CLIENT: PFS LLC
CLIENT NO.: PSF-01
SNC NO.: PFS01-10.02.04
REVISON NO.: 0

# DESIGN CALCULATION

**FOR INFORMATION ONLY**

# SOIL-STRUCTURE INTERACTION ANALYSIS FOR EVALUATION OF TRANSTOR™ STORAGE CASK SESMIC STABILITY

**NONPROPRIETARY**

PREPARED BY

SIERRA NUCLEAR CORPORATION

APPROVED: William McConaghy
PROJECT MANAGER

DATE: 7/24/97

APPROVED:
ENGINEERING MANAGER

DATE: 7/24/97

Title: Soil-Structure Interaction Analysis for Evaluation of TranStor™ Storage Cask Seismic Stability
SNC No: PFS01-10.02.04

## REVISION CONTROL SHEET

| Rev. | Date | Reason | Affected pages | Preparer | Checker | Proj. Eng. |
|---|---|---|---|---|---|---|
| 0 | 7/97 | Initial issue | All ( 1-30 , Attachm. I-III) | BAC | IS | BAC |

## SIGNATURES

| Name/Title | Initials | Date |
|---|---|---|
| Boris Chechelnitsky/PE | BAC | 7/24/97 |
| Igor Shekhtman | IS | 7/24/97 |
| | | |
| | | |
| | | |
| | | |
| | | |

## 1.0 PURPOSE

The purpose of this calculation is to develop design basis seismic time histories at top surface of the PFS storage pad loaded with TranStor™ storage casks. These time histories are further used to evaluate the TranStor™ cask stability under the seismic loads it may experience during long-term storage at the Private Fuel Storage Facility site. The cask must withstand the specified seismic loads without tipping over.

## 2.0 RESULTS/CONCLUSIONS

Soil-structure interaction results in slight de-amplification of the free field motion and the peak accelerations at the cask base are somewhat lower than the original free field values. However, while the horizontal response spectra for different pad loading configurations are completely bounded by the corresponding spectrum used in the generic TranStor analysis, the vertical spectra are not. Therefore, to demonstrate the cask stability under the seismic excitation specified for the PFSF site, the possibility of tipover should be analyzed using the ANSYS finite element code similarly to the TranStor™ generic analysis.

By comparison of the resulting time histories and their spectra, the most critical excitations were determined to be the X-direction horizontal time history for the fully loaded pad and the vertical time history corresponding to the 1 cask condition. Although these loads correspond to different configurations and can not occur at the same time, the ANSYS analysis is conservatively performed using these time histories (the horizontal time history used is appropriately increased to account for the two-directional excitation).

## 3.0 DESIGN INPUT AND ASSUMPTIONS

3.1 Site soil properties are provided by Stone and Webster Engineering Corporation (SWEC) in Ref. 7.

3.2 The facility layout is provided in Ref. 1. The casks will be placed on 3' thick 64' x 30' storage pads in the 2 x 4 arrangement (e.g., groups of 8).

3.3 The free-field response spectra for the site (vertical and horizontal) are provided in Ref. 1. Three-dimensional earthquake is assumed.

3.4 The cask dimensions and properties are taken from Ref. 2 as follows:

| | |
|---|---|
| Cask diameter | 136" |
| Cask height | 220" |
| Cask c.g. height | 113.9" |
| Cask weight | 285 kips (conservative) |

3.5 The following loading permutations have been studied and evaluated to determine the worst-case accelerations:

a) all eight casks on the storage pad
b) four casks on one side of the pad
c) one cask near the pad center

3.6 The vertical and horizontal excitations are modeled by vertically propagating waves (P-wave for the vertical input, S-wave for the horizontal input).

## 4.0 METHODOLOGY

One of the important factors that must be considered when defining the structure response to an earthquake is that the ground input at the base of foundation may be influenced by presence of the structure itself. From the dynamics viewpoint, the seismic response of a dynamic system (free field soil) may be altered when another system of comparable mass (structure) is attached. As a result, the motion at the structure base may be different from the free field motion if the structure is heavy enough. Even if the structure is fairly light, there is a kinematic interaction effect such as a reflection of the vertically propagating seismic waves from the foundation. These soil-structure interaction effects are discussed in ASCE 4, Section 3.3 and the Commentary [Ref. 5].

To take into account soil-structure interaction at the PFSF site, the SASSI (System for Analysis of Soil-Structure Interaction) computer program is used. This program is a specialized finite-element code originally developed at UC Berkeley by Prof. J. Lysmer and his associates. The mainframe version of SASSI was modified into a PC version by Stevenson and Associates [Ref. 4]. The sequence of analysis is as follows:

a. Develop free field vertical and horizontal time histories which envelope the provided response spectra. 20 second time histories are generated.
b. Use SASSI to model the structure and soil in three dimensions. Embedment of the structure is adequately represented using 3-D solid elements. The casks are modeled as rigid bodies
c. Provide the generated free field time histories as input for SASSI.
d. Obtain the ~~time~~ translational time histories at the base of storage cask. This time history is to be used in the cask tipover analysis.

# 5.0 CALCULATIONS

## 5.1 Free-field time histories

Three free-field time histories were generated using STARDYNE 4.4. The time history produced by the program is such that its response spectrum matches or envelopes the SWEC response spectra provided as input. The duration was selected to be seconds and the time step is second. The resultant time histories are presented in Figures 1, 2, and 3 respectively. They are also provided in tabulated form in Attachment I. It must be noted that, although the vertical time history enveloped the input response spectrum, it did not achieve the specified ZPA value of 0.69g. Therefore, two points on the curve were manually forced up to the 0.69g level to meet this requirement.

The response spectra generated using the input time histories and their comparison with the original SWEC response spectra are shown in Figures 4, 5, and 6. The figures demonstrate close match between the target and actual response spectra. In addition, to assure adequate power distribution across the frequency spectrum the power spectral density (PSD) functions of the time histories have been generated using Fast Fourie Transforms on MathCad. The smoothed and actual PSDs for all three time histories are shown in Attachment III. It can be seen that the generated free-field time histories have a broad-band energy distribution (.4 Hz to 20 Hz as described in Ref. 8). Since the target response spectra are enveloped, the generated time histories accurately describes the PFSF site-specific earthquake.

## 5.2 Soil-structure interaction

The soil properties are provided in Ref. 1. In order to achieve SASSI convergence and to be consistent with Ref. 5, the highest frequency of the analysis were specified at approximately 25 Hz for both S-wave and P-wave. The soil layer thickness is determined in accordance with the SASSI manual (based on Ref. 5) which provides the following formula:

Since the soil properties change significantly with depth, the layer thickness also has to be varied. An EXCEL spreadsheet has been developed to determine the thicknesses to be used in the model. The corresponding properties are established by interpolation between the data point in Ref. 1. The spreadsheet is presented in Table 1.

The SASSI model is presented in Figure 7. Three-dimensional solid elements are used to model the storage foundation; the cask footprints are represented by high-stiffness beam elements and the cask mass properties are lumped at the footprint center.

The cask moment of inertia about an axis in the bottom plane is calculated as follows:

The cask moment of inertia about the vertical axis is calculated as follows:

Attachment II contains a printout of the SASSI input files. Figures 8 through 16 present the resulting time histories at the cask base and Figures 17 through 25 present the corresponding response spectra and their comparison to the generic spectra used in the TranStor analysis. The time histories for different casks in the same loading pattern were found to be essentially identical. As can be seen, the TranStor spectra bound the PFSF site-specific horizontal spectra with a comfortable margin. However, the vertical spectra in the range from approximately10 to 30 Hz are not bounded. Therefore, the additional tipover analysis is required to demonstrate the cask stability under the site-specific conditions.

## 6.0 REFERENCES

1. Letter S-V-118, Site-specific Cask Stability Analysis, SWEC (Stan Macie) to SNC (Bill McConaghy) , March 31, 1997.
2. Calc. TSL01-10.06.01, TranStor™ Storage System Weight and CG, Rev. 1.
3. M. Lindeberg, Seismic Design of Building Structures, Professional Publications, 1990.
4. Super SASSI/PC User's Manual, Rev. 0, Stevenson & Associates
5. ASCE-4, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, 1986
6. Not used.
7. Letter S-V-139, Site-specific Cask Stability Analysis, SWEC (Stan Macie) to SNC (Bill McConaghy), June 3, 1997.
8. NUREG/CR-5347, Recommendations for Resolutions of Public Comments on USI-40, "Seismic Design Criteria", Brookhaven National Laboratory

[ Pages 5 of 30 thru 30 of 30
are all proprietary. ]

[ Attachment I, pages I-1
thru I. 3-10, 31 pages
are all proprietary. ]

[ Attachment II, pages II-1
thru II. 12-11, 49 pages are all
proprietary. ]

[ Attachment III, pages III-1
thru 4 of 4, 4 pages are all
proprietary. ]