HOLTEC INTERNATIONAL

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# MULTI-CASK SEISMIC RESPONSE AT THE PFS ISFSI

for

## PRIVATE FUEL STORAGE L.L.C.

**Holtec Report No.: HI-971631**

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# REVIEW AND CERTIFICATION LOG

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# EXECUTIVE SUMMARY

The Private Storage Facility (PSF) contains over 4000 dry storage casks configured as a series of 2 x 4 cask arrays on individual ISFSI concrete pads. The current proposed array allots a 15' x 15' pad space to each spent fuel storage cask. In this analysis, the final three dimensional (3-D) time history set is applied to an array of casks on a 30' x 64' x 3' concrete pad (at each long end of the pad, an additional 2' of concrete is present). The cask system weight and dimensions are those of the HI-STORM 100. The purpose of the analyses contained herein is to establish the stability of the cask-pad system under the postulated dynamic acceleration seismic event for limiting arrays of storage casks.

It is concluded, based on the dynamic simulations performed with the design basis seismic event, using the soil data underlying the storage pad that:

The HI-STORM-100 system meets the requirements of dynamic stability with considerable margin of safety against tip-over.

No cask-to-cask impact are indicated in any of the simulations; the cask motions are generally in-phase with each other.

The results of the simulations herein suggest that the most significant rocking motions of the cask(s) under high coefficients of friction will occur when the pad does not have a full complement of casks.

The interface forces produced by between cask and pad during any of the simulations are bounded by the design basis G levels for the HI-STORM system.

The sliding excursion (under a coefficient of friction = 0.2) of HI-STORM is generally larger than the excursion of the top center-point of the cask (under a coefficient of friction = 0.8) except for the case of a “lightly loaded” pad (a single cask located at a pad corner).

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## 1.0 INTRODUCTION

The Private Storage Facility (PSF) contains over 4000 dry storage casks configured as a series of 2 x 4 cask arrays on individual ISFSI concrete pads. The current proposed array allots a 15' x 15' pad space to each spent fuel storage cask. In this analysis, the final three dimensional (3-D) time history set is applied to an array of casks on a 30' x 64' x 3' concrete pad (at each long end of the pad, an additional 2' of concrete is present). The cask system weight and dimensions are those of the HI-STORM 100. The purpose of the analyses contained herein is to establish the stability of the cask-pad system under the postulated dynamic acceleration seismic event for limiting arrays of storage casks. The HI-STORM system consists of a free standing concrete/steel cylindrical overpack and a free standing MPC containing fuel assemblies which is placed inside of the overpack. There will be one to eight casks on the pad being simulated; all casks on the pad are assumed fully loaded with a maximum weight MPC.

## 2.0 METHODOLOGY

The array of casks (overpack plus internal MPC loaded with fuel) is treated as a system of free standing rigid bodies resting on a concrete pad which is connected to the ground by a series of soil springs and dampers and has virtual soil mass moving with the pad. The dynamic system model includes compression only gap elements to simulate the potential for impact between casks and between each MPC and its surrounding overpack. The contact surfaces between casks and the pad are also modeled by compression only elements together with piecewise linear elements simulating frictional characteristics. A development of the equations of motion is provided in Attachment A for reference. The system is subjected to three seismic time histories which are developed from the site specific response spectra.

## 3.0 ACCEPTANCE CRITERIA

The array of casks must be shown to be stable in the sense that the center of the top cover of the cask must remain within the original contact circle that the cask makes with the pad. This criteria assures that the casks will not slide excessively, nor will they tip over. It is also required to demonstrate that the casks will not impact adjacent casks during the seismic event.

## 4.0 ASSUMPTIONS AND MODELING OF THE CASK / PAD SIMULATION

Each HI-STORM cask system is modeled as a two body system. Each overpack is described by six degrees of freedom which capture the rigid body motion of the overpack in inertial space. Within each overpack, the internal MPC is modeled by an additional five degrees of freedom sufficient to capture all but the rotational motion of the MPC about its own longitudinal axis. There is no loss of generality in this five degree of freedom system since there is no interest in the omitted rotational degree of freedom. The dynamic model of each of the HI-STORM casks, therefore, has eleven degrees of freedom so that eighty-eight (88) degrees of freedom are used to simulate the assemblage of casks for the case when the pad is assumed fully populated. Finally, to complete the model, six degrees of freedom establish the rigid body motion of the ISFSI pad relative to inertial space.

The degrees of freedom describing cask J (J = 1,2,...8) are numbered as follows:

Let N = (J-1) x 11 = the last degree of freedom number assigned to the previous cask. Then, for the HI-STORM overpack associated with cask J, the numbering associated with the 6 degree of freedom system constituting cask J is in accordance with the following definitions:

$q_{N+1}$ = absolute displacement of overpack centroid in x (horizontal)

$q_{N+2}$ = absolute displacement of overpack centroid in y (horizontal)

$q_{N+3}$ = absolute displacement of overpack centroid in z (vertical)

$q_{N+4}$ = rotation of overpack about centroidal axis parallel to x direction.

$q_{N+5}$ = rotation of overpack about centroidal axis parallel to y direction.

$q_{N+6}$ = rotation of overpack about vertical z axis through centroid.

Five degrees of freedom are associated with the rigid body motion of the MPC plus contents contained within the overpack.

$q_{N+7}$ = absolute displacement of MPC centroid in x.

$q_{N+8}$ = absolute displacement of MPC centroid in y.

$q_{N+9}$ = absolute displacement of MPC centroid in z.

$q_{N+10}$ = rotation of MPC about centroidal axis parallel to x direction.

$q_{N+11}$ = rotation of MPC about centroidal axis parallel to y direction.

The characteristics of the pad are based on the assumption that the 30' x 64' section responds to seismic excitation as a rigid body; this assumption has been based on the recommendation of the project architect and engineering group responsible for the ISFSI design of the PSF facility. If M denotes the last degree of freedom number for the assemblage of casks on the pad in the current simulation, then the dynamic model simulating concrete pad behavior is characterized by the 6 degrees of freedom $q_{M+1}$ to $q_{M+6}$ with

$q_{M+1}, q_{M+2}, q_{M+3}$ = absolute displacements in x, y and z directions of pad centroid, respectively.

$q_{M+4}, q_{M+5}, q_{M+6}$ = rotations about axes through pad centroid parallel to x, y, z axes, respectively.

Note that in all of the analyses, the global X axis of the pad and each cask is parallel to the short side of the pad, the global Y axis of the pad and each cask is parallel to the long side of the pad, and, the global Z axis is vertical.

Figure 4.1 shows an exploded view of the HI-STORM dynamic model with all degrees of freedom included for a single cask. This model is identical to the model used to investigate seismic stability in the Holtec TSAR [1]. A development of the equations of motion for a single cask/MPC system has been provided in [2]; for completeness of this report, the equations of motion are also included here as Attachment A. The equations used here are essentially identical to the set developed in Attachment A except that multiple casks are modeled here and the casks are coupled to one another through their contact with the pad. The change in length of the compression only elements simulating this contact are functions of the degrees of freedom of the cask and the motion of the underlying pad. The system is characterized by the aforementioned degrees of freedom, by the mass and inertia properties of the component parts, and by the springs (linear and non-linear) which are used to characterize contact and friction between components and to characterize underlying pad base-mat properties.

## 5.0 INPUT DATA

### 5.1 Seismic Loads

Based on final ground response spectra provided by the PSF architect and engineering group, 3-D time histories (2 horizontal and 1 vertical) have been developed and documented in the latest revision of [3]. These time histories satisfy bounding and statistical independence requirements of the USNRC [4]. The developed time histories are based on spectra data with zero period accelerations (ZPA) = 0.67 (horizontal) and 0.69 (vertical).

### 5.2 Mass and Inertia Properties

The calculation of the MPC mass and inertia properties is based on dimensions and weights from [5]. Of the three possible MPC's, the heaviest unit is chosen for simulation since the response to seismic loading will be increased The heaviest loaded MPC is the MPC-32 with the following characteristics:

weight = 88857 lb. Diameter = 68.375 in. Length = 190.5"

The location of the center of gravity of the MPC, relative to the ISFSI surface is

$$cg_{mpc} = 123.4"$$

The calculation of the HI-STORM overpack is based on the weight specified in the latest Holtec TSAR submittal for Docket Number 72-1008 [1]; the following values are used:

weight = 267664 lb. Outer Diameter = 132.5" Length = 231.25"
Inner Diameter = 73.5"

The location of the center of gravity of the HI-STORM overpack, relative to the ISFSI surface, is

$$cg_{ovp} = 116.3"$$

In [4], for calculation of mass moments of inertia, the overpack is considered as a hollow cylinder; and the MPC plus contents is considered as a solid cylinder whose mass, diameter, and length are known.

The ISFSI pad section modeled assumes a concrete weight density of

150 lb./cu. ft.

in the calculation of ISFSI pad mass and mass moments of inertia.
Appendix B contains details of the calculations of the overpack and MPC mass and inertia properties used in the dynamic analysis.

## 5.3 Spring Constants

Interface spring constants are developed for the overpack-to-concrete pad piecewise linear compression only contact springs and for the associated friction springs at the contact locations. Spring constants are also developed to simulate the contact stiffness between the MPC and the overpack cavity which comes into play during internal impact. Finally, the appropriate soil spring constants are developed to reflect the characterization of the underlying base mat supporting the concrete pad. The soil springs are developed for a characteristic pad section of 30' x 64' ; the deformations for the assumed rigid ISFSI pad are all computed in terms of the six degrees of freedom associated with the centroid of the pad. The soil springs are assumed to be applied at the pad-soil interface.

For overpack-to-concrete pad stiffness, the elastic spring rate based on the solution for a rigid punch on a semi-infinite half space is used [6]. The resulting spring constant is assigned to compression only springs which are distributed around the periphery of the circular contact patch to reflect the fact that the classical solution predicts that the major contribution to punch indentation is, in fact, around the periphery of the punch. The value used in this analysis, assuming a contact location at every 10 degrees around the outer circumference, is

$$k = 12610000 \text{ lb./in.}$$

and a value 1000 times larger is used to simulate the interface behavior, prior to slip, of the piecewise linear friction spring elements in each of two horizontal directions at each of the thirty six contact locations for each spent fuel cask on the pad.

The local contact stiffness reflecting impact sites between MPC and overpack are calculated based on classical surface to surface contact problems and reflect the values of the adjacent material properties. For these dynamic analyses, the following contact stiffness values are used to reflect local stiffness between MPC and overpack at a potential contact location:

| | |
|---|---|
| MPC-to-overpack at base | K1 = 234300000 lb./in. |
| MPC shell-to-overpack inside shell - | K2 = 3292000 lb./in. |

To reflect the underlying base mat elastic behavior, soil modulus data appropriate to a high strain environment in the soil has been obtained by the

PSF architect and engineering group. The soil data transmitted to Holtec is used to determine horizontal, vertical, rocking, and torsion spring rates for the soil using equations presented in [7]. Appropriate soil damping values are also calculated as well as soil mass and inertia properties. The soil Young's Modulus, shear modulus, and Poisson's Ratio used to obtain the spring rates are[8]:

E = 1915000 lb./sq. ft.

G = 668000 lb./sq. ft.

$\nu$ = 0.433

Using the cited reference [7], the following soil spring rates, acting at the base of the concrete pad, directly under the pad centroid, are calculated. The soil spring rate generalized extension rates are all expressible in terms of the six degrees of freedom assigned to the pad centroid. The following spring rates are assigned based on the latest soil data provided.

Kv = 9679000 lb./in. (vertical)

Khs = 6990720 lb./in. (horizontal-x)

Khl = 6641190 lb./in. (horizontal-y)

Krs = 1.042E+12 lb.in./radian (rotation about horizontal axis parallel to short side of pad)

Krl = 3.664E+11 lb.-in./radian. (rotation about horizontal axis parallel to long side of pad)

Kt = 8.146E+11 lb.-in./radian (rotation about vertical axis)

The supporting theoretical development and the details of the calculations are presented in Appendix C.

## 6.0 DOCUMENTATION OF COMPUTER CODES

Appendix A presents a list of approved Holtec analysis codes. The Codes used herein are identified.

## 7.0 SEISMIC ANALYSES

### 7.1 Two Dimensional Static Stability of the HI-STORM System

The current HI-STORM geometry has a total height above the pad equal to

$$H=231.25".$$

The diameter of the circular contact interface for each cask is

$$D=132.5"$$

Therefore, to maintain static moment equilibrium at the instant of incipient tipping assuming conservatively that the vertical seismic acceleration of the system opposes the gravitational acceleration (worst case) requires that the net horizontal "G" level be such that

$$G < .571$$

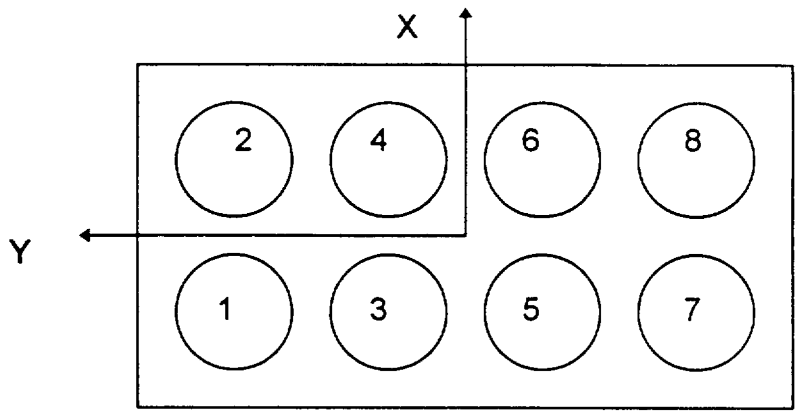
Since the zero period acceleration (ZPA) of the site specific seismic events are greater than this conservatively computed limiting value, incipient tipping analysis is not appropriate to qualify the casks on this site.

### 7.2 Three Dimensional Dynamic Stability of the HI-STORM System

The analyses to follow evaluate the propensity for the cask system to remain stable during a dynamic load event consisting of an appropriate set of seismic time histories. The HI-STORM system is deemed to be dynamically stable if the locus of the point at the center of the cask top remains within the envelope of the original contact shadow on the pad.

Simulations are performed for interface coefficients of friction (between cask base and ISFSI pad) of 0.8 and 0.2 to emphasize either tipping or sliding characteristics. The simulation code which solves the equations of motion is the Holtec QA validated code DYNACASK (called MR216 in Appendix A) which has been used to qualify spent fuel storage casks in the current Holtec TSAR submittals for both metal and concrete storage casks. The results of the time history simulations provide archive data for all displacement and rotation variables, for all contact spring forces, and for all interface friction forces. Therefore, the response of the various cask components and the pad under the postulated seismic event is easily established. For the study herein, results have been obtained for the basic time history inputs (ZPA = 0.67G's horizontal and 0.69G's vertical). The results are summarized in tabular form to show the maximum excursions of the casks on the pad in each simulation and the final position of the casks on the pad. Representative time histories of the cask response are plotted to demonstrate graphically that the HI-STORM system is stable; the locus of the cask top center point displacement remains within the original cask contact patch envelope.

A total of 16 simulations are carried out (one to eight casks on the pad with each case simulated twice with coefficients of friction 0.8 and 0.2, respectively). The following sketch identifies the axes and the cask numbering scheme used in the simulations:




## 8.0 LISTING OF COMPUTER FILES

Appendix E contains a directory listing of all files and codes used for this project. A total of nearly 500 MB of results has been obtained during the course of this project.

## 9.0 RESULTS OF SEISMIC ANALYSES

Tables 9.1 to 9.16 summarize the results obtained for each cask in each of the sixteen simulations. It is seen from perusal of the tabular results for the limiting high coefficient of friction of 0.8, that there is minimal rotation of the cask vertical centerline and very little evidence of any cask edging and rolling on the pad for all cases except the case with a single cask on the pad. The solution for run 108 (Table 9.2) shows a considerably larger to center-point displacement and evidence that the cask edges and rolls to a new position during the seismic event. Nevertheless, the acceptance criteria for the array of casks for all of the cases considered is met with a large margin of safety. For the cases with limiting low coefficient of friction of 0.2, the array of casks exhibit a sliding motion without any propensity to tip; the magnitude of the sliding motion is larger than the excursions observed with the higher coefficient of friction cases (except for the case of a single cask on the pad), but the motion of the entire assemblage is generally in-phase.

No cask-to-cask impacts are observed at any time during any of the simulations. The tables also contain the final position of each cask centroid; there are minor changes in the final position of the casks. It is not expected that these position changes will have any thermal or radiological consequences in the post-earthquake environment.

Figures 9.1 to 9.5 present results from representative cases. Figure 9.1 presents a plot of the vertical interface force vs. time for cask#8 for the case when there are eight fully loaded casks on the pad. The figure shows that there are a few time instants where the cask has tipped up slightly, and then "slaps down" on its full base. At this instant in time, a substantial G load may be produced; a survey of all of the simulations shows that the G forces on the cask (due to vertical or to horizontal contact forces) do not exceed the design basis G levels for the HI-STORM 100 system. Figure 9.2 presents a similar result for the case of a single cask on the pad. The instant of high G level is clearly shown for this cask. Figure 9.3 is a plot of the locus of the top center-point for the case of one cask on the pad. Despite the evidence of considerable rotation of the vertical axis of the cask, Figure 9.3 demonstrates that the stability criterion is met; namely, the locus of the top center point of the HI-STORM system remains within the original 132.5" diameter contact circle envelope on the pad. Figure 9.4 is a plot of the locus of the bottom center-point movement. The scale of the plot is the same as Figure 9.3; the re-location of the bottom center-point is evident The results for cof = 0.8 indicate that there is no propensity for the cask to tip. Finally, Figure 9.5 shows a plot of the net rotation of the vertical axis of cask #1 about the horizontal plane. This result bounds the rotations obtained from any of the other simulations.

For each simulation, the vertical and horizontal interface force time histories have been archived in a form suitable for use as input loading into a structural analysis of the ISFSI pad. These archives are maintained as permanent records associated with this project and have also been transmitted to the ISFSI pad designer for his use. Appendix D is the letter of transmittal which documents the data sent to the ISFSI pad designer.

## 10.0 CONCLUSIONS

It is concluded, based on the dynamic simulations performed with the design basis seismic event, using the soil data underlying the storage pad that:

The HI-STORM-100 system meets the requirements of dynamic stability with considerable margin of safety against tip-over.

No cask-to-cask impact are indicated in any of the simulations; the cask motions are generally in-phase with each other.

The results of the simulations herein suggest that the most significant rocking motions of the cask(s) under high coefficients of friction will occur when the pad does not have a full complement of casks.

The interface forces produced by between cask and pad during any of the simulations are bounded by the design basis G levels for the HI-STORM system.

The sliding excursion (under a coefficient of friction = 0.2) of HI-STORM is generally larger than the excursion of the top center-point of the cask (under a coefficient of friction = 0.8) except for the case of a "lightly loaded" pad (a single cask located at a pad corner).

## 11.0 REFERENCES

[1] HI-951312, Rev.1, HI-STORM 100 TSAR Submittal to USNRC, 1997, Docket #72-1008.

[2] HI-961574, Scoping Analysis of HI-STORM on a Western Area ISFSI, November, 1996.

[3] HI-961556, 3-D Time Histories for Private Storage Facility, Project 60531, Revision 2, April,1997.

[4] NUREG 0800, SRP 3.7.1, USNRC, Rev. 2, August, 1989.

[5] HI-971659, Rev. 0, Calculation Package Supporting HI-STORM 100 TSAR, 1997.

[6] S. Timoshenko and J. Goodier, Theory of Elasticity, Third Edition, McGraw Hill, 1970, pp. 407-409.

[7] AISC Standard, "Seismic Analysis of Safety Related Structures and Commentary.....", Approved by AISC, Sept., 1986, Tables 3300-1 and 2, and Figure 3300-3 (used for springs and damping); Newmark and Rosenblueth, Fundamentals of Earthquake Engineering, Prentice Hall, 1971, p.98 (used for mass computations)

[8] Stone and Webster Letter S-V-119 (3/31/97) which includes a transmittal from Geomatrix Consultants, Inc.

**TABLE 9.1 DISPLACEMENT SUMMARY - RUN 102 -1 CASK, COF=0.2**

NUMBER OF CASKS ON PAD= 1

FILENAME
plotdis.102

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.45956 | AT TIME= | 4.20005 |
| MAXIMUM IN Y(top)= | 2.71281 | AT TIME= | 5.34007 |
| MAXIMUM IN X(bot)= | 1.47915 | AT TIME= | 4.20005 |
| MAXIMUM IN Y(bot)= | 2.68961 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.32112 | AT TIME= | 9.13016 |
| MINIMUM IN Y(top)= | -6.05947 | AT TIME= | 12.2002 |
| MINIMUM IN X(bot)= | -7.29878 | AT TIME= | 9.13016 |
| MINIMUM IN Y(bot)= | -6.07707 | AT TIME= | 12.2002 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.89000 Y(final)= -1.74000

**TABLE 9.2 DISPLACEMENT SUMMARY -RUN 108 - 1 CASK, COF =0.8**

NUMBER OF CASKS ON PAD= 1

FILENAME
plotdis.108

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 12.1340 | AT TIME= | 9.64017 |
| MAXIMUM IN Y(top)= | 10.0258 | AT TIME= | 10.9452 |
| MAXIMUM IN X(bot)= | 3.86571 | AT TIME= | 15.7053 |
| MAXIMUM IN Y(bot)= | 0.121530E-01 | AT TIME= | 6.57510 |
| MINIMUM IN X(top)= | -9.15101 | AT TIME= | 10.3402 |
| MINIMUM IN Y(top)= | -13.0444 | AT TIME= | 10.3152 |
| MINIMUM IN X(bot)= | -0.388124 | AT TIME= | 10.7152 |
| MINIMUM IN Y(bot)= | -5.04300 | AT TIME= | 14.6153 |

FINAL COORDINATES OF CASK CENTROID
X(final)= 3.81000 Y(final)= -4.16000

**TABLE 9.3 DISPLACEMENT SUMMARY - RUN 202 - 2 CASKS, COF=0.2**

NUMBER OF CASKS ON PAD= 2

FILENAME
plotdis.202

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.62714 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.65488 | AT TIME= | 5.34507 |
| MAXIMUM IN X(bot)= | 1.62731 | AT TIME= | 4.17505 |
| MAXIMUM IN Y(bot)= | 2.60673 | AT TIME= | 5.34507 |
| MINIMUM IN X(top)= | -7.34178 | AT TIME= | 9.12516 |
| MINIMUM IN Y(top)= | -5.89902 | AT TIME= | 12.2002 |
| MINIMUM IN X(bot)= | -7.33692 | AT TIME= | 9.12516 |
| MINIMUM IN Y(bot)= | -5.93570 | AT TIME= | 12.2102 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.72000 Y(final)= -1.34000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.60096 | AT TIME= | 4.21505 |
| MAXIMUM IN Y(top)= | 2.48251 | AT TIME= | 5.34007 |
| MAXIMUM IN X(bot)= | 1.60199 | AT TIME= | 4.21505 |
| MAXIMUM IN Y(bot)= | 2.43580 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.67343 | AT TIME= | 9.13016 |
| MINIMUM IN Y(top)= | -6.14411 | AT TIME= | 12.2202 |
| MINIMUM IN X(bot)= | -7.67010 | AT TIME= | 9.14016 |
| MINIMUM IN Y(bot)= | -6.18278 | AT TIME= | 12.2202 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.25000 Y(final)= -1.51000

TABLE 9.4 DISPLACEMENT SUMMARY - RUN 208 - 2 CASKS, COF=0.8

NUMBER OF CASKS ON PAD= 2

FILENAME
plotdisd.208

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.77840 | AT TIME= | 8.08014 |
| MAXIMUM IN Y(top)= | 2.73249 | AT TIME= | 8.13014 |
| MAXIMUM IN X(bot)= | 0.127954 | AT TIME= | 8.03014 |
| MAXIMUM IN Y(bot)= | 0.170748 | AT TIME= | 9.13016 |
| MINIMUM IN X(top)= | -0.775093 | AT TIME= | 12.9402 |
| MINIMUM IN Y(top)= | -0.831033 | AT TIME= | 7.84513 |
| MINIMUM IN X(bot)= | -0.355282 | AT TIME= | 9.12516 |
| MINIMUM IN Y(bot)= | -0.806600E-01 | AT TIME= | 8.03514 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.296000 Y(final)= 0.141000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.74897 | AT TIME= | 8.07514 |
| MAXIMUM IN Y(top)= | 2.56177 | AT TIME= | 8.13014 |
| MAXIMUM IN X(bot)= | 0.822012E-01 | AT TIME= | 8.02014 |
| MAXIMUM IN Y(bot)= | 0.353202 | AT TIME= | 15.7003 |
| MINIMUM IN X(top)= | -0.912659 | AT TIME= | 9.75018 |
| MINIMUM IN Y(top)= | -0.756183 | AT TIME= | 8.37514 |
| MINIMUM IN X(bot)= | -0.490722 | AT TIME= | 9.12516 |
| MINIMUM IN Y(bot)= | -0.645480E-01 | AT TIME= | 8.03514 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.417000 Y(final)= 0.374000

TABLE 9.5 DISPLACEMENT SUMMARY - RUN 302 - 3 CASKS, COF = 0.2

NUMBER OF CASKS ON PAD= 3

FILENAME
plotdis.302

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.79817 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.45020 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 1.81552 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.39487 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.39852 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -6.04320 | AT TIME= | 12.0552 |
| MINIMUM IN X(bot)= | -7.36935 | AT TIME= | 9.13516 |
| MINIMUM IN Y(bot)= | -6.08476 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID

X(final)= -1.63000 Y(final)= -1.30000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.67817 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.41149 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 1.69552 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.35616 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.87486 | AT TIME= | 9.14016 |
| MINIMUM IN Y(top)= | -5.93607 | AT TIME= | 12.2152 |
| MINIMUM IN X(bot)= | -7.84569 | AT TIME= | 9.14016 |
| MINIMUM IN Y(bot)= | -5.97960 | AT TIME= | 12.2152 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.51000 Y(final)= -1.20000

RESULTS FOR CASK NUMBER 3

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.65030 | AT TIME= | 4.19505 |
| MAXIMUM IN Y(top)= | 2.62494 | AT TIME= | 5.34507 |
| MAXIMUM IN X(bot)= | 1.66863 | AT TIME= | 4.20505 |
| MAXIMUM IN Y(bot)= | 2.56775 | AT TIME= | 5.34507 |
| MINIMUM IN X(top)= | -7.49187 | AT TIME= | 9.14016 |
| MINIMUM IN Y(top)= | -5.82240 | AT TIME= | 12.2052 |
| MINIMUM IN X(bot)= | -7.46381 | AT TIME= | 9.12016 |
| MINIMUM IN Y(bot)= | -5.86476 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.06000 Y(final)= -1.12000

**TABLE 9.6 DISPLACEMENT SUMMARY - RUN 308 - 3 CASKS, COF =0.8**

NUMBER OF CASKS ON PAD= 3

FILENAME
plotdis.308

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 1.83591 AT TIME= 8.08014
MAXIMUM IN Y(top)= 2.29879 AT TIME= 8.13514
MAXIMUM IN X(bot)= 0.923258E-01 AT TIME= 8.02014
MAXIMUM IN Y(bot)= 0.381614 AT TIME= 9.59017

MINIMUM IN X(top)= -1.03926 AT TIME= 11.9152
MINIMUM IN Y(top)= -0.677269 AT TIME= 7.84513
MINIMUM IN X(bot)= -0.404616 AT TIME= 9.23516
MINIMUM IN Y(bot)= -0.497580E-01 AT TIME= 8.02514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.353000 Y(final)= 0.398000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.86469 AT TIME= 8.08014
MAXIMUM IN Y(top)= 2.80006 AT TIME= 8.15514
MAXIMUM IN X(bot)= 0.622080E-01 AT TIME= 8.01014
MAXIMUM IN Y(bot)= 0.323314 AT TIME= 8.45515

MINIMUM IN X(top)= -1.21218 AT TIME= 8.38514
MINIMUM IN Y(top)= -0.750652 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.610740 AT TIME= 9.14516
MINIMUM IN Y(bot)= -0.407580E-01 AT TIME= 8.02514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.584000 Y(final)= 0.277000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 1.75390 AT TIME= 8.08514
MAXIMUM IN Y(top)= 2.40335 AT TIME= 8.12514
MAXIMUM IN X(bot)= 0.979730E-01 AT TIME= 8.03014
MAXIMUM IN Y(bot)= 0.300208 AT TIME= 9.17516

MINIMUM IN X(top)= -0.862030 AT TIME= 8.38514
MINIMUM IN Y(top)= -0.784431 AT TIME= 9.43517
MINIMUM IN X(bot)= -0.311932 AT TIME= 9.14016
MINIMUM IN Y(bot)= -0.788395E-01 AT TIME= 9.54517

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.185000 Y(final)= 0.101000E-01

TABLE 9.7 DISPLACEMENT SUMMARY - RUN 402 - 4 CASKS, COF=0.2

NUMBER OF CASKS ON PAD= 4

FILENAME
plotdis.402

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.04825 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(top)= | 2.30176 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.04751 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.23764 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.32367 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -5.99612 | AT TIME= | 12.0552 |
| MINIMUM IN X(bot)= | -7.31397 | AT TIME= | 9.15516 |
| MINIMUM IN Y(bot)= | -6.04112 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.40000 Y(final)= -1.05000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.93101 | AT TIME= | 4.20505 |
| MAXIMUM IN Y(top)= | 2.23597 | AT TIME= | 5.34507 |
| MAXIMUM IN X(bot)= | 1.93008 | AT TIME= | 4.22505 |
| MAXIMUM IN Y(bot)= | 2.16999 | AT TIME= | 5.34507 |
| MINIMUM IN X(top)= | -7.86382 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -5.90382 | AT TIME= | 12.0402 |
| MINIMUM IN X(bot)= | -7.85239 | AT TIME= | 9.13516 |
| MINIMUM IN Y(bot)= | -5.94816 | AT TIME= | 12.2352 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.52000 Y(final)= -0.945000

RESULTS FOR CASK NUMBER 3

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.70892 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(top)= | 2.50654 | AT TIME= | 5.34507 |
| MAXIMUM IN X(bot)= | 1.70831 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.44056 | AT TIME= | 5.34507 |
| MINIMUM IN X(top)= | -7.58281 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -5.73601 | AT TIME= | 12.0552 |
| MINIMUM IN X(bot)= | -7.57250 | AT TIME= | 9.13516 |
| MINIMUM IN Y(bot)= | -5.78112 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.03000 Y(final)= -0.795000

RESULTS FOR CASK NUMBER 4

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.73164 | AT TIME= | 4.19505 |
| MAXIMUM IN Y(top)= | 2.44597 | AT TIME= | 5.34507 |
| MAXIMUM IN X(bot)= | 1.72987 | AT TIME= | 4.19505 |
| MAXIMUM IN Y(bot)= | 2.37999 | AT TIME= | 5.34507 |

| | | | |
|---|---|---|---|
| MINIMUM IN X(top)= | -7.92970 | AT TIME= | 9.13016 |
| MINIMUM IN Y(top)= | -5.66633 | AT TIME= | 12.0352 |
| MINIMUM IN X(bot)= | -7.91861 | AT TIME= | 9.13016 |
| MINIMUM IN Y(bot)= | -5.71324 | AT TIME= | 12.2202 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.76000 Y(final)= -0.677000

TABLE 9.8 DISPLACEMENT SUMMARY - RUN 408 - 4 CASKS, COF = 0.8

NUMBER OF CASKS ON PAD= 4

FILENAME
plotdis.408

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 1.96412 AT TIME= 8.08014
MAXIMUM IN Y(top)= 2.15588 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.159282 AT TIME= 8.00514
MAXIMUM IN Y(bot)= 0.397262 AT TIME= 9.17516

MINIMUM IN X(top)= -0.950404 AT TIME= 8.38014
MINIMUM IN Y(top)= -0.733448 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.363506 AT TIME= 9.12016
MINIMUM IN Y(bot)= -0.947160E-01 AT TIME= 8.01514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.281000 Y(final)= 0.395000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.83564 AT TIME= 8.07514
MAXIMUM IN Y(top)= 2.42875 AT TIME= 8.15014
MAXIMUM IN X(bot)= 0.686170E-01 AT TIME= 8.03514
MAXIMUM IN Y(bot)= 0.545120 AT TIME= 14.1603

MINIMUM IN X(top)= -1.09056 AT TIME= 8.38014
MINIMUM IN Y(top)= -0.716826 AT TIME= 7.85513
MINIMUM IN X(bot)= -0.577885 AT TIME= 8.47515
MINIMUM IN Y(bot)= -0.388080E-01 AT TIME= 8.00014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.478000 Y(final)= 0.566000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 1.81319 AT TIME= 8.08014
MAXIMUM IN Y(top)= 1.94995 AT TIME= 8.13014
MAXIMUM IN X(bot)= 0.268920E-01 AT TIME= 8.01014
MAXIMUM IN Y(bot)= 0.491056 AT TIME= 15.4553

MINIMUM IN X(top)= -1.05241 AT TIME= 8.37514
MINIMUM IN Y(top)= -0.589211 AT TIME= 7.84013
MINIMUM IN X(bot)= -0.406342 AT TIME= 11.1552
MINIMUM IN Y(bot)= -0.364260E-01 AT TIME= 8.02514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.375000 Y(final)= 0.524000

RESULTS FOR CASK NUMBER 4
MAXIMUM IN X(top)= 1.81797 AT TIME= 8.07514
MAXIMUM IN Y(top)= 2.18457 AT TIME= 8.14014
MAXIMUM IN X(bot)= 0.388220E-01 AT TIME= 8.00514
MAXIMUM IN Y(bot)= 0.589770 AT TIME= 14.1853

MINIMUM IN X(top)= -1.11348 AT TIME= 8.38014
MINIMUM IN Y(top)= -0.633965 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.558520 AT TIME= 9.12016
MINIMUM IN Y(bot)= -0.258000E-01 AT TIME= 8.01014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.499000 Y(final)= 0.608000

TABLE 9.9 DISPLACEMENT SUMMARY - RUN 502 - 5 CASKS, COF = 0.2

NUMBER OF CASKS ON PAD= 5

FILENAME
plotdis.502

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.23053 | AT TIME= | 4.19505 |
| MAXIMUM IN Y(top)= | 2.16611 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.24729 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.10846 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.28763 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -6.16235 | AT TIME= | 12.0352 |
| MINIMUM IN X(bot)= | -7.25314 | AT TIME= | 9.15516 |
| MINIMUM IN Y(bot)= | -6.19302 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.37000 Y(final)= -1.18000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.04051 | AT TIME= | 4.19505 |
| MAXIMUM IN Y(top)= | 2.13749 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.05729 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.07984 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.91224 | AT TIME= | 9.14516 |
| MINIMUM IN Y(top)= | -5.90422 | AT TIME= | 12.0402 |
| MINIMUM IN X(bot)= | -7.87751 | AT TIME= | 9.14516 |
| MINIMUM IN Y(bot)= | -5.94303 | AT TIME= | 12.2402 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.64000 Y(final)= -0.914000

RESULTS FOR CASK NUMBER 3

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.01143 | AT TIME= | 4.20505 |
| MAXIMUM IN Y(top)= | 2.35611 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.02983 | AT TIME= | 4.22005 |
| MAXIMUM IN Y(bot)= | 2.29847 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.47246 | AT TIME= | 9.14016 |
| MINIMUM IN Y(top)= | -5.92080 | AT TIME= | 12.0502 |
| MINIMUM IN X(bot)= | -7.43864 | AT TIME= | 9.13016 |
| MINIMUM IN Y(bot)= | -5.95302 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.91000 Y(final)= -0.913000

RESULTS FOR CASK NUMBER 4

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.90657 | AT TIME= | 4.17505 |
| MAXIMUM IN Y(top)= | 2.35130 | AT TIME= | 5.34507 |
| MAXIMUM IN X(bot)= | 1.92266 | AT TIME= | 4.20005 |
| MAXIMUM IN Y(bot)= | 2.29181 | AT TIME= | 5.34507 |

| | | | |
|---|---|---|---|
| MINIMUM IN X(top)= | -7.99246 | AT TIME= | 9.14016 |
| MINIMUM IN Y(top)= | -5.63411 | AT TIME= | 12.0402 |
| MINIMUM IN X(bot)= | -7.95864 | AT TIME= | 9.13016 |
| MINIMUM IN Y(bot)= | -5.67552 | AT TIME= | 12.2352 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.90000 Y(final)= -0.580000

RESULTS FOR CASK NUMBER 5

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.81871 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.46611 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 1.83462 | AT TIME= | 4.23005 |
| MAXIMUM IN Y(bot)= | 2.40846 | AT TIME= | 5.35007 |

| | | | |
|---|---|---|---|
| MINIMUM IN X(top)= | -7.65648 | AT TIME= | 9.14516 |
| MINIMUM IN Y(top)= | -5.68395 | AT TIME= | 12.0302 |
| MINIMUM IN X(bot)= | -7.62245 | AT TIME= | 9.14516 |
| MINIMUM IN Y(bot)= | -5.72290 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.26000 Y(final)= -0.727000

**TABLE 9.10 DISPLACEMENT SUMMARY - RUN 508 - 5 CASKS, COF=0.8**

NUMBER OF CASKS ON PAD= 5

FILENAME
plotdis.508

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 1.84941 AT TIME= 8.07514
MAXIMUM IN Y(top)= 1.87771 AT TIME= 8.14014
MAXIMUM IN X(bot)= 0.110144 AT TIME= 8.01514
MAXIMUM IN Y(bot)= 0.387276 AT TIME= 14.0603

MINIMUM IN X(top)= -0.943908 AT TIME= 5.33507
MINIMUM IN Y(top)= -0.626294 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.326596 AT TIME= 9.22016
MINIMUM IN Y(bot)= -0.876180E-01 AT TIME= 8.02514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.297000 Y(final)= 0.414000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.63673 AT TIME= 8.07014
MAXIMUM IN Y(top)= 2.11060 AT TIME= 8.15514
MAXIMUM IN X(bot)= 0.305280E-01 AT TIME= 8.00514
MAXIMUM IN Y(bot)= 0.424342 AT TIME= 14.1803

MINIMUM IN X(top)= -1.15562 AT TIME= 12.9552
MINIMUM IN Y(top)= -0.687909 AT TIME= 7.85513
MINIMUM IN X(bot)= -0.504390 AT TIME= 9.11016
MINIMUM IN Y(bot)= -0.485900E-01 AT TIME= 8.00014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.468000 Y(final)= 0.439000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 1.70361 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.61519 AT TIME= 8.13514
MAXIMUM IN X(bot)= 0.785300E-01 AT TIME= 7.99514
MAXIMUM IN Y(bot)= 0.385705 AT TIME= 11.7902

MINIMUM IN X(top)= -0.764456 AT TIME= 8.27014
MINIMUM IN Y(top)= -0.510004 AT TIME= 7.83513
MINIMUM IN X(bot)= -0.218204 AT TIME= 8.38014
MINIMUM IN Y(bot)= -0.587680E-01 AT TIME= 7.98514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.161000 Y(final)= 0.402000

RESULTS FOR CASK NUMBER 4
MAXIMUM IN X(top)= 1.61979 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.87593 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.491403E-02 AT TIME= 8.00014
MAXIMUM IN Y(bot)= 0.448027 AT TIME= 14.2503

MINIMUM IN X(top)= -1.03751 AT TIME= 12.9552
MINIMUM IN Y(top)= -0.599994 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.406343 AT TIME= 8.41014
MINIMUM IN Y(bot)= -0.336060E-01 AT TIME= 8.01514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.369000 Y(final)= 0.460000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 1.57933 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.70139 AT TIME= 8.12514
MAXIMUM IN X(bot)= 0.482740E-01 AT TIME= 8.00014
MAXIMUM IN Y(bot)= 0.329193 AT TIME= 14.1653

MINIMUM IN X(top)= -0.708268 AT TIME= 8.26514
MINIMUM IN Y(top)= -0.519108 AT TIME= 7.84013
MINIMUM IN X(bot)= -0.194456 AT TIME= 8.37514
MINIMUM IN Y(bot)= -0.160480E-01 AT TIME= 7.98514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.979000E-01 Y(final)= 0.349000

TABLE 9.11 DISPLACEMENT SUMMARY - RUN 602 - 6 CASKS, COF =0.2

NUMBER OF CASKS ON PAD= 6

FILENAME
plotdis.602

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.22159 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(top)= | 2.11208 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.21986 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.06092 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.46579 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -6.27332 | AT TIME= | 12.0302 |
| MINIMUM IN X(bot)= | -7.44699 | AT TIME= | 9.13516 |
| MINIMUM IN Y(bot)= | -6.30225 | AT TIME= | 12.2152 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.48000 Y(final)= -1.21000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.09425 | AT TIME= | 4.18005 |
| MAXIMUM IN Y(top)= | 2.13416 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.09096 | AT TIME= | 4.18005 |
| MAXIMUM IN Y(bot)= | 2.08300 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -8.03592 | AT TIME= | 9.13516 |
| MINIMUM IN Y(top)= | -6.18355 | AT TIME= | 12.0352 |
| MINIMUM IN X(bot)= | -8.01773 | AT TIME= | 9.15516 |
| MINIMUM IN Y(bot)= | -6.21545 | AT TIME= | 12.2202 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.85000 Y(final)= -1.14000

RESULTS FOR CASK NUMBER 3

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.11872 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.27208 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.11654 | AT TIME= | 4.22505 |
| MAXIMUM IN Y(bot)= | 2.22092 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.51423 | AT TIME= | 9.14516 |
| MINIMUM IN Y(top)= | -6.04334 | AT TIME= | 12.0302 |
| MINIMUM IN X(bot)= | -7.49861 | AT TIME= | 9.14516 |
| MINIMUM IN Y(bot)= | -6.07321 | AT TIME= | 12.2102 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.82000 Y(final)= -0.944000

RESULTS FOR CASK NUMBER 4

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.86586 | AT TIME= | 4.18005 |
| MAXIMUM IN Y(top)= | 2.28416 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 1.86250 | AT TIME= | 4.18005 |
| MAXIMUM IN Y(bot)= | 2.23300 | AT TIME= | 5.35007 |

MINIMUM IN X(top)= -8.21773 AT TIME= 9.14016
MINIMUM IN Y(top)= -5.89646 AT TIME= 12.0302
MINIMUM IN X(bot)= -8.20011 AT TIME= 9.14016
MINIMUM IN Y(bot)= -5.92749 AT TIME= 12.2152

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.13000 Y(final)= -0.784000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 1.93748 AT TIME= 4.18005
MAXIMUM IN Y(top)= 2.40567 AT TIME= 5.34507
MAXIMUM IN X(bot)= 1.93403 AT TIME= 4.18005
MAXIMUM IN Y(bot)= 2.35312 AT TIME= 5.34507

MINIMUM IN X(top)= -7.67620 AT TIME= 9.13016
MINIMUM IN Y(top)= -5.85831 AT TIME= 12.0502
MINIMUM IN X(bot)= -7.65900 AT TIME= 9.13016
MINIMUM IN Y(bot)= -5.88637 AT TIME= 12.2052

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.14000 Y(final)= -0.769000

RESULTS FOR CASK NUMBER 6
MAXIMUM IN X(top)= 1.79041 AT TIME= 4.19005
MAXIMUM IN Y(top)= 2.37416 AT TIME= 5.35007
MAXIMUM IN X(bot)= 1.78721 AT TIME= 4.19005
MAXIMUM IN Y(bot)= 2.32300 AT TIME= 5.35007

MINIMUM IN X(top)= -8.25079 AT TIME= 9.14516
MINIMUM IN Y(top)= -5.77654 AT TIME= 12.2102
MINIMUM IN X(bot)= -8.23548 AT TIME= 9.14516
MINIMUM IN Y(bot)= -5.80988 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.15000 Y(final)= -0.650000

TABLE 9.12 DISPLACEMENT SUMMARY RUN 608 - 6 CASKS, COF = 0.8

NUMBER OF CASKS ON PAD= 6

FILENAME
plotdis.608

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 1.86481 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.79038 AT TIME= 8.15014
MAXIMUM IN X(bot)= 0.120428 AT TIME= 8.00014
MAXIMUM IN Y(bot)= 0.388643 AT TIME= 14.1903

MINIMUM IN X(top)= -0.957983 AT TIME= 5.34007
MINIMUM IN Y(top)= -0.603017 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.289901 AT TIME= 8.48015
MINIMUM IN Y(bot)= -0.766580E-01 AT TIME= 8.00014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.249000 Y(final)= 0.398000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.52427 AT TIME= 8.06514
MAXIMUM IN Y(top)= 1.76603 AT TIME= 8.15014
MAXIMUM IN X(bot)= 0.382880E-01 AT TIME= 8.00014
MAXIMUM IN Y(bot)= 0.524885 AT TIME= 13.3903

MINIMUM IN X(top)= -1.16371 AT TIME= 13.4503
MINIMUM IN Y(top)= -0.631511 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.404735 AT TIME= 8.39014
MINIMUM IN Y(bot)= -0.536980E-01 AT TIME= 8.00014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.208000 Y(final)= 0.428000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 1.73521 AT TIME= 8.07514
MAXIMUM IN Y(top)= 1.50298 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.726440E-01 AT TIME= 7.99014
MAXIMUM IN Y(bot)= 0.352061 AT TIME= 14.1903

MINIMUM IN X(top)= -0.739903 AT TIME= 12.9502
MINIMUM IN Y(top)= -0.513917 AT TIME= 7.84513
MINIMUM IN X(bot)= -0.149764 AT TIME= 8.37514
MINIMUM IN Y(bot)= -0.742620E-01 AT TIME= 8.03514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.939000E-01 Y(final)= 0.376000

RESULTS FOR CASK NUMBER 4
MAXIMUM IN X(top)= 1.51497 AT TIME= 8.06514
MAXIMUM IN Y(top)= 1.67070 AT TIME= 8.14014
MAXIMUM IN X(bot)= 0.241399E-02 AT TIME= 2.89502
MAXIMUM IN Y(bot)= 0.505740 AT TIME= 14.1803

MINIMUM IN X(top)= -1.05774 AT TIME= 12.9602
MINIMUM IN Y(top)= -0.554271 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.371324 AT TIME= 8.37514
MINIMUM IN Y(bot)= -0.322760E-01 AT TIME= 7.99514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.280000 Y(final)= 0.510000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 1.60365 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.64947 AT TIME= 8.14014
MAXIMUM IN X(bot)= 0.217240E-01 AT TIME= 7.99014
MAXIMUM IN Y(bot)= 0.411422 AT TIME= 14.1653

MINIMUM IN X(top)= -0.843590 AT TIME= 8.27014
MINIMUM IN Y(top)= -0.529397 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.236756 AT TIME= 8.37514
MINIMUM IN Y(bot)= -0.187940E-01 AT TIME= 7.99014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.178000 Y(final)= 0.436000

RESULTS FOR CASK NUMBER 6
MAXIMUM IN X(top)= 1.49057 AT TIME= 8.06514
MAXIMUM IN Y(top)= 1.57963 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.227402E-02 AT TIME= 2.89502
MAXIMUM IN Y(bot)= 0.453096 AT TIME= 14.1653

MINIMUM IN X(top)= -0.949447 AT TIME= 12.9552
MINIMUM IN Y(top)= -0.524056 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.328781 AT TIME= 8.36014
MINIMUM IN Y(bot)= -0.220940E-01 AT TIME= 7.99014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.225000 Y(final)= 0.455000

TABLE 9.13 DISPLACEMENT SUMMARY RUN 702 - 7 CASKS, COF = 0.2

NUMBER OF CASKS ON PAD= 7

FILENAME
plotdis.702

RESULTS FOR CASK NUMBER 1

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.34965 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.05071 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.36415 | AT TIME= | 4.22005 |
| MAXIMUM IN Y(bot)= | 2.02154 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.27683 | AT TIME= | 9.14516 |
| MINIMUM IN Y(top)= | -6.27035 | AT TIME= | 12.0402 |
| MINIMUM IN X(bot)= | -7.23771 | AT TIME= | 9.14516 |
| MINIMUM IN Y(bot)= | -6.28024 | AT TIME= | 12.2102 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.43000 Y(final)= -1.29000

RESULTS FOR CASK NUMBER 2

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.01953 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.10739 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.03415 | AT TIME= | 4.22005 |
| MAXIMUM IN Y(bot)= | 2.07823 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -8.08879 | AT TIME= | 9.14016 |
| MINIMUM IN Y(top)= | -6.22315 | AT TIME= | 12.2152 |
| MINIMUM IN X(bot)= | -8.05215 | AT TIME= | 9.13016 |
| MINIMUM IN Y(bot)= | -6.23371 | AT TIME= | 12.2152 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.97000 Y(final)= -1.25000

RESULTS FOR CASK NUMBER 3

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 2.21680 | AT TIME= | 4.18505 |
| MAXIMUM IN Y(top)= | 2.16071 | AT TIME= | 5.35007 |
| MAXIMUM IN X(bot)= | 2.22984 | AT TIME= | 4.21005 |
| MAXIMUM IN Y(bot)= | 2.13154 | AT TIME= | 5.35007 |
| MINIMUM IN X(top)= | -7.47310 | AT TIME= | 9.14016 |
| MINIMUM IN Y(top)= | -6.08316 | AT TIME= | 12.0352 |
| MINIMUM IN X(bot)= | -7.43575 | AT TIME= | 9.15516 |
| MINIMUM IN Y(bot)= | -6.09293 | AT TIME= | 12.2052 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.77000 Y(final)= -1.14000

RESULTS FOR CASK NUMBER 4

| | | | |
|---|---|---|---|
| MAXIMUM IN X(top)= | 1.94870 | AT TIME= | 4.19005 |
| MAXIMUM IN Y(top)= | 2.22474 | AT TIME= | 5.35507 |
| MAXIMUM IN X(bot)= | 1.96204 | AT TIME= | 4.20005 |
| MAXIMUM IN Y(bot)= | 2.19696 | AT TIME= | 5.35507 |

MINIMUM IN X(top)= -8.22667 AT TIME= 9.13516
MINIMUM IN Y(top)= -6.00960 AT TIME= 12.0302
MINIMUM IN X(bot)= -8.18970 AT TIME= 9.16016
MINIMUM IN Y(bot)= -6.01945 AT TIME= 12.2052

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.12000 Y(final)= -0.926000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 2.17794 AT TIME= 4.19005
MAXIMUM IN Y(top)= 2.24071 AT TIME= 5.35007
MAXIMUM IN X(bot)= 2.19074 AT TIME= 4.19005
MAXIMUM IN Y(bot)= 2.21154 AT TIME= 5.35007

MINIMUM IN X(top)= -7.58521 AT TIME= 9.14516
MINIMUM IN Y(top)= -5.93818 AT TIME= 12.2152
MINIMUM IN X(bot)= -7.54679 AT TIME= 9.15016
MINIMUM IN Y(bot)= -5.94872 AT TIME= 12.2152

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.95000 Y(final)= -0.880000

RESULTS FOR CASK NUMBER 6
MAXIMUM IN X(top)= 1.89787 AT TIME= 4.19005
MAXIMUM IN Y(top)= 2.31739 AT TIME= 5.35007
MAXIMUM IN X(bot)= 1.91146 AT TIME= 4.20005
MAXIMUM IN Y(bot)= 2.28823 AT TIME= 5.35007

MINIMUM IN X(top)= -8.34742 AT TIME= 9.14016
MINIMUM IN Y(top)= -5.81316 AT TIME= 12.2152
MINIMUM IN X(bot)= -8.31130 AT TIME= 9.12516
MINIMUM IN Y(bot)= -5.82369 AT TIME= 12.2152

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.25000 Y(final)= -0.656000

RESULTS FOR CASK NUMBER 7
MAXIMUM IN X(top)= 2.07493 AT TIME= 4.18505
MAXIMUM IN Y(top)= 2.35818 AT TIME= 5.35507
MAXIMUM IN X(bot)= 2.08871 AT TIME= 4.22505
MAXIMUM IN Y(bot)= 2.33040 AT TIME= 5.35507

MINIMUM IN X(top)= -7.75508 AT TIME= 9.13516
MINIMUM IN Y(top)= -5.73996 AT TIME= 12.2102
MINIMUM IN X(bot)= -7.71757 AT TIME= 9.13516
MINIMUM IN Y(bot)= -5.75021 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.15000 Y(final)= -0.617000

TABLE 9.14 DISPLACEMENT SUMMARY - RUN 708 - 7 CASKS, COF =0.8

NUMBER OF CASKS ON PAD= 7

FILENAME
plotdis.708

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 1.80794 AT TIME= 8.08014
MAXIMUM IN Y(top)= 1.71596 AT TIME= 8.15014
MAXIMUM IN X(bot)= 0.372680E-01 AT TIME= 8.01014
MAXIMUM IN Y(bot)= 0.462801 AT TIME= 14.1753

MINIMUM IN X(top)= -1.00958 AT TIME= 8.36014
MINIMUM IN Y(top)= -0.615871 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.332028 AT TIME= 8.50015
MINIMUM IN Y(bot)= -0.637120E-01 AT TIME= 8.00014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.281000 Y(final)= 0.450000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.45394 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.77684 AT TIME= 8.15514
MAXIMUM IN X(bot)= 0.134300E-01 AT TIME= 5.27007
MAXIMUM IN Y(bot)= 0.556882 AT TIME= 13.4203

MINIMUM IN X(top)= -1.32873 AT TIME= 13.4553
MINIMUM IN Y(top)= -0.701669 AT TIME= 7.85513
MINIMUM IN X(bot)= -0.430325 AT TIME= 8.40014
MINIMUM IN Y(bot)= -0.351960E-01 AT TIME= 8.00514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.318000 Y(final)= 0.463000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 1.74157 AT TIME= 8.07514
MAXIMUM IN Y(top)= 1.56729 AT TIME= 8.15514
MAXIMUM IN X(bot)= 0.675180E-01 AT TIME= 7.99514
MAXIMUM IN Y(bot)= 0.399722 AT TIME= 14.1553

MINIMUM IN X(top)= -0.868511 AT TIME= 12.9552
MINIMUM IN Y(top)= -0.547496 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.198894 AT TIME= 9.26016
MINIMUM IN Y(bot)= -0.503100E-01 AT TIME= 7.99514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.162000 Y(final)= 0.394000

RESULTS FOR CASK NUMBER 4
MAXIMUM IN X(top)= 1.44583 AT TIME= 8.06514
MAXIMUM IN Y(top)= 1.56423 AT TIME= 8.15014
MAXIMUM IN X(bot)= 0.106170E-01 AT TIME= 5.24007
MAXIMUM IN Y(bot)= 0.494453 AT TIME= 13.4253

MINIMUM IN X(top)= -1.25730 AT TIME= 13.4553
MINIMUM IN Y(top)= -0.586054 AT TIME= 7.85513
MINIMUM IN X(bot)= -0.347819 AT TIME= 8.36014
MINIMUM IN Y(bot)= -0.394700E-01 AT TIME= 7.99514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.236000 Y(final)= 0.436000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 1.62826 AT TIME= 8.07514
MAXIMUM IN Y(top)= 1.53981 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.602180E-01 AT TIME= 7.99514
MAXIMUM IN Y(bot)= 0.435824 AT TIME= 14.1753

MINIMUM IN X(top)= -0.897077 AT TIME= 8.27014
MINIMUM IN Y(top)= -0.520686 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.198897 AT TIME= 8.36514
MINIMUM IN Y(bot)= -0.339520E-01 AT TIME= 7.99014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.155000 Y(final)= 0.443000

RESULTS FOR CASK NUMBER 6
MAXIMUM IN X(top)= 1.43197 AT TIME= 8.06514
MAXIMUM IN Y(top)= 1.49946 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.549801E-02 AT TIME= 7.99514
MAXIMUM IN Y(bot)= 0.536220 AT TIME= 13.4303

MINIMUM IN X(top)= -1.19939 AT TIME= 13.4503
MINIMUM IN Y(top)= -0.533723 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.344505 AT TIME= 8.35014
MINIMUM IN Y(bot)= -0.288700E-01 AT TIME= 7.99514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.191000 Y(final)= 0.524000

RESULTS FOR CASK NUMBER 7
MAXIMUM IN X(top)= 1.51473 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.55143 AT TIME= 8.14514
MAXIMUM IN X(bot)= 0.483040E-01 AT TIME= 7.98514
MAXIMUM IN Y(bot)= 0.483533 AT TIME= 14.1553

MINIMUM IN X(top)= -0.984547 AT TIME= 8.28014
MINIMUM IN Y(top)= -0.528132 AT TIME= 7.84513
MINIMUM IN X(bot)= -0.245799 AT TIME= 8.35514
MINIMUM IN Y(bot)= -0.215520E-01 AT TIME= 7.99014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.201000 Y(final)= 0.492000

**TABLE 9.15 DISPLACEMENT SUMMARY RUN 802 - 8 CASKS, COF = 0.2**

NUMBER OF CASKS ON PAD= 8

FILENAME
plotdis.802

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 2.26418 AT TIME= 4.19505
MAXIMUM IN Y(top)= 2.04077 AT TIME= 5.35007
MAXIMUM IN X(bot)= 2.25943 AT TIME= 4.19505
MAXIMUM IN Y(bot)= 2.03404 AT TIME= 5.35007

MINIMUM IN X(top)= -7.29646 AT TIME= 9.13516
MINIMUM IN Y(top)= -6.31164 AT TIME= 12.0402
MINIMUM IN X(bot)= -7.27436 AT TIME= 9.15516
MINIMUM IN Y(bot)= -6.30258 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.48000 Y(final)= -1.45000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.96412 AT TIME= 4.19505
MAXIMUM IN Y(top)= 2.14840 AT TIME= 5.35507
MAXIMUM IN X(bot)= 1.95949 AT TIME= 4.19505
MAXIMUM IN Y(bot)= 2.14263 AT TIME= 5.35507

MINIMUM IN X(top)= -8.07271 AT TIME= 9.13016
MINIMUM IN Y(top)= -6.21190 AT TIME= 12.2102
MINIMUM IN X(bot)= -8.05084 AT TIME= 9.13016
MINIMUM IN Y(bot)= -6.20280 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -2.92000 Y(final)= -1.24000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 2.26964 AT TIME= 4.20005
MAXIMUM IN Y(top)= 2.08077 AT TIME= 5.35007
MAXIMUM IN X(bot)= 2.26539 AT TIME= 4.23505
MAXIMUM IN Y(bot)= 2.07404 AT TIME= 5.35007

MINIMUM IN X(top)= -7.38636 AT TIME= 9.13516
MINIMUM IN Y(top)= -6.13163 AT TIME= 12.2102
MINIMUM IN X(bot)= -7.36641 AT TIME= 9.18016
MINIMUM IN Y(bot)= -6.12258 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.52000 Y(final)= -1.20000

RESULTS FOR CASK NUMBER 4
MAXIMUM IN X(top)= 1.92347 AT TIME= 4.19505
MAXIMUM IN Y(top)= 2.19083 AT TIME= 5.35007
MAXIMUM IN X(bot)= 1.91881 AT TIME= 4.19505
MAXIMUM IN Y(bot)= 2.18409 AT TIME= 5.35007

MINIMUM IN X(top)= -8.22257 AT TIME= 9.13016

MINIMUM IN Y(top)= -6.04236 AT TIME= 12.0402
MINIMUM IN X(bot)= -8.20163 AT TIME= 9.12516
MINIMUM IN Y(bot)= -6.03280 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.00000 Y(final)= -0.996000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 2.26895 AT TIME= 4.20005
MAXIMUM IN Y(top)= 2.13077 AT TIME= 5.35007
MAXIMUM IN X(bot)= 2.26499 AT TIME= 4.23505
MAXIMUM IN Y(bot)= 2.12404 AT TIME= 5.35007

MINIMUM IN X(top)= -7.49626 AT TIME= 9.13516
MINIMUM IN Y(top)= -5.95163 AT TIME= 12.2102
MINIMUM IN X(bot)= -7.47345 AT TIME= 9.13516
MINIMUM IN Y(bot)= -5.94258 AT TIME= 12.2102

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.55000 Y(final)= -0.964000

RESULTS FOR CASK NUMBER 6
MAXIMUM IN X(top)= 1.84280 AT TIME= 4.19505
MAXIMUM IN Y(top)= 2.22083 AT TIME= 5.35007
MAXIMUM IN X(bot)= 1.83815 AT TIME= 4.19505
MAXIMUM IN Y(bot)= 2.21409 AT TIME= 5.35007

MINIMUM IN X(top)= -8.41634 AT TIME= 9.13516
MINIMUM IN Y(top)= -5.89948 AT TIME= 12.0302
MINIMUM IN X(bot)= -8.39452 AT TIME= 9.15516
MINIMUM IN Y(bot)= -5.88598 AT TIME= 12.2052

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.09000 Y(final)= -0.786000

RESULTS FOR CASK NUMBER 7
MAXIMUM IN X(top)= 2.20826 AT TIME= 4.20005
MAXIMUM IN Y(top)= 2.17078 AT TIME= 5.35007
MAXIMUM IN X(bot)= 2.20365 AT TIME= 4.20005
MAXIMUM IN Y(bot)= 2.16402 AT TIME= 5.35007

MINIMUM IN X(top)= -7.67615 AT TIME= 9.13516
MINIMUM IN Y(top)= -5.79457 AT TIME= 12.0352
MINIMUM IN X(bot)= -7.65460 AT TIME= 9.15516
MINIMUM IN Y(bot)= -5.78592 AT TIME= 12.2052

FINAL COORDINATES OF CASK CENTROID
X(final)= -1.68000 Y(final)= -0.742000

RESULTS FOR CASK NUMBER 8
MAXIMUM IN X(top)= 1.87214 AT TIME= 4.19505
MAXIMUM IN Y(top)= 2.24083 AT TIME= 5.35007
MAXIMUM IN X(bot)= 1.86747 AT TIME= 4.19505
MAXIMUM IN Y(bot)= 2.23409 AT TIME= 5.35007

MINIMUM IN X(top)= -8.50226 AT TIME= 9.13016

| | | | |
|---|---|---|---|
| MINIMUM IN Y(top)= | -5.76106 | AT TIME= | 12.2202 |
| MINIMUM IN X(bot)= | -8.48123 | AT TIME= | 9.12516 |
| MINIMUM IN Y(bot)= | -5.75225 | AT TIME= | 12.2252 |

FINAL COORDINATES OF CASK CENTROID
X(final)= -3.08000 Y(final)= -0.589000

TABLE 9.16 DISPLACEMENT SUMMARY - RUN 808 - 8 CASKS, COF = 0.8

NUMBER OF CASKS ON PAD= 8

FILENAME
plotdis.808

RESULTS FOR CASK NUMBER 1
MAXIMUM IN X(top)= 1.87803 AT TIME= 8.08514
MAXIMUM IN Y(top)= 1.36363 AT TIME= 8.15014
MAXIMUM IN X(bot)= 0.697850E-01 AT TIME= 8.01014
MAXIMUM IN Y(bot)= 0.480397 AT TIME= 14.1203

MINIMUM IN X(top)= -0.793332 AT TIME= 4.40505
MINIMUM IN Y(top)= -0.522608 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.153397 AT TIME= 8.36014
MINIMUM IN Y(bot)= -0.645064E-01 AT TIME= 8.03014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.995000E-02 Y(final)= 0.464000

RESULTS FOR CASK NUMBER 2
MAXIMUM IN X(top)= 1.79818 AT TIME= 14.2053
MAXIMUM IN Y(top)= 2.27734 AT TIME= 15.5253
MAXIMUM IN X(bot)= 0.955200E-02 AT TIME= 5.27007
MAXIMUM IN Y(bot)= 0.593956 AT TIME= 13.2603

MINIMUM IN X(top)= -1.93077 AT TIME= 14.4753
MINIMUM IN Y(top)= -1.27657 AT TIME= 14.3503
MINIMUM IN X(bot)= -0.605963 AT TIME= 13.1253
MINIMUM IN Y(bot)= -0.374930E-01 AT TIME= 8.01014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.201000 Y(final)= 0.470000

RESULTS FOR CASK NUMBER 3
MAXIMUM IN X(top)= 1.88184 AT TIME= 8.08014
MAXIMUM IN Y(top)= 1.50053 AT TIME= 8.16514
MAXIMUM IN X(bot)= 0.589559E-01 AT TIME= 8.01514
MAXIMUM IN Y(bot)= 0.446937 AT TIME= 14.1103

MINIMUM IN X(top)= -0.876092 AT TIME= 12.9602
MINIMUM IN Y(top)= -0.607793 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.185381 AT TIME= 8.39514
MINIMUM IN Y(bot)= -0.680440E-01 AT TIME= 8.02014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.131000 Y(final)= 0.442000

RESULTS FOR CASK NUMBER 4
MAXIMUM IN X(top)= 1.54213 AT TIME= 8.07514
MAXIMUM IN Y(top)= 1.83432 AT TIME= 8.17014
MAXIMUM IN X(bot)= 0.119560E-01 AT TIME= 8.01514
MAXIMUM IN Y(bot)= 0.616442 AT TIME= 13.5003

MINIMUM IN X(top)= -1.41715 AT TIME= 12.9702
MINIMUM IN Y(top)= -0.771819 AT TIME= 7.86013
MINIMUM IN X(bot)= -0.510480 AT TIME= 13.1303
MINIMUM IN Y(bot)= -0.365330E-01 AT TIME= 8.01014

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.456000 Y(final)= 0.594000

RESULTS FOR CASK NUMBER 5
MAXIMUM IN X(top)= 1.85859 AT TIME= 8.08014
MAXIMUM IN Y(top)= 1.54287 AT TIME= 8.17014
MAXIMUM IN X(bot)= 0.606359E-01 AT TIME= 8.01514
MAXIMUM IN Y(bot)= 0.522730 AT TIME= 14.1453

MINIMUM IN X(top)= -0.990698 AT TIME= 8.34514
MINIMUM IN Y(top)= -0.597793 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.219197 AT TIME= 9.25516
MINIMUM IN Y(bot)= -0.530080E-01 AT TIME= 8.00514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.189000 Y(final)= 0.511000

RESULTS FOR CASK NUMBER 6
MAXIMUM IN X(top)= 1.52104 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.58569 AT TIME= 14.0003
MAXIMUM IN X(bot)= 0.297721E-02 AT TIME= 2.89502
MAXIMUM IN Y(bot)= 0.687469 AT TIME= 14.1703

MINIMUM IN X(top)= -1.31966 AT TIME= 12.9752
MINIMUM IN Y(top)= -0.656109 AT TIME= 7.85513
MINIMUM IN X(bot)= -0.421295 AT TIME= 8.37014
MINIMUM IN Y(bot)= -0.325840E-01 AT TIME= 8.00514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.335000 Y(final)= 0.616000

RESULTS FOR CASK NUMBER 7
MAXIMUM IN X(top)= 1.83924 AT TIME= 8.08514
MAXIMUM IN Y(top)= 1.63422 AT TIME= 8.17014
MAXIMUM IN X(bot)= 0.670061E-01 AT TIME= 8.02014
MAXIMUM IN Y(bot)= 0.587239 AT TIME= 14.1703

MINIMUM IN X(top)= -1.16972 AT TIME= 8.34514
MINIMUM IN Y(top)= -0.628008 AT TIME= 7.85013
MINIMUM IN X(bot)= -0.264346 AT TIME= 13.8253
MINIMUM IN Y(bot)= -0.437900E-01 AT TIME= 7.99514

FINAL COORDINATES OF CASK CENTROID
X(final)= -0.256000 Y(final)= 0.577000

RESULTS FOR CASK NUMBER 8
MAXIMUM IN X(top)= 1.56895 AT TIME= 8.07014
MAXIMUM IN Y(top)= 1.57740 AT TIME= 8.16514
MAXIMUM IN X(bot)= 0.265959E-02 AT TIME= 2.89502
MAXIMUM IN Y(bot)= 0.779092 AT TIME= 14.2403

```
MINIMUM IN X(top)=  -1.38135    AT TIME=   12.9702
MINIMUM IN Y(top)=  -0.569789   AT TIME=   7.85513
MINIMUM IN X(bot)=  -0.432101   AT TIME=   8.37014
MINIMUM IN Y(bot)=  -0.208140E-01 AT TIME=   7.99514

FINAL COORDINATES OF CASK CENTROID
 X(final)=  -0.371000    Y(final)=  0.754000
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REPORT HI-971631

PROPRIETARY INFORMATION

FIGURE 4.1; HI-STORM 100 DYNAMIC MODEL

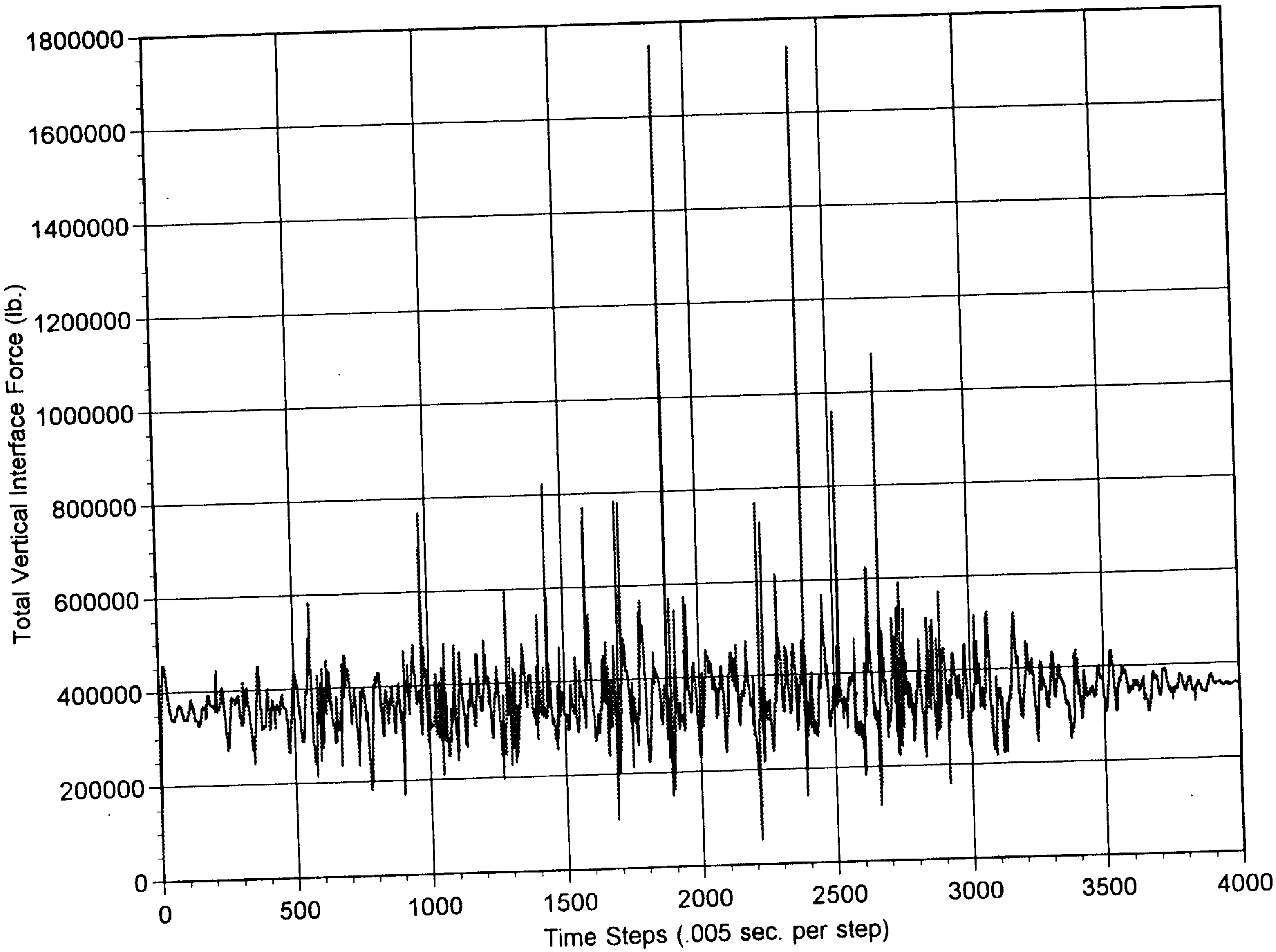


FIGURE 9.1 VERTICAL INTERFACE FORCE VS. TIME, CASK #8, 8 CASKS ON PAD, COF=0.8

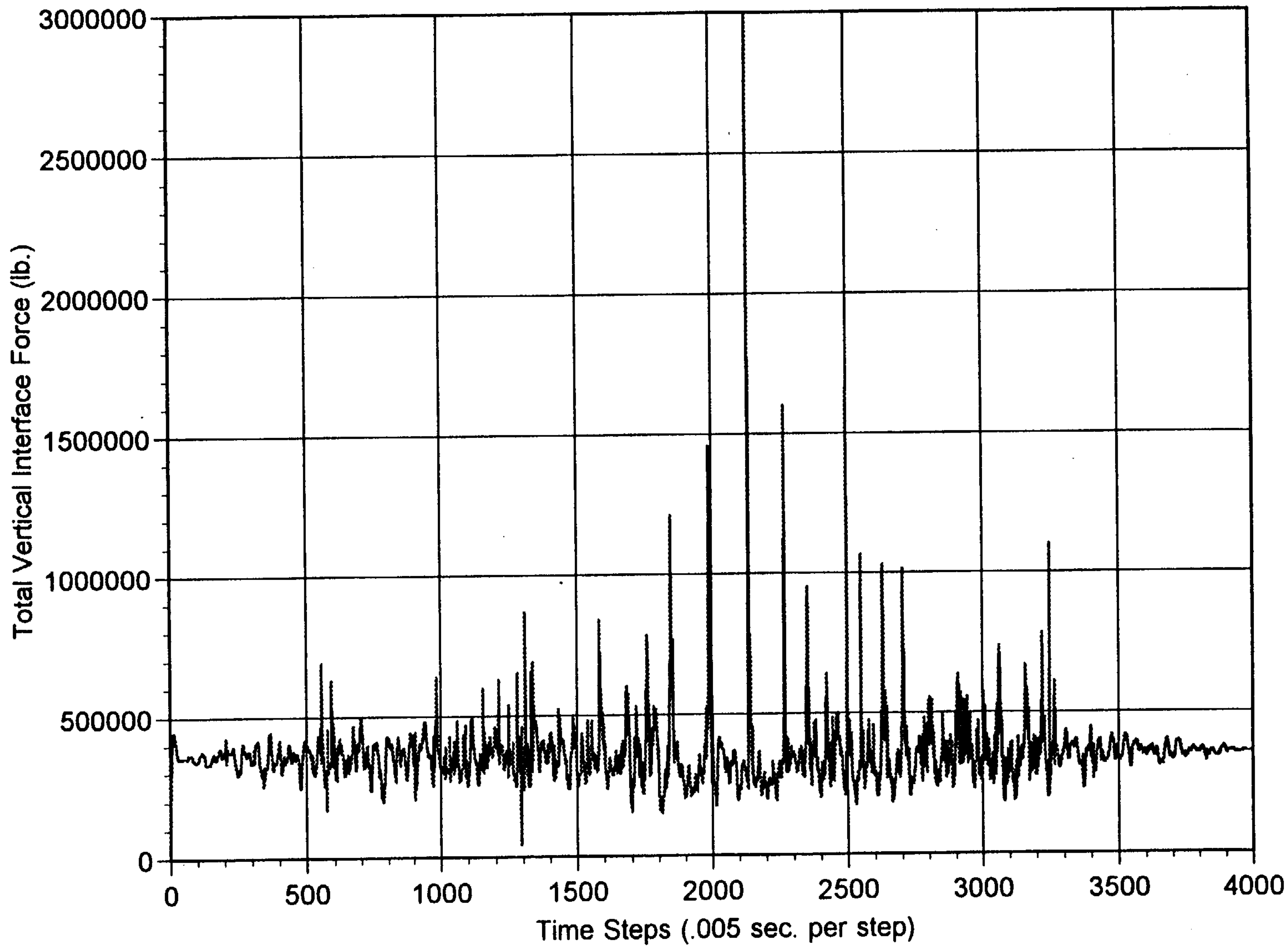


FIGURE 9.2 VERTICAL INTERFACE FORCE VS. TIME, CASK #1, 1 CASK ON PAD, COF =0.8

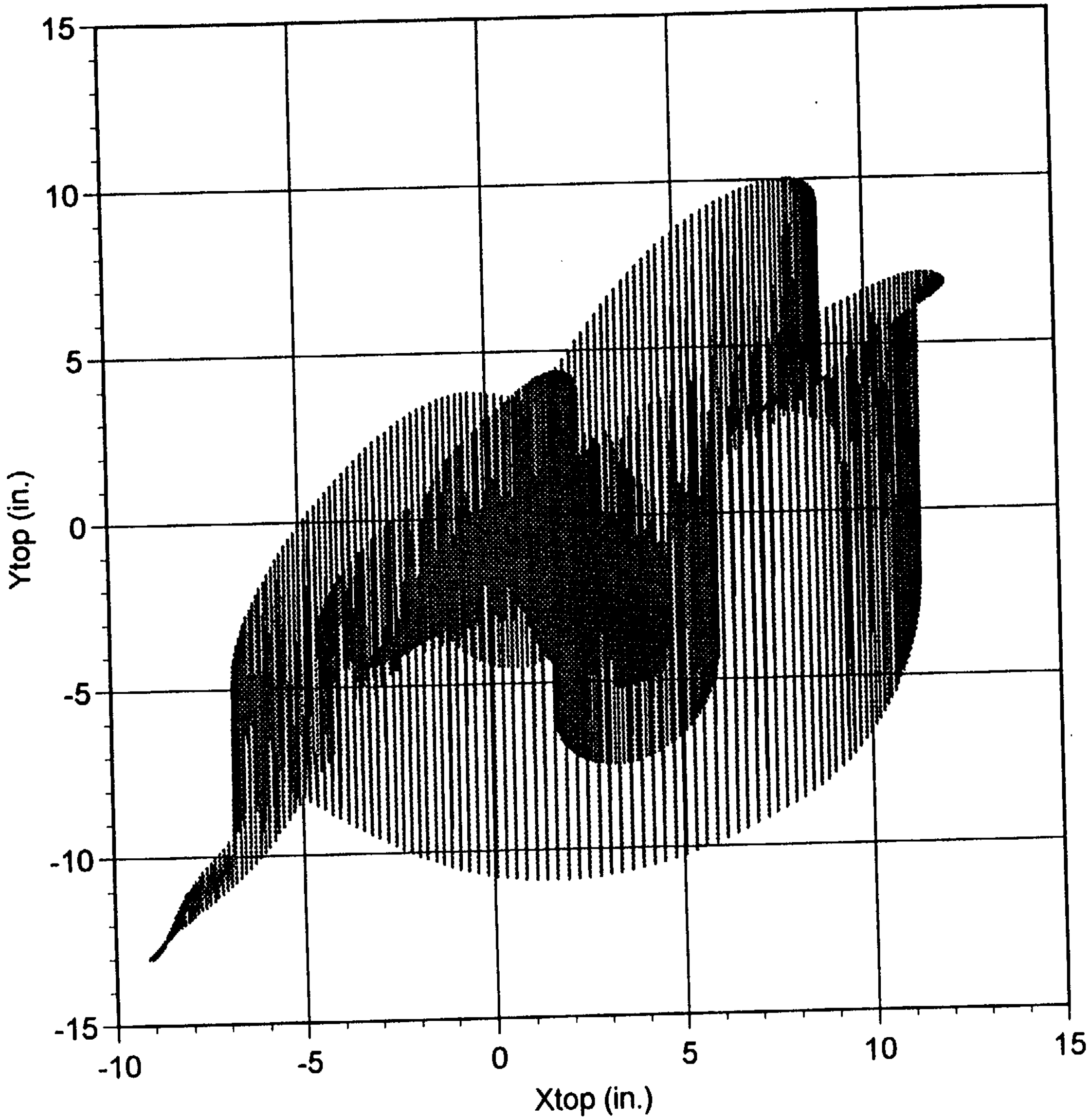


FIGURE 9.3 LOCUS OF TOP CENTERPOINT MOVEMENT - CASK#1, 1 CASK ON PAD, COF=0.8

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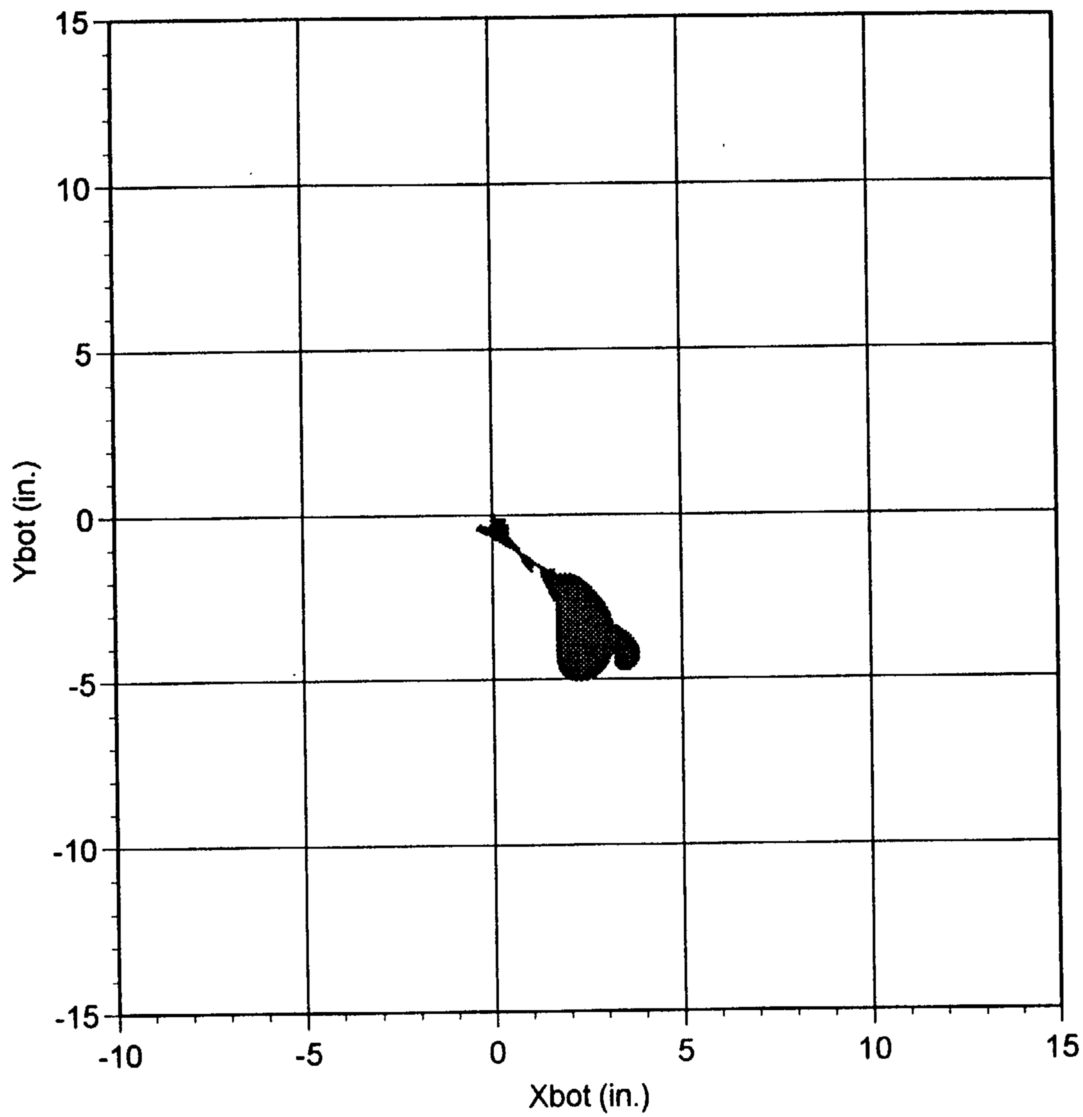


FIGURE 9.4 OCUS OF BOTTOM CENTERPOINT MOVEMENT - CASK #1, 1 CASK ON PAD, COF = 0.8

# APPENDIX A

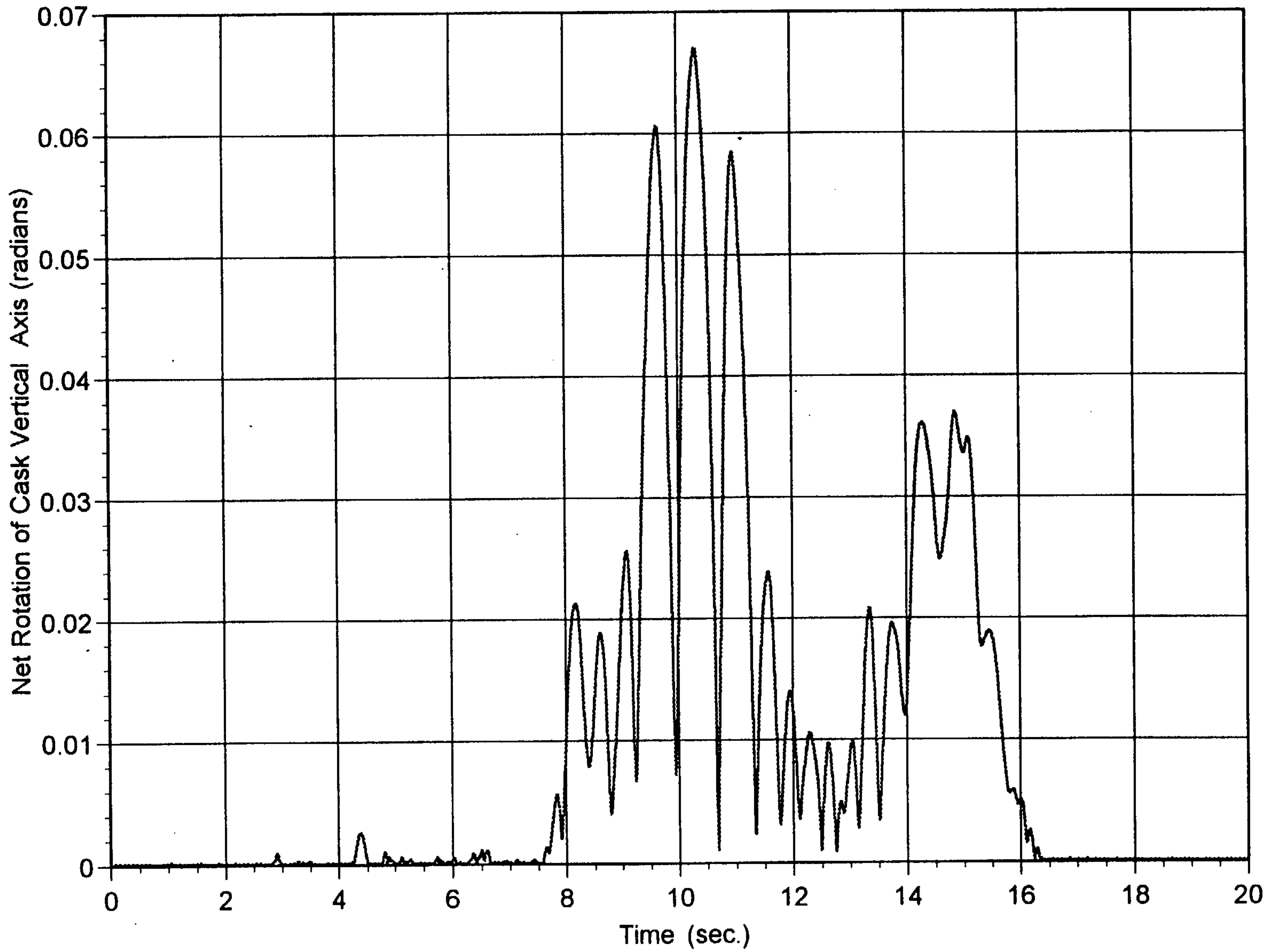


FIGURE 9.5 NET ROTATION OF CASK LONGITUDINAL AXIS ABOUT HORIZONTAL AXIS - CASK #1, 1 CASK ON PAD, COF = 0.8

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EXHIBIT 3.2-3 (Page 1 of 4)
QA VALIDATED COMPUTER PROGRAM LIST

| PROGRAM | VERSION | CODE USED† | Computer Environment |
|---|---|---|---|
| CASMO-3 | 4.4, 4.7 | | |
| KENO-5A (INCLUDES WORKER AND NITAWL) | 2.3 | | |
| ANSYS | 5.0, 5.0A, 5.1, 5.2, 5.3 | | |
| MCNP | 4A | | |
| SCANS | 1A | | |
| AC-XPERT | 1.12 | | |
| AIRCOOL | 5.01E, 5.01F, 5.02G, 5.11H, 5.2I, 6.1 | | |
| AIRSYS | 1.03 | | |
| ANYSHEET | 1.3 | | |
| AVESPC | 1.0 | | |
| AXISOL | 1.0 | | |
| BOXEQ | 1.0 | | |
| BULKTEM | 2.0 | | |
| CANISTER | 1.0 | | |
| CELLDAN | 4.3 | | |
| CHANBP6.TRU | 1.0 | | |
| CONPRO | 1.0 | | |
| CORRE.FOR | 1.3 | | |
| CROSSTIE.FOR | 1.0 | | |
| DECAY | 1.4 | | |
| DYNARACK (also known as DYNAMO XXXX) | 1.5 thru 1.13 inclusive | | |

† The code(s) used in this report are checkmarked (x) in this column.
* This list is adapted from the "Holtec Approved Computer Program List" issued by Holtec Quality Assurance Manager.

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**EXHIBIT 3.2-3 (Page 2 of 4)**
**QA VALIDATED COMPUTER PROGRAM LIST**

| PROGRAM | VERSION | CODE USED | Computer Environment |
|---|---|---|---|
| DYNA-2D | HI-95 | | |
| FLANGE | 2.0 | | |
| FLUENT | 4.3, 4.32 | | |
| SFMR2 | 1.1 | | |
| ST-XPERT | 2.01 | | |
| STAT1CD.FOR | 1.0 | | |
| STER | 3.12B, 3.22A, 3.22C, 3.24D, 3.3E, 4.12, 5.04 | | |
| TBOIL | 1.7, 1.6 | | |
| THERPOOL | 1.2, 1.2A | | |
| TUBVIB | 2.0 | | |
| UBAX | 1.0 | | |
| UFLOW.FOR | 1.0 | | |
| VIB1DOF | 1.0 | | |
| VMCHANGE.FOR | 1.4, 1.3 | | |
| BOUND.FOR | 1.0 | | |
| MAXDISP.FOR | 1.2 | | |
| SFMR2A.FOR | 1.0 | | |
| PD16 | 1.1, 1.0 | | |
| SPG16 | 1.0 | | |
| FIMPACT | 1.0 | | |
| MAXDIS16 | 1.0 | | |
| PREDYNA1 | 1.5, 1.4 | | |
| GENEQ.FOR | 1.3 | | |

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EXHIBIT 3.2-3 (Page 3 of 4)
QA VALIDATED COMPUTER PROGRAM LIST

| PROGRAM | VERSION | CODE USED | Computer Environment |
|---|---|---|---|
| HEATER | 1.0 | | |
| HEXTEM | 1.0 | | |
| HEXTRAN | 1.2 | | |
| HYSYST | 1.01 | | |
| IBP.DAT | 1.0 | | |
| INSYST | 2.01 | | |
| LONGOR | 1.0 | | |
| LNSMTH2.FOR | 1.0 | | |
| LUINVS.F | 1.0 | | |
| MASSINV.FOR | 1.5 | 1.5 | WIN 95 Pentium |
| MR2.FOR | 1.4 through 1.9 | 1.8 | WIN 95 Pentium |
| MR216.FOV | 1.0 | | |
| MRPLOT.FOR | 1.2 | | |
| MR2 POST PROCESSORS | 2.0 | | |
| MSREFINE.FOR | 1.3 | 1.3 | WIN 95 Pentium |
| MULPOOLD | 1.4, 1.3 | | |
| MULTI1.FOR | 1.3, 1.4, 1.5 | | |
| ONEPOOL | 1.4, 1.4.1, 1.5 | | |
| PIPE PLUS | 5.04-3H | | |
| LS-DYNA3D | 936 | | |
| PREMULT2.FOR | 1.0 | | |
| PREMULT8.FOR | 1.0 | | |
| PRESPRG8.FOR | 1.0 | | |

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EXHIBIT 3.2-3 (Page 4 of 4)
QA VALIDATED COMPUTER PROGRAM LIST

| PROGRAM | VERSION | CODE USED | Computer Environment |
|---|---|---|---|
| SACS | 1.0 | | |
| SCALE (SAS2H AND ORIGEN-S MODULES) | 4.3 | | |
| TRIEL | 2.0 | | |
| WORKING MODEL | 3.0 | | |

**NOTES:**

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

# APPENDIX B

# APPENDIX B - CALCULATION OF HI-STORM CASK MASS AND INERTIA PROPERTIES FOR PSF AND PAD MASS AND INERTIA PROPERTIES

## B-1.0 Assumptions

For calculating masses and inertia, use bounding weights of MPC-32.

Assume centroids of cylinders are at half length when computing property values. This is consistent with approximations of modeling and is conservative.

Assume centroid of composite structure is at center of cylinder when obtaining total inertia properties. Any numerical differences due to this assumption are within the accuracy of the basic model.

## B-2.0 Analysis

### B-2.1 Overpack

Consider as hollow cylinder with specified weight

Input Data from [2]

$a_o := .5 \cdot 132.5 \cdot in$ $\quad a_i := .5 \cdot 73.5 \cdot in$ $\quad L := 231.25 \cdot in$

Overpack weight is the total weight on the pad - weight of bounding MPC for PSF

$W_{ovp} := 267664 \cdot lbf$ $\quad W_{mpc} := 88857 \cdot lbf$ [2,table 3.2.1]

$W_{total} := W_{ovp} + W_{mpc}$ $\quad W_{total} = 3.565 \cdot 10^5 \cdot lbf$

Compute the cross-section area so that an equivalent mass density may be defined

$$Area := \pi \cdot \left(a_o^2 - a_i^2\right) \qquad Area = 9.546 \cdot 10^3 \cdot in^2$$

$$\rho_{eff} := \frac{W_{ovp}}{g \cdot Area \cdot L} \qquad \rho_{eff} = 3.141 \cdot 10^{-4} \cdot lbf \cdot \frac{sec^2}{in^4}$$

$$mass_{ovp} := \frac{W_{ovp}}{g} \qquad mass_{ovp} = 693.272 \cdot lbf \cdot \frac{sec^2}{in}$$

Therefore, the inertia property of the hollow cylinder about a lateral axis is

$$I_{ovp} := \frac{1}{12}\cdot\left(\rho_{eff}\right)\cdot\left(\pi\cdot a_o^{2}\cdot L\right)\cdot\left(3\cdot a_o^{2}+L^{2}\right)\ \ldots$$
$$+\left(-\frac{1}{12}\cdot\rho_{eff}\right)\cdot\left(\pi\cdot a_i^{2}\cdot L\right)\cdot\left(3\cdot a_i^{2}+L^{2}\right)$$

$$I_{ovp} = 4.084\cdot10^{6}\ \cdot lbf\cdot sec^{2}\cdot in$$

The moment of inertia about a longitudinal axis through the center of the overpack is

$$I_{longovp} := \frac{1}{2}\cdot\left(\rho_{eff}\,\pi\cdot a_o^{2}\cdot L\right)\cdot a_o^{2} - \frac{1}{2}\cdot\left(\rho_{eff}\,\pi\cdot a_i^{2}\cdot L\right)\cdot a_i^{2}$$

$$I_{longovp} = 1.99\cdot10^{6}\ \cdot lbf\cdot sec^{2}\cdot in$$

B-2.2 MPC

B-2.2.1 Input data

$a_o := .5\cdot68.375\cdot in$ $L := 190.5\cdot in$

Properties are computed assuming MPC is a solid cylinder

$Area := \pi\cdot a_o^{2}$ $Area = 3.672\cdot10^{3}\ \cdot in^{2}$

$mass_{mpc} := \frac{W_{mpc}}{g}$ $mass_{mpc} = 230.147\cdot lbf\cdot\frac{sec^{2}}{in}$

$I_{mpc} := \left(\frac{1}{12}\cdot mass_{mpc}\right)\cdot\left(3\cdot a_o^{2}+L^{2}\right)$ $I_{mpc} = 7.633\cdot10^{5}\ \cdot lbf\cdot sec^{2}\cdot in$

B-2.3 Pad

The pad size for this analysis is 30' x 64' x 3' - Ref. SWEC 3/31/97 letter

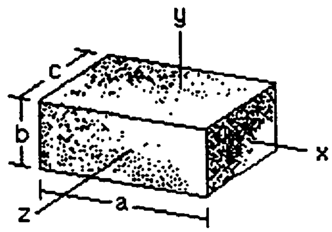
$$\gamma_{concrete} := 150\cdot\frac{lbf}{ft^{3}}$$

$a := 64 \cdot ft$ $b := 3 \cdot ft$ $c := 30 \cdot ft$

$$mass := \frac{\gamma_{concrete}}{g} \cdot a \cdot c \cdot b$$

$$mass = 2.238 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$$

$mass_c := mass$




**Mass moment of inertia:**

$$I_x := \frac{1}{12} \cdot mass \cdot \left(b^2 + c^2\right)$$ $$I_x = 2.441 \cdot 10^7 \cdot lbf \cdot in \cdot sec^2$$

moment about x

$$I_y := \frac{1}{12} \cdot mass \cdot \left(c^2 + a^2\right)$$ $$I_y = 1.342 \cdot 10^8 \cdot lbf \cdot in \cdot sec^2$$

moment about y

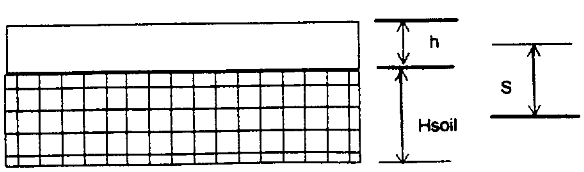
$$I_z := \frac{1}{12} \cdot mass \cdot \left(a^2 + b^2\right)$$ $$I_z = 1.102 \cdot 10^8 \cdot lbf \cdot in \cdot sec^2$$

moment about z

B-2.4 Mass and Inertia Properties for Underlying Soil

In this section, we assume an equivalent thickness of soil moves with the pad. The equivalent thickness is different for each mode of motion and is computed in the calculation of foundation spring constants. In all cases, it is assumed that the soil block is rectangular and lies below the cask soil interface. Therefore, the desired inertia properties must reflect the distance between the centroid of the soil block and the centroid of the pad. Note that in the dynamic analysis, the pad degrees of freedom are defined at the centroid of the pad.

In all inertia calculations, the soil is located as follows:



$\gamma_s := 81 \cdot \frac{lbf}{ft^3}$   $L := 64 \cdot ft$   $B := 30 \cdot ft$ SWEC Letter

$h_c := b$   $h_c = 3 \cdot ft$

$A := L \cdot B$   $A = 1.92 \cdot 10^3 \cdot ft^2$

Vertical mode

$h_v := .27 \cdot A^{.5}$   $h_v = 11.831 \cdot ft$

$M_v := \frac{\gamma_s}{g} \cdot A \cdot h_v$   $M_v = 4.766 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$

Horizontal mode

$h_h := .05 \cdot A^{.5}$   $h_h = 2.191 \cdot ft$

$M_h := \frac{\gamma_s}{g} \cdot A \cdot h_h$   $M_h = 882.512 \cdot lbf \cdot \frac{sec^2}{in}$

Rocking mode

$h_r := .35 \cdot A^{.5}$   $h_r = 15.336 \cdot ft$

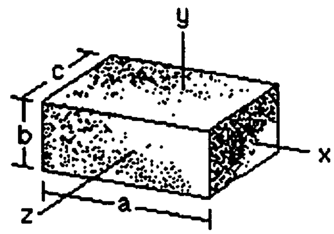
$M_r := \frac{\gamma_s}{g} \cdot A \cdot h_r$   $M_r = 6.178 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$

For soil inertia properties for the rocking mode, let

$S := \frac{1}{2} \cdot (h_c + h_r)$   $S = 9.168 \cdot ft$

$a = 64 \cdot ft$   $b := h_r$   $c = 30 \cdot ft$   $mass := M_r$

Then, inertia properties with respect to the soil block centroid, and then referred to the concrete pad centroid are given as:




**Mass moment of inertia about pad centroid:**

$I_{xs} := \frac{1}{12}\cdot mass\cdot\left(b^2 + c^2\right) + mass\cdot S^2$ $\quad I_{xs} = 1.589\cdot 10^8 \cdot lbf\cdot in\cdot sec^2$

moment about x

$I_{zs} := \frac{1}{12}\cdot mass\cdot\left(a^2 + b^2\right) + mass\cdot S^2$ $\quad I_{zs} = 3.958\cdot 10^8 \cdot lbf\cdot in\cdot sec^2$

moment about z

## Torsional mode

$h_t := .25\cdot A^{.5}$ $\quad h_t = 10.954\cdot ft$

$M_t := \frac{\gamma_s}{g}\cdot A\cdot h_t$ $\quad M_t = 4.413\cdot 10^3 \cdot lbf\cdot\frac{sec^2}{in}$

$mass := M_t$ $\quad b := h_t$

$I_{ys} := \frac{1}{12}\cdot mass\cdot\left(a^2 + b^2\right)$ $\quad I_{ys} = 2.232\cdot 10^8 \cdot lbf\cdot in\cdot sec^2$

moment about z

Therefore, the final combined mass and inertia properties for input into the dynamic analysis program are

Vertical

$mass_y := mass_c + M_v$

$mass_y = 7.003\cdot 10^3 \cdot lbf\cdot\frac{sec^2}{in}$

horizontal

$mass_h := mass_c + M_h$

$mass_h = 3.12\cdot 10^3 \cdot lbf\cdot\frac{sec^2}{in}$

rotation about x and z axes

$I_{rx} := I_x + I_{xs}$ $I_{rx} = 1.833 \cdot 10^8 \cdot lbf \cdot sec^2 \cdot in$

$I_{rz} := I_z + I_{zs}$ $I_{rz} = 5.061 \cdot 10^8 \cdot lbf \cdot sec^2 \cdot in$

rotation about the vertical y axis

$I_{ry} := I_y + I_{ys}$ $I_{ry} = 3.574 \cdot 10^8 \cdot lbf \cdot sec^2 \cdot in$

B-3.0 References

All dimensions and weights used are estimates based on:

[1] HI-951327, Rev. 1, Calc. 1 (the HI-STAR backup calculation package) for the MPC

[2] HI-951312, Rev. 1 (the HI-STORM TSAR) for the overpack.

# APPENDIX C

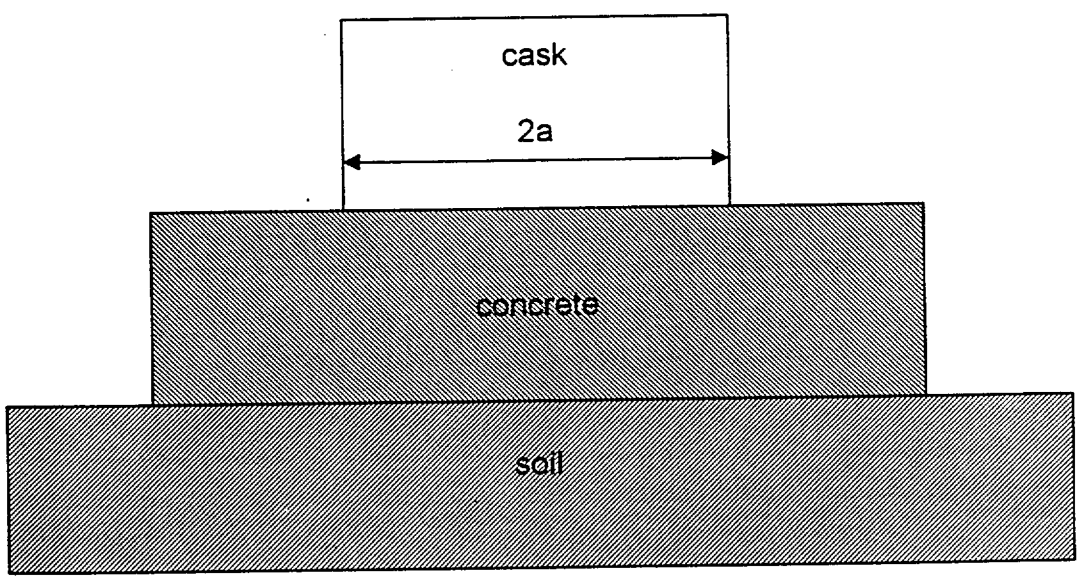
# APPENDIX C CALCULATION OF SPRING CONSTANTS FOR HI-STORM SEISMIC ANALYSIS IN STORAGE FACILITY

Scope: Determine all spring rates for HI-STORM seismic model for storage scenario.

## C-1.0 Spring rate for concrete contact

Conservatively use elastic spring rate based on classical solution for rigid punch on a semi-infinite half space. We neglect the effect of the underlying soil since this effect is included in the spring set representing the soil behavior. For the purpose of establishing a local spring rate for the pad resistance, the solution for a circular contact patch on a concrete half space is used. Following the reference below,

Reference: Timoshenko and Goodier, Theory of Elasticity, Third Edition, McGraw-Hill, 1970, pp. 407-409.



Properties

Concrete compressive strength

$f_c := 4000 \cdot psi$

Concrete Young's Modulus

$E_c := 57000 \cdot \sqrt{f_c \cdot psi}$ (ACI Code, 318-89, or similar)

$E_c = 3.605 \cdot 10^6 \cdot psi$

Poisson's Ratio of Concrete $\nu_c := .17$

Contact Patch Radius of Each Cask

$a := \frac{132.5}{2} \cdot in$ $a = 66.25 \cdot in$

$Area_t := \pi \cdot a^2$ $Area_t = 95.754 \cdot ft^2$

The spring rate for the contact between cask and concrete pad is set as

$K = (E_c (Area_t)^{1/2})/(m(1-\nu_c^2))$ $m := .96$

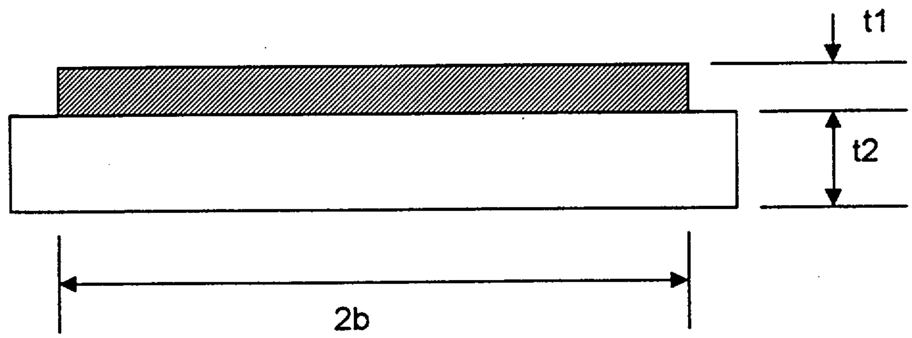
$$K := \frac{E_c \cdot \sqrt{Area_t}}{m \cdot \left(1 - \nu_c^2\right)} \qquad K = 4.541 \cdot 10^8 \cdot \frac{lbf}{in}$$

The resistance to the cask motion is concentrated around the periphery; therefore, if NS is the number of individual springs situated around the periphery, the value for K for each spring is

$$NS := 36 \qquad k := \frac{K}{NS} \qquad k = 1.261 \cdot 10^7 \cdot \frac{lbf}{in}$$

## C-2.0 Flat Plate-to-Flat Plate Contact

### C-2.1 MPC-to Overpack at base of cask




$b := \frac{68.375}{2} \cdot in$ $t1 := 2.5 \cdot in$ MPC

$b = 34.188 \cdot in$ $t2 := 22 \cdot in$ Overpack Concrete

$\nu := .3$

Use solution for concrete patch subjected to rigid punch

$f_{c1} := 4000 \cdot psi$ $Area_t := \pi \cdot b^2$

$E_{c1} := 57000 \cdot \sqrt{f_{c1} \cdot psi}$ $E_{c1} = 3.605 \cdot 10^6 \cdot psi$

$K := \frac{E_{c1} \cdot \sqrt{Area_t}}{m \cdot \left(1 - \nu_c^2\right)}$ $K = 2.343 \cdot 10^8 \cdot \frac{lbf}{in}$

Use 10% of this value for MPC-overpack contact at the top of the unit based on engineering judgement of the relative stiffnesses.

## C-3.0 MPC Cannister to Overpack Containment Shell

Since the impact is of a steel structure (the MPC) radially against a concrete structure (the overpack), use the solution given above with 4000 psi concrete assuming a 6"diameter contact patch.

$b_2 := 3 \cdot in$ $f_{c2} := 4000 \cdot psi$ $Area_t := \pi \cdot b_2^2$

$E_{c2} := 57000 \cdot \sqrt{f_{c2} \cdot psi}$ $E_{c2} = 3.605 \cdot 10^{6} \cdot psi$

$K := \frac{E_{c2} \cdot \sqrt{Area_t}}{m \cdot \left(1 - \nu_c^{2}\right)}$ $K = 2.056 \cdot 10^{7} \cdot \frac{lbf}{in}$

This spring acts in series with the spring constant from a channel. The finite element results give a spring constant per channel (6" length)

$k_{chan} := 1788990. \cdot \frac{lbf}{in}$

We conservatively assume 1 channel acts in concert with 1 circular patch, but that two sets are in contact for any impact. Therefore, the calculated spring rate for the combination is doubled for input into the dynamic analysis program.

$K_{combo} := \frac{2 \cdot k_{chan} \cdot K}{K + k_{chan}}$

$K_{combo} = 3.292 \cdot 10^{6} \cdot \frac{lbf}{in}$

C-4.0 Soil Springs Per Compression and Shear Wave Data Provided by SWEC - 30' x 64' Pad

Based on final soil measurements, the soil compression and shear moduli have been measured and provided to Holtec.

Ref. Stone and Webster Letter of 3/31/97, S-V-119, File # PO100PR1.2C

$E_{soil} := 1915000 \cdot \frac{lbf}{ft^{2}}$ $G_{soil} := 668000 \cdot \frac{lbf}{ft^{2}}$ $\nu_{soil} := .433$

Based on this data, calculations are performed for horizontal, vertical, rocking, and torsional modes of vibration of the soil. These calculations establish spring constants, damping coefficients, and virtual mass that are used to characterize the soil in the dynamic model. The references for the calculations are:

a) AISC Standard, "Seismic Analysis of Safety Related Nuclear Structures and Commentary.........", Approved, September, 1986, Tables 3300-1 and 2, and Figure 3300-3.

b) Newmark and Rosenblueth, Fundamentals of Earthquake Engineering, Prentice Hall, 1971, p.98.

a) is used for spring constants and dashpots, and b) is used for calculation of effective prism heights of soil in determining virtual mass effects.

C-4.1 Calculation of Spring Constants

$L := 64 \cdot ft$ $B := 30 \cdot ft$ $H := 3 \cdot ft$ $\gamma_s := 81 \cdot \frac{lbf}{ft^3}$ From SWEC reference letter

$\gamma_c := 150 \cdot \frac{lbf}{ft^3}$

For horizontal motion in either direction,

following the formulas from reference a),

Horizontal excitation parallel to long direction of pad

$L_p := L$ $L_n := B$ $\frac{L_p}{L_n} = 2.133$ $\beta_x := .95$

$K_{hl} := 2 \cdot (1 + \nu_{soil}) \cdot \beta_x \cdot G_{soil} \cdot \sqrt{L_p \cdot L_n}$ $K_{hl} = 6.64119 \cdot 10^6 \cdot \frac{lbf}{in}$

Horizontal excitation parallel to short direction of pad

$L_p := B$ $L_n := L$ $\frac{L_p}{L_n} = 0.469$ $\beta_x := 1.0$

$K_{hs} := 2 \cdot (1 + \nu_{soil}) \cdot \beta_x \cdot G_{soil} \cdot \sqrt{L_p \cdot L_n}$ $K_{hs} = 6.99072 \cdot 10^6 \cdot \frac{lbf}{in}$

For vertical motion

$\beta_z := 2.25$

$$K_{v1} := \beta_z \cdot G_{soil} \cdot \frac{\sqrt{L \cdot B}}{\left(1 - \nu_{soil}\right)} \qquad K_{v1} = 9.679 \cdot 10^{6} \cdot \frac{lbf}{in}$$

For rocking about an axis parallel to the short side of the pad

$$\beta_{\psi s} := .6$$

$$K_{rs} := \beta_{\psi s} \cdot G_{soil} \cdot \frac{B \cdot L^2}{\left(1 - \nu_{soil}\right)} \qquad K_{rs} = 1.042 \cdot 10^{12} \cdot lbf \cdot in$$

For rocking about an axis parallel to the long side of the pad

$$\beta_{\psi l} := .45$$

$$K_{rl} := \beta_{\psi l} \cdot G_{soil} \cdot \frac{L \cdot B^2}{\left(1 - \nu_{soil}\right)} \qquad K_{rl} = 3.664 \cdot 10^{11} \cdot lbf \cdot in$$

For torsional motion,

$$R := \left[\frac{B \cdot L}{6 \cdot \pi} \cdot \left(B^2 + L^2\right)\right]^{.25} \qquad R = 26.709 \cdot ft$$

$$K_{t1} := 16 \cdot G_{soil} \cdot \frac{R^3}{3} \qquad K_{t1} = 8.146 \cdot 10^{11} \cdot lbf \cdot in$$

The soil damping values for each spring are computed as follows:

Define the following effective radii

$$R_d := \sqrt{L \cdot \frac{B}{\pi}} \qquad R_d = 24.722 \cdot ft$$

$$R_{short} := \left(B \cdot \frac{L^3}{3 \cdot \pi}\right)^{.25} \qquad R_{short} = 30.224 \cdot ft$$

$$R_{long} := \left(L \cdot \frac{B^3}{3 \cdot \pi}\right)^{.25} \qquad R_{long} = 20.693 \cdot ft$$

Then, the damping constants appropriate to the various modes are:

displacement parallel to long direction

$$c_{hl} := .576 \cdot K_{hl} \cdot R_d \cdot \sqrt{\frac{\gamma_s}{g \cdot G_{soil}}} \qquad c_{hl} = 1.836 \cdot 10^5 \cdot lbf \cdot \frac{sec}{in}$$

displacement parallel to short direction

$$c_{hs} := .576 \cdot K_{hs} \cdot R_d \cdot \sqrt{\frac{\gamma_s}{g \cdot G_{soil}}} \qquad c_{hs} = 1.933 \cdot 10^5 \cdot lbf \cdot \frac{sec}{in}$$

displacement vertical

$$c_{vl} := .85 \cdot K_{vl} \cdot R_d \cdot \sqrt{\frac{\gamma_s}{g \cdot G_{soil}}} \qquad c_{vl} = 3.949 \cdot 10^5 \cdot lbf \cdot \frac{sec}{in}$$

To compute appropriate damping values for the rocking and torsion soil springs, certain mass moments of inertia of the pad are required:

Io = mass moment of inertia about the pad base rocking axis
It = mass moment of inertia about the pad torsional axis

$$mass := \frac{\gamma_c}{g} \cdot L \cdot B \cdot H \qquad I_t := \frac{1}{12} \cdot mass \cdot \left(L^2 + B^2\right) \qquad I_t = 1.342 \cdot 10^8 \cdot lbf \cdot sec^2 \cdot in$$

about an axis parallel to the long side of the pad

$$I_{ol} := \frac{1}{12} \cdot mass \cdot \left(B^2 + H^2\right) + mass \cdot \left(\frac{H}{2}\right)^2 \qquad I_{ol} = 2.514 \cdot 10^7 \cdot lbf \cdot sec^2 \cdot in$$

about an axis parallel to the short side of the pad

$$I_{os} := \frac{1}{12} \cdot mass \cdot \left(L^2 + H^2\right) + mass \cdot \left(\frac{H}{2}\right)^2 \qquad I_{os} = 1.11 \cdot 10^8 \cdot lbf \cdot sec^2 \cdot in$$

Then, following the reference cited above, define, for axis of rotation parallel to the short side of the pad,

$$\beta_s := \frac{3 \cdot \left(1 - \nu_{soil}\right) \cdot I_{os}}{8 \cdot \frac{\gamma_s}{g} \cdot R_{short}^{\;5}} \qquad \beta_s = 0.031$$

$$c_{rs} := \frac{.3}{(1+\beta_s)} \cdot K_{rs} \cdot R_{short} \cdot \sqrt{\frac{\gamma_s}{g \cdot G_{soil}}} \qquad c_{rs} = 1.78 \cdot 10^{10} \cdot \mathrm{lbf \cdot sec \cdot in}$$

For axis of rotation parallel to the short side of the pad,

$$\beta_l := \frac{3 \cdot (1 - \nu_{soil}) \cdot I_{ol}}{8 \cdot \frac{\gamma_s}{g} \cdot R_{long}^{5}} \qquad \beta_l = 0.047$$

$$c_{rl} := \frac{.3}{(1+\beta_l)} \cdot K_{rl} \cdot R_{long} \cdot \sqrt{\frac{\gamma_s}{g \cdot G_{soil}}} \qquad c_{rl} = 4.219 \cdot 10^{9} \cdot \mathrm{lbf \cdot sec \cdot in}$$

For rotation about the vertical axis

$$c_{tl} := \frac{\sqrt{K_{tl} \cdot I_t}}{1 + 2 \cdot I_t \cdot \frac{g}{\gamma_s \cdot R^5}} \qquad c_{tl} = 6.322 \cdot 10^{9} \cdot \mathrm{lbf \cdot sec \cdot in}$$

C-4.2 Height of Soil Prism for Virtual Mass Calculation

To define virtual mass of the soil, the height of the soil prism is needed. Following the Ref. b), we compute the the prism height, and the virtual soil mass using the specified density from the SWEC letter.

$$A := L \cdot B \qquad A = 1.92 \cdot 10^{3} \cdot \mathrm{ft}^2$$

Vertical mode

$$h_v := .27 \cdot A^{.5} \qquad h_v = 11.831 \cdot \mathrm{ft}$$

$$M_v := \frac{\gamma_s}{g} \cdot A \cdot h_v \qquad M_v = 4.766 \cdot 10^{3} \cdot \mathrm{lbf} \cdot \frac{\mathrm{sec}^2}{\mathrm{in}}$$

Horizontal mode

$h_h := .05 \cdot A^{.5}$ $\quad h_h = 2.191 \cdot ft$

$M_h := \frac{\gamma_s}{g} \cdot A \cdot h_h$ $\quad M_h = 882.512 \cdot lbf \cdot \frac{sec^2}{in}$

Rocking mode

$h_r := .35 \cdot A^{.5}$ $\quad h_r = 15.336 \cdot ft$

$M_r := \frac{\gamma_s}{g} \cdot A \cdot h_r$ $\quad M_r = 6.178 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$

Torsional mode

$h_t := .25 \cdot A^{.5}$ $\quad h_t = 10.954 \cdot ft$

$M_t := \frac{\gamma_s}{g} \cdot A \cdot h_t$ $\quad M_t = 4.413 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$

## C-4.3 Calculated Results from the SWEC Document

The SWEC letter provided some information concerning springs, dampers, and soil masses given in terms of the pad area. Here, we present those evaluations for comparison with the results obtained here.

Using the value for the representative pad section A = 30' x 64'

$A := 30 \cdot 64 \cdot ft^2$

Vertical $\quad K_{v3} := 59000 \cdot \frac{lbf}{ft^3} \cdot A$ $\quad K_{v3} = 9.44 \cdot 10^6 \cdot \frac{lbf}{in}$

$c_{v3} := 1940 \cdot lbf \cdot \frac{sec}{ft^3} \cdot A$ $\quad c_{v3} = 3.104 \cdot 10^5 \cdot lbf \cdot \frac{sec}{in}$

$M_{v3} := 30 \cdot \frac{lbf}{3} \cdot sec^2 \cdot A$ $\quad M_{v3} = 4.8 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$

$M_{v3} := 30 \cdot \frac{lbf}{ft^3} \cdot sec^2 \cdot A$ $\quad M_{v3} = 4.8 \cdot 10^3 \cdot lbf \cdot \frac{sec^2}{in}$

**Horizontal**

$K_{h3} := 40000 \cdot \frac{lbf}{ft^3} \cdot A$ $\quad K_{h3} = 6.4 \cdot 10^6 \cdot \frac{lbf}{in}$

$c_{h3} := 970 \cdot lbf \cdot \frac{sec}{ft^3} \cdot A$ $\quad c_{h3} = 1.552 \cdot 10^5 \cdot lbf \cdot \frac{sec}{in}$

$M_{h3} := 5.5 \cdot \frac{lbf}{ft^3} \cdot sec^2 \cdot A$ $\quad M_{h3} = 880 \cdot lbf \cdot \frac{sec^2}{in}$

# APPENDIX D

To: Stan Macie, Stone and Webster
From: Dr. Alan I. Soler, Holtec International
Subject: Final Results for PSF Pad Loading
Holtec Project 60531
Date: 5/19/97

## TRANSMITTAL OF FINAL RESULTS (QA'd Material)

Enclosed find final results of the PSF seismic analysis pad interface forces for all cases considered. All of the data is transmitted in compressed form using the PKZIP file compression program. The files contain all of the information requested per our e-mail transmittals in early May, 1997. The files provided are self-extracting zipped files (e.g.,out808.exe); that is, copy the file to a hard disc and type "File.exe" to extract all of the compressed files in the zipped file "File.exe".

All results are presented in column format with the first column representing the time step (1-4000). The time interval between steps is 0.005 seconds. The file naming convention is shown by the following two representative names.

**H8082.CSV** H= horizontal force file, **8**=number of casks on pad, **0**=no significance, **8**=coeff. of friction=0.8, **2** =results are for cask #2 .

**V6023.CSV** V= vertical force file, **6**=number of casks on pad, **0**=no significance, **2**=coeff. of friction=0.2, **3**=results are for cask #3.

The files beginning with **V** have six columns, separated by commas, The columnar data represented is

col 1 time step
col 2 total vertical interface force from 36 interface elements (element 1 is at 3 o'clock (y=0, x positive)

col 3 total vertical interface force from 9 elements in first quadrant (elements 6-14)

col 4 total vertical interface force from 9 elements in second quadrant (elements 15-23)

col 5 total vertical interface force from 9 elements in third quadrant (elements 24-32)

col 6 total vertical interface force from 9 elements in fourth quadrant (elements 33-36; 1-5)

The files beginning with **H** have four columns, separated by commas, The columnar data represented is

col 1 time step

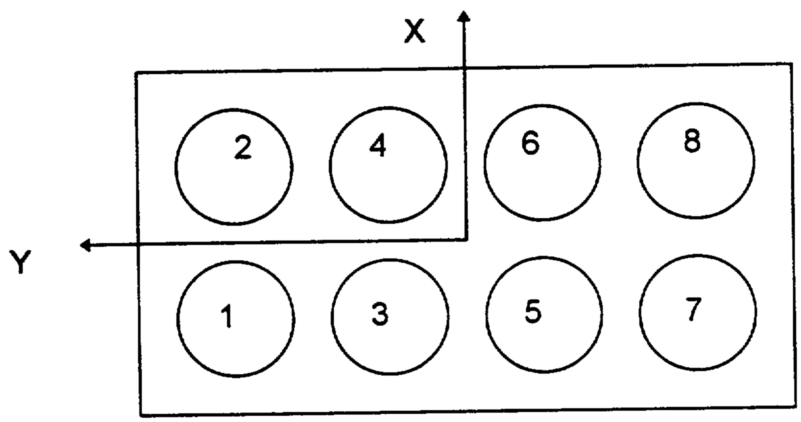
col 2 total x direction interface force from 36 interface friction elements (element 1 is at 3 o'clock (y=0, x positive)

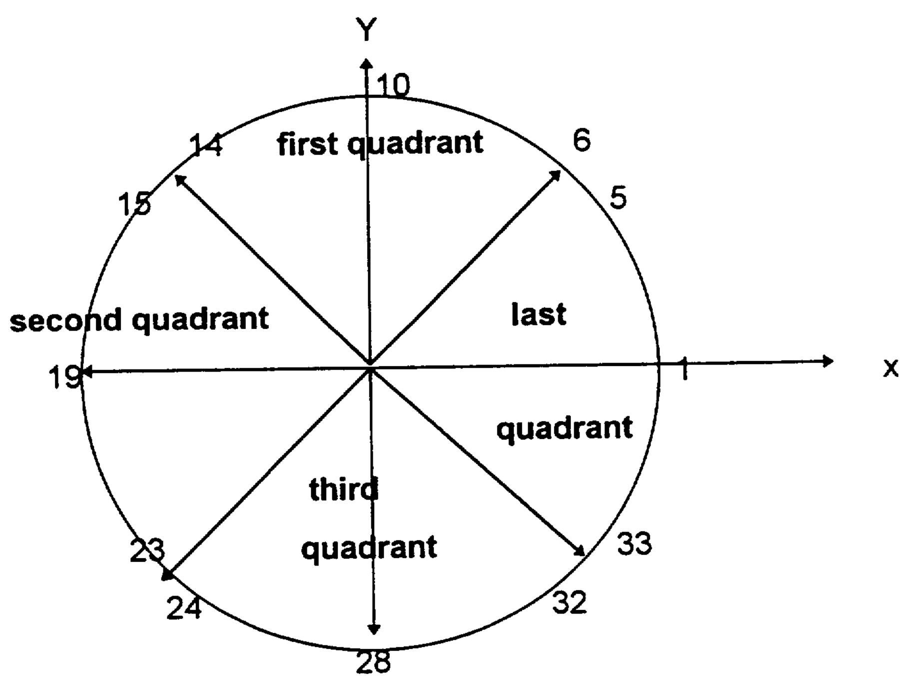
col 3 total y direction interface force from 36 interface friction elements

col 4 total resultant interface friction force (SRSS of column 2, column 3)

There is a third set of files on within each zipped file, labeled **O8024.OUT**, etc. These files are provided for information only. The only information which may be of use is a summary of maximum G level in the vertical and horizontal directions, respectively due to the interface forces for a given cask in a given run.

There are a total of 16 runs submitted: pad loaded with from 1 to 8 casks with each case performed twice with limiting coefficients of friction._The files are in ASCII format and can be read with any text processor once they are uncompressed. The numbering system for casks is as shown in the figure below:


X
Y
2
4
6
8
1
3
5
7


Y
10
first quadrant
14
6
15
5
second quadrant
last
19
1
X
quadrant
third
quadrant
23
33
24
32
28

Attachments: 8 floppy discs

| DISC# | SIMULATIONS |
|---|---|
| 1 | 602 |
| 2 | 202,308,508 |
| 3 | 208,608 |
| 4 | 302,808 |
| 5 | 802 |
| 6 | 702 |
| 7 | 402,708 |
| 8 | 102,108,408,502 |

# APPENDIX E

(CONTAINS PROPRIETARY INFORMATION)

# ATTACHMENT A

(CONTAINS PROPRIETARY INFORMATION)