HOLTEC INTERNATIONAL

Holtec Center, 555 Lincoln Drive West, Marlton, NJ 08053

Telephone (609) 797-0900
Fax (609) 797-0909

SCOPING SEISMIC ANALYSES OF HI-STORM ON A WESTERN AREA ISFSI

Holtec Report No.: HI-961574

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NON-PROPRIETARY VERSION

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Holtec Center, 555 Lincoln Drive West, Marlton, NJ 08053
Telephone (609) 797-0900
Fax (609) 797-0909

REVIEW AND CERTIFICATION LOG

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1.0 INTRODUCTION

The private storage facility (PSF) envisions over 4000 dry storage casks configured as a series of 2 x 4 arrays on a concrete pad. The current proposed array allots a 15' x 15' pad space to each spent fuel storage cask. In this scoping analysis, a three dimensional (3-D) time history set is applied to a single cask on a 15' x 15' x 3' concrete pad. The cask system weight and dimensions are those contemplated for HI-STORM. The purpose of the analyses contained herein is to establish the stability of the cask-pad system under the postulated high acceleration seismic event. 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.

Results from this study are considered preliminary in that

1. The seismic event postulated is not necessarily the finalized version for the site.

2. Results are based on preliminary soil data.

3. The dynamic model neglects interactions between casks arising from multiple casks placed on the same concrete pad.

This scoping report contains the following sections following this introduction:

Section 2 presents a brief summary of the input seismic time history and references a separate report for documentation.

Section 3 describes the cask-pad dynamic model. An appendix to this section contains an outline of the equations of motion governing the dynamic behavior .

Section 4 summarizes the cask and pad mass and inertia properties.

Section 5 summarizes the elastic and inelastic spring constant values used in the dynamic simulations.

Section 6 presents the results and of the dynamic simulations performed herein.

Section 7 is a conclusion section and section 8 lists references.

2.0 SEISMIC INPUTS

Based on preliminary ground response spectra, 3-D time histories (2 horizontal and 1 vertical) have been developed and documented in [1]. These time histories satisfy all bounding and statistical independence requirements of the USNRC [2]. The developed time histories are based on spectra data with zero period acceleration (ZPA) = 0.8.

3.0 CASK / PAD DYNAMIC MODEL

The HI-STORM cask system is modeled as two rigid bodies. The overpack is described by the behavior of six degrees of freedom which captures the rigid body motion of the overpack in inertial space. The internal MPC is modeled by 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 that rotational degree of freedom that is omitted. The dynamic model of the HI-STORM cask has eleven degrees of freedom. Six degrees of freedom establish the rigid body motion of the HI-STORM overpack in accordance with the following definitions:

q_1 = absolute displacement of overpack centroid in x (horizontal)

q_2 = absolute displacement of overpack centroid in y (horizontal)

q_3 = absolute displacement of overpack centroid in z (vertical)

q_4 = rotation of overpack about centroidal axis parallel to x direction.

q_5 = rotation of overpack about centroidal axis parallel to y direction.

q_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_7 = absolute displacement of MPC centroid in x.

q_8 = absolute displacement of MPC centroid in y.

q_9 = absolute displacement of MPC centroid in z.

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

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

The dynamic model simulating concrete pad behavior is characterized by the 6 degrees of freedom q_{12} to q_{17} with

q_{12}, q_{13}, q_{14} = absolute displacements in x, y and z directions of pad centroid.

q_{15}, q_{16}, q_{17} = rotations about axes through pad centroid parallel to x, y, z axes, respectively.

Figure 3.1 shows an exploded view of the dynamic model with all degrees of freedom included. Appendix A provides a brief development of the system equations of motion. 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.

4.0 MASS AND INERTIA PROPERTIES

The calculation of the MPC mass and inertia properties is based on dimensions and weights from [3]. The heaviest loaded MPC is the MPC-68 with the following characteristics:

weight = 86132 lb. Diameter = 68.375 in. Length = 190.5"

For the calculation of mass moments of inertia, the MPC is considered as a solid cylinder.

The calculation of the HI-STORM overpack is based on the weight specified in the initial TSAR submittal [4]; the weight has been amplified by an additional 5% to reflect an anticipated weight increase due to an increase in height. For this scoping analysis, the following values are used:

weight = 254000 lb. Outer Diameter = 132" Length = 231"
Inner Diameter = 73.5"

For calculation of mass moments of inertia, the overpack is considered as a hollow cylinder.

The ISFSI pad section modeled assumes a concrete weight density of 150 lb./cu. ft. in the calculation of pad mass and pad mass moments of inertia.

The detailed calculation methodology with results are maintained within Holtec's archive calculations for this project.

5.0 SPRING CONSTANTS FOR DYNAMIC SIMULATION6

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 preliminary characterization of the underlying base mat supporting the concrete pad.

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 [5]. The resulting spring constant assigned to compression only springs 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 scoping analysis, assuming a contact location at every 10 degrees round the outer circumference, is

k = 14050000 lb./in.

and a value 1000 times larger is used to simulate the interface friction behavior in each of two horizontal directions at each of the thirty six contact locations.

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 scoping 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 or top of overpack - K1 = 117200000 lb./in.
MPC shell-to-overpack inside shell - K2 = 41120000 lb./in.

To reflect the underlying base mat elastic behavior, preliminary soil modulus data appropriate to a high strain environment in the soil is used to determine horizontal, vertical, rocking, and torsion spring rates for the soil [6]. Appropriate soil damping values are also calculated. The soil Young's Modulus, shear modulus, and Poisson's Ratio used to obtain the spring rates are:

E = 250000 lb./sq. ft.
G = 80000 lb./sq. ft.
ν = 0.499

Using the cited reference, the following soil spring rates, acting at the base of the concrete pad, are calculated and used in the scoping study to connect the pad to a fixed reference.

Kv = 450500 lb./in.	(vertical)
Kh = 196600 lb./in.	(horizontal (2))
Kr = 3079000000 lb./in.	(rotation about horizontal axes (2))
Kt = 3103000000 lb./in.	(rotation about vertical axis)

The supporting theoretical development and the details of the calculations are maintained within Holtec's archival calculations for this project.

6.0 SEISMIC ANALYSES

6.1 Static Stability of the HI-STORM System

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

$$H=231".$$

The diameter of the circular contact interface is

$$D=132"$$

Therefore, to maintain static moment equilibrium at the instant of incipient tipping of the system requires that the horizontal "G" level be such that

$$G < .571$$

6.2 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 top of the cask 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 described in Appendix A is the Holtec QA validated code DYNACASK [7] 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 variable, 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 = 0.8G's), and for cases where the input time histories are all attenuated uniformly by a constant value to lower the peak amplitude of the time history (which is equal to the ZPA) to .70G's and to .60G's. The time histories of the response are plotted to demonstrate that the HI-STORM system is stable; the locus of the cask top center point displacement, relative to the point on the pad directly under the top center point at time t=0 sec., remains within the original contact patch envelope. Figures 6.1 to 6.3 present results for the design basis seismic event with interface coefficient of friction = 0.8. Figure 6.1 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" contact patch envelope on the pad. Figure 6.2 is a plot of the top center point displacement in the x direction versus time. Large motion occurs only for two cycles. Finally, Figure 6.3 shows that the position of the top center point of the cask also remains within the required envelope when the interface coefficient of friction is 0.2.

The effect of any reduction in the strength of the seismic event (i.e., a reduction in the ZPA and hence a reduction of the peak amplitude) is examined in the table below where the HI-STORM overpack maximum centroidal horizontal displacement (at elevation 115.5")in either direction is plotted for the case of coefficient of friction at the pad interface equal to 0.8 for ZPA levels of 0.8, 0.7, and 0.6. It is clear that any reduction in the strength of the design basis seismic event has considerable effect on the cask seismic behavior.

Maximum Centroid Displacement of Overpack

Peak Seismic Amplitude	0.8	0.7	0.6
X-displacement	18.1"	10.22"	3.03"
Y-displacement	15.3"	6.304"	3.24"

7.0 CONCLUSIONS

It is concluded, based on the dynamic simulations performed with the preliminary design basis seismic event, and with the preliminary soil data underlying the storage pad, that the HI-STORM system meets the requirements of dynamic stability with considerable margin of safety. Since only a single spent fuel storage cask has been modeled, however, no conclusions can be drawn concerning cask-to-cask impact with the current proposed cask spacing. A multi cask dynamic simulation is required with the underlying pad simulated as an elastic structure.

8.0 REFERENCES

[1] HI-961556, 3-D Time Histories for Private Storage Facility, Project 60531, 1996.

[2] NUREG 0800, SRP 3.7.1

[3] HI-951327, Rev. 1, Calculation Package Supporting HI-STAR 100 TSAR, 1996.

[4] HI-951312, Rev.1, HI-STORM 100 TSAR Submittal to USNRC, 1996, Docket #72-1014.

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

[6] Soil Spring SSI Improvements Based on Test Correlation of the Lotung SSI Experiment - Horizontal Excitation, A.H. Hadjian and H.T. Tang, Specialty Conference 92TRM252.

[7] DYNACASK (MR216 Version 1.0), 1996, Module 1.81.

FIGURE 3.1 DYNAMIC MODEL

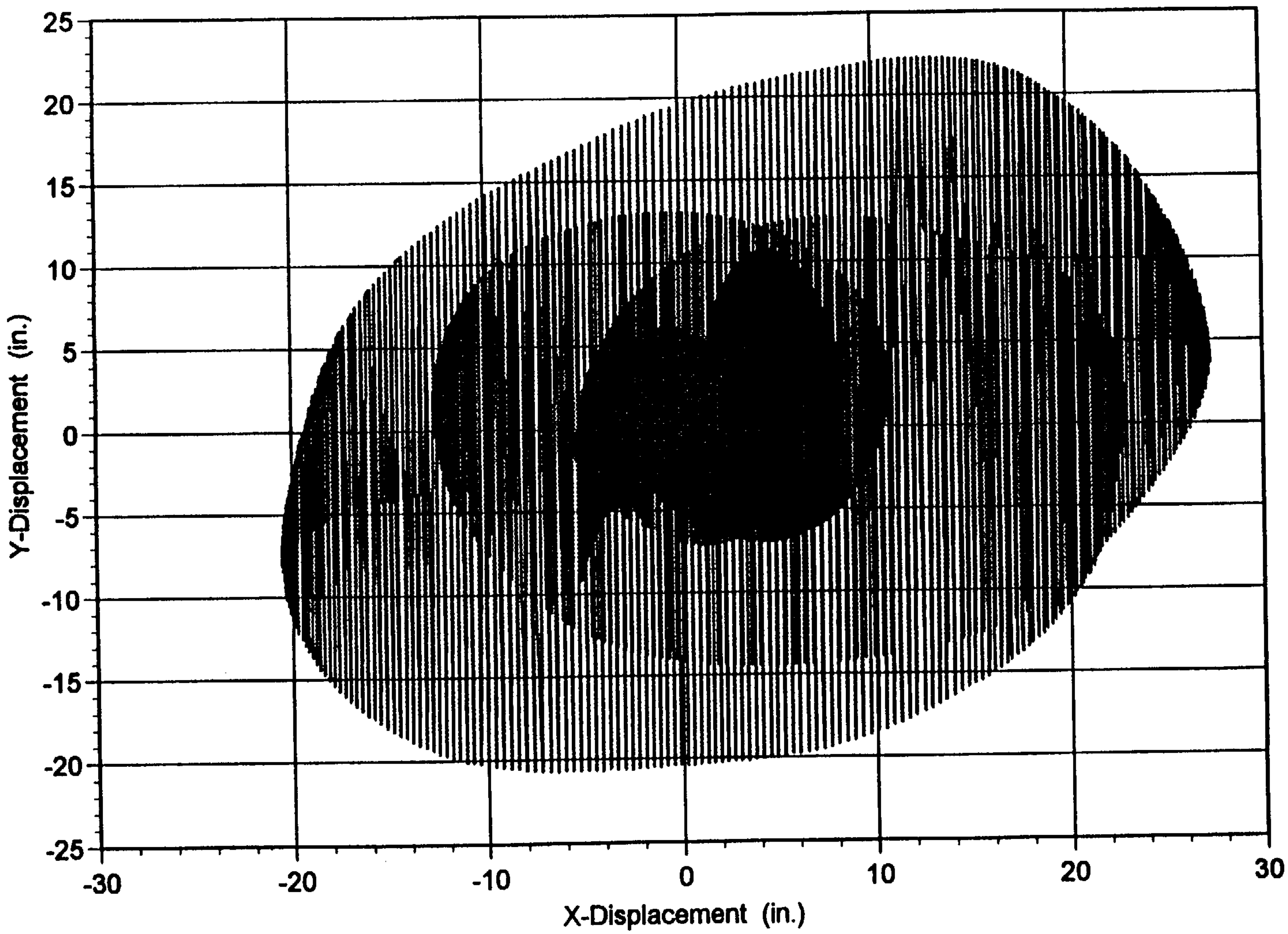

FIGURE 6.1 - LOCUS OF TOP CENTER POINT - HI-STORM SUBJECT TO .8G PSF SEISMIC EVENT - COF = 0.8

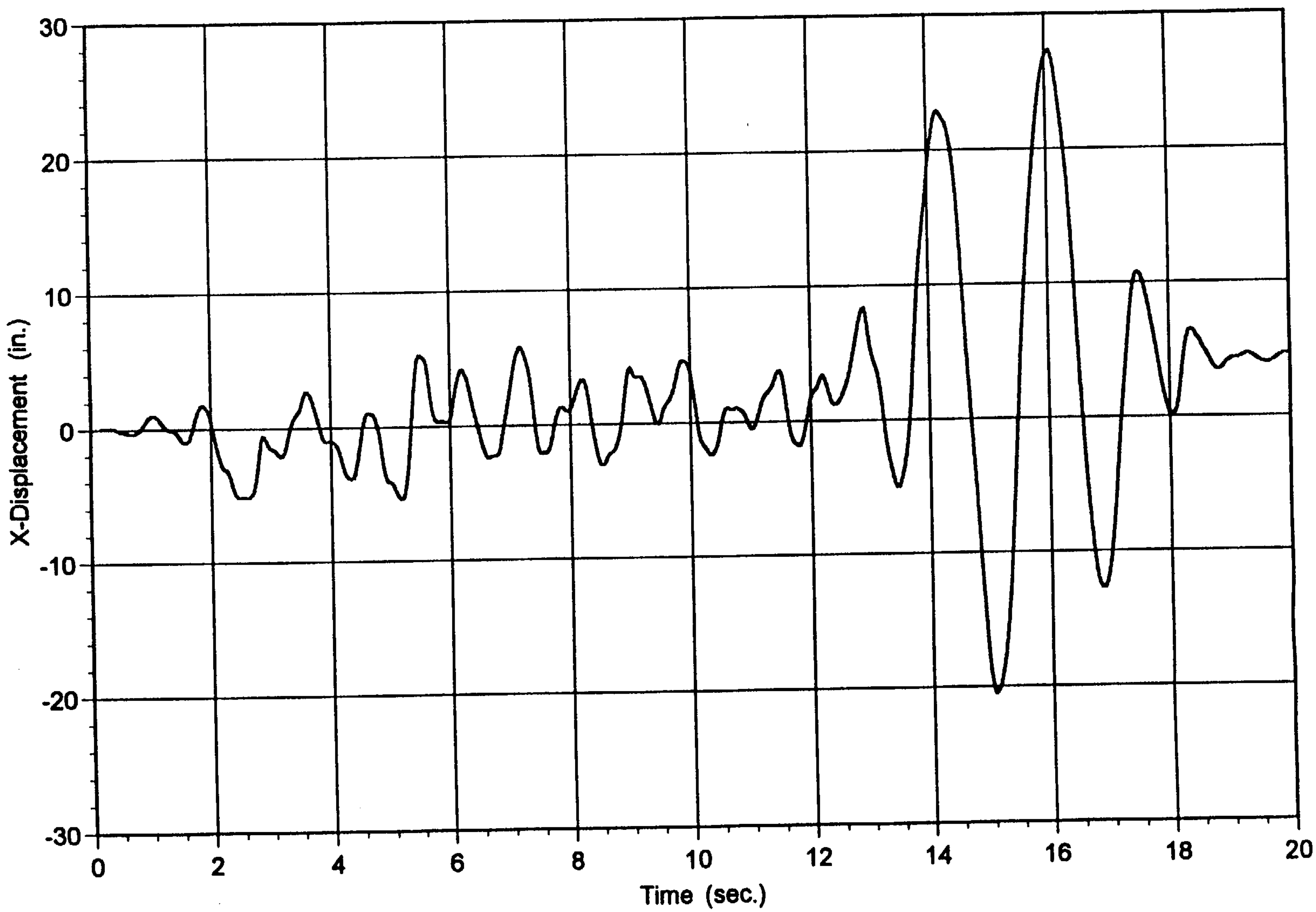

FIGURE 6.2 TOP CENTER DISPLACEMENT IN X VS. TIME - .8G, COF=0.8

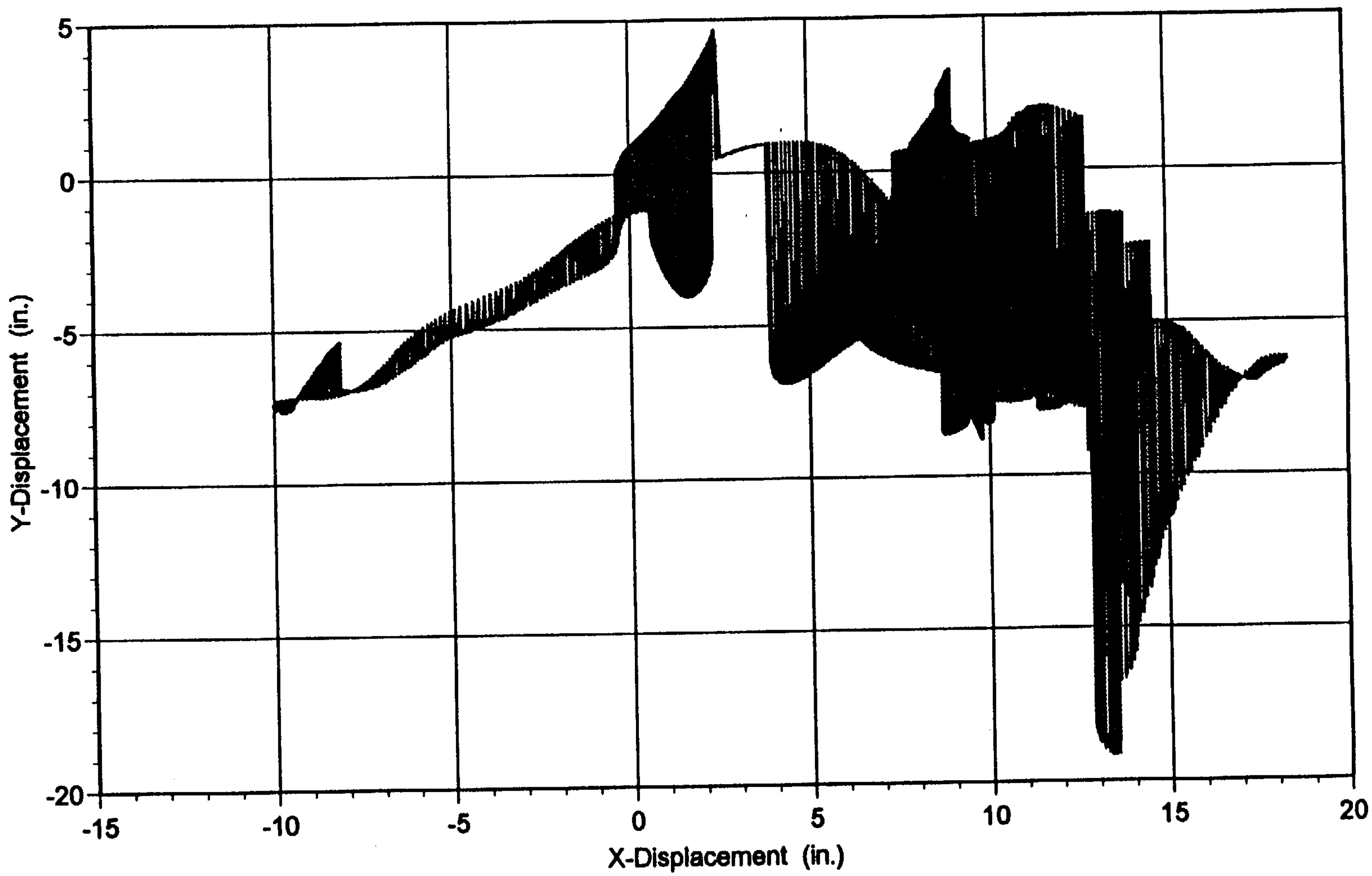

FIGURE 6.3 - LOCUS OF TOP CENTER POINT - HI-STORM SUBJECT TO .8G PSF SEISMIC EVENT - COF = 0.2

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APPENDIX A

HOLTEC PROPRIETARY INFORMATION

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