CR-6608.
The
average density for these soils is ~91 pcf. Similarly, the underlying
silty
sand/sandy silt layer has a thickness of ~ 7 ft, an estimated E(subscript:
s) of
~12,000 psi, an assumed density of 115 pcf, and Poisson's ratio is assumed
to be
~0.3. The underlying soils are comprised of sands that are very dense (SPT
N-values typically exceed 100 blows/ft); therefore, we have labeled this an
incompressible base for the cask tipover analyses.
I do not believe that your analysis is very sensitive to density values.
We do
not have a good value for the density of the soil cement yet. Therefore,
if you
will be specifying the value used as a not-to-exceed-value, please use
densities
of 125 pcf for the soil cement and the in situ soils.
Note: If this value of E(subscript: s) for the soil cement works out OK,
please
also increase the E(subscript: s) value for the underlying soils to
determine
how sensitive your analysis is to E(subscript: s). If we can demonstrate

how sensitive your analysis is to E(subscript. s). If we can demonstrate that E
(subscript. s) can exceed these values by a wide margin, then we will have less
need to test these soils in the field to demonstrate that we do not exceed the
specified limit(s).

You can reach me at home this weekend. 508-747-0394 or email to:
pjtrudeau@adelphia.net

Generalized profile: (See attached file: Holtec-1.PDF)

Thanks,

Paul J. Trudeau

Lead Geotechncial Engineer - PFSF

(See attached file: Holtec-1.PDF)

HOLTEC APPROVED COMPUTER PROGRAM LIST

(Total No. Of Pages = 4)

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 46 April 9, 2002	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
ANSYS (A)	5.3, 5.4, 5.6,5.6.2,5.7	JZ, EBR, PKC, CWB, SPA, AIS, IR, SP, JRT	Windows		
AC-XPERT	1.12		Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ELR, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13 04.	
CASMO-3 (A)	4.4, 4.7	ELR, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PKC, CWB, AIS, SP,JRT	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PKC, SJ	DOS/Windows		
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST **REV. 46**

April 9, 2002

PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
FLUENT (A)	4.32, 4.48, 4.56, 5.1 (see error notice), 4.2.8 (UNS),5.5	EBR, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ELR, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950	JZ, AIS, SPA, SP	Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ELR, SPA, KC, ST, DMM,VJB	Windows/ UNIX		
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PKC, SJ,JRT	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4		Windows	V. 6.4 aka VN 2001 R2	X (6.4)
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGEN	2.1		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0, 2.0		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PSD1	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST **REV. 46**

April 9, 2002

PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
QAD	CGGP		Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		
SOLIDWORKS	2001		DOS/Windows	Only Weight and Volume calculated using this program can be used as input to other evaluations. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 46 April 9, 2002	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:
1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

NUCLEAR REGULATORY COMMISSION

Docket No. ______ Official Exh. No. 225

In the matter of ______

Staff ______ IDENTIFIED ✓

Applicant ✓ RECEIVED ______

Intervenor ______ REJECTED ______

Other ______ WITHDRAWN ______

DATE 060802 Witness Soler

Clerk SMS

replaces old 225