Seismic Structure-Soil-Structure Interaction Analysis of a Consolidated Dry Storage Module for CANDU Spent Fuels

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1. Introduction

The MACSTOR/KN-400 module has been developed as an effective alternative to the existing stand alone concrete canister for dry storage of CANDU spent fuel. The structure is a concrete monolith of 21.67 m long and 12.66 m wide and has a height equal to 7.518 m including the bottom slab. Inside the concrete module consists of 40 storage cylinders accommodating ten 60-bundle dry storage baskets, which are suspended from the top slab and eventually restrained at 10 cm above the bottom slab with horizontal seismic restraints. The main cooling process of the MACSTOR/KN-400 module shall be by air convection through air inlets and outlets. The civil design parameters, with respect to meteorological and seismic loads applied to the module are identical to those specified for the Wolsung CANDU 3&4 plants, except for local site characteristics required for soil-structure interaction (SSI) analysis.

It is required for the structural integrity to fulfill the licensing requirements. As per USNRC SRP Section 3.7.2 [1], it shall be reviewed how to consider the phenomenon of coupling of the dynamic response of adjacent structures through the soil, which is referred to as structure-soil-structure interaction (SSSI). The presence of closely spaced multiple structural foundations creates coupling between the foundations of individual structures [2]. Some observations of the actual seismic response of structures have indicated that SSSI effects do exist, but they are generally secondary for the overall structural response motions [3]. SSSI effects, however, may be important for a relatively small structure which is to be close to a relatively large structure, while they may be generally neglected for overall structural response of a large massive structure, such as nuclear power plant [4].

As such the scope of the present paper is to carry out a seismic SSSI analysis in case of the MACSTOR/KN-400 module, in order to investigate whether or not SSSI effect shall be included in the overall seismic structural response.

2. Analyses

In this section are described analysis procedure with seismic input motion and local site condition, and the techniques used to model the MACSTOR/KN-400 module. The computer program SHAKE [5] and SASSI [6] are used in the site response analysis and seismic SSSI analysis, respectively.

2.1 Analysis Procedure

The procedure in the SHAKE local site amplification analysis by an earthquake motion is mainly composed of preparing a site soil profile along with the control motion defined at the base as a rock outcrop motion, and calculating the free surface acceleration. The SASSI program is composed of a general 3-D finite element sub-structuring method adopting the standard frequency domain solution procedure, using the FFT algorithm.

The loadings considered in the seismic SSSI analysis for the MACSTOR/ KN-400 module consist of the followings:

Dead Load: The dead load consists of weight of the structure based on a reinforced concrete density of 2.5 ton/m^3, and fuel storage baskets.

Live Load: A uniformly distributed load of 1.0 ton/m^2 is considered to account for any equipment and/or people working on the top slab. A 25% of the live load is also considered as a seismic live load per code requirements.

Seismic load: The Design Basis Earthquake (DBE) is defined as a 0.2 g peak ground acceleration and a velocity equal to 182.9 mm/sec.

2.2 Local Site Condition

As the local site condition, namely soil topography and material properties is selected bore hole CE-7 [Table 1] because it has been determined as the weakest soil zone through SHAKE analysis comparing those done for investigated bore holes; CE-3, CE-9 and CE-10.

Table 1. Soil profile and properties of bore hole CE-7

Hole ID	Depth GL.-m	Soil Class	Density (ton/m^3)	Vs (m/sec)	Gs (kg/cm^2)	Poisson Ratio	Water Table
CE-7	4.05	SR	2.00	580	6,856	0.23	26.59
	12.07	HR	2.61	1,108	32,696	0.31	
	18.05	”	2.61	1,277	43,403	0.32	
	26.59	”	2.61	902	21,685	0.23	
	35.09	”	2.61	2,073	114,468	0.20	

2.3 Foundation Model

The foundation medium to be assumed in SASSI is horizontally layered, damped-elastic soil stratum overlying a uniform elastic halfspace of which model has a frequency-dependent variable depth to the model base and a viscous wave transmitting boundary at the bottom. The soil material properties above the elastic halfspace are represented by complex moduli with constant hysteretic material damping.

2.4 Structure Model

The structure is represented by 3-D lumped-mass stick model supported on a rigid or flexible foundation [Figures 1]. The structural materials are represented by complex moduli with constant (frequency-independent) hysteretic material damping.

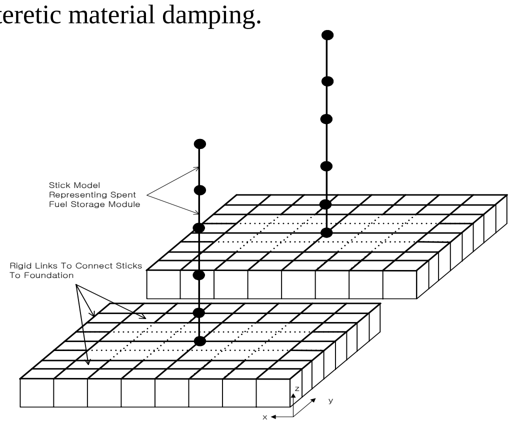

Figure 1. 3-D lumped-mass model of MACSTOR/KN-400 modules

2.5 Seismic Input

The input motion in SASSI analysis is assumed to be prescribed on the ground surface. Therefore the input motion shall be defined as the motion [Figure 2] calculated separately using SHAKE mentioned above, in order to consider the local site amplification effect. The horizontal motion can be simulated by plane body wave SH, whereas the vertical motion by P wave with the incident angle of zero degree to the ground surface.

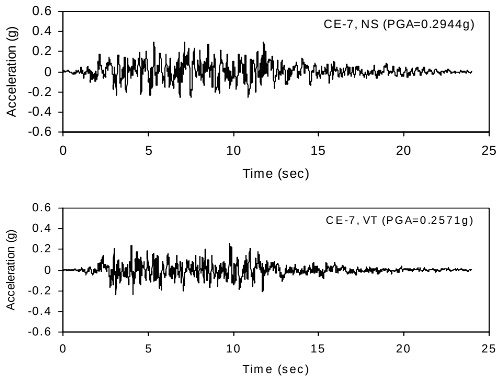

Figure 2. Seismic input motions specified on the ground surface convolved using the SHAKE

3. Results

A detailed seismic SSSI analysis of the MACSTOR /KN-400 module has been carried out. Table 2 contains a summary of the maximum floor accelerations at various locations of structure for horizontal and vertical component of an earthquake motion, while Figure 3 shows the floor response spectrum at some typical locations. As can be seen from the results the SSSI effects should not be an important factor in the SSI analysis because they could not give a great change in the overall structural response motions.

Table 2. Comparison of maximum floor accelerations

Elev.(m)	Horizontal Acc.(g)			Vertical Acc.(g)			Remark
	Single	Double	Diff.(%)	Single	Double	Diff.(%)	
7.518	0.454	0.451	0.66	0.349	0.348	0.29	Roof
6.438	0.454	0.451	0.66	0.349	0.348	0.29	
4.775	0.435	0.432	0.69	0.347	0.346	0.29	
2.515	0.396	0.397	0.25	0.342	0.341	0.29	
0.457	0.364	0.369	1.37	0.339	0.338	0.29	
0.0	0.364	0.369	1.37	0.338	0.338	0.0	Base
-1.0	0.362	0.367	1.38	0.338	0.338	0.0	Ground

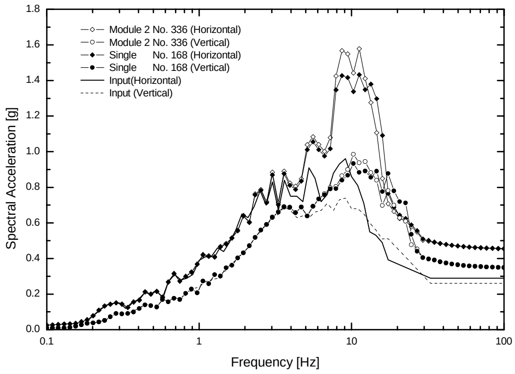

Figure 3. Acceleration floor response spectra at key locations

4. Conclusion

The results of the MACSTOR /KN-400 module SSSI analysis tell us that the SSSI effects shall be ignored in case of a small structure which is situated close to a comparably same size structure, not to a relatively large one.

REFERENCES

[1] U.S. Nuclear Regulatory Commission, "Standard Review Plan," Section 3.7.2, Revision 2, August 1989.

[2] Tajimi, H., "Recent Tendency of the Practice of Soil-Structure Interaction Design Analysis in Japan and Its Theoretical Background,"

[3] Ostadan, F., Tseng, W. S., and Liu, A. S., "Effect of Site Soil Properties on Seismic SSI Response of Embedded Structures,"

[4] ASCE Standard 4-98, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary," 1998.

[5] Schanbel, P. B., Lysmer, J., and Seed, H. B., "SHAKE - A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites,"

[6] Lysmer, J., Tabatabaie-Raissi, M., tajirian, F., Vahdani, S., and Ostadan, F., "SASSI - A System for Analysis of Soil-Structure Interaction,"