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Seismic 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 of the concrete module are built 40 storage cylinders accommodating ten 60-bundle dry storage baskets, which are suspended from the top slab and eventually constrained at 10 cm above the bottom slab with horizontal seismic restraints. The main cooling process of the MACSTOR/KN-400 module is 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 geologic characteristics.

As per USNRC SRP Section 3.7.2 [1] and current US practices, Soil-Structure Interaction (SSI) effect shall be considered for all structures not supported by a rock or rock-like soil foundation materials. An SSI is a very complicated phenomenon of the structure coupled with the soil medium that is usually semi-infinite in extent and highly nonlinear in its behavior. And the effect of the SSI is noticeable especially for stiff and massive structures resting on relatively soft ground. Thus the SSI effect has to be considered in the seismic design of MACSTOR/KN-400 module resting on soil medium.

The scope of the this paper is to carry out a seismic SSI analysis of the MACSTOR/KN-400 module, in order to show how much the SSI gives an effect on the structural responses by comparing with the fixed-base analysis.

2. Analyses

This section describes the SSI 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 [2] and SASSI [3] are used in the site response analysis and seismic SSI analysis, respectively.

2.1 Analysis Procedure

The procedure in the SHAKE 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-field spatial acceleration responses. The basic method of analysis adopted by the computer program SASSI is called the flexible volume substructuring method which is formulated in the frequency domain using the complex response method and the finite element technique.

The load considered in the seismic SSI 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 0.2 g peak ground acceleration and a velocity equal to 182.9 mm/sec.

2.2 Local Site Condition

As the local site conditions, represented by soil stratigraphy and material properties, typically chosen for the SSI analysis is selected bore hole CE-7 [Table 1] because it has been proven to be the weakest soil zone thru SHAKE analysis, when compared with those done for other 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, viscoelastic 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 for each soil layer.

2.4 Structure Model

The structure is represented by 3-D finite element model (3-D solid model) to consider the dynamic coupling and torsional effects of the structure [Figures 1]. The structural materials are also represented by complex moduli with constant (frequency-independent) hysteretic material damping as described in Section 2.3.

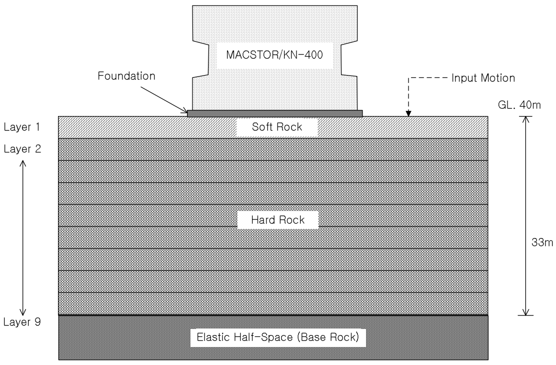

Figure 1. SSI analysis model of MACSTOR/KN-400 module

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 control motion, however, is directly applied at the ground surface in case of the fixed-base condition. 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, i.e., vertically propagating body waves.

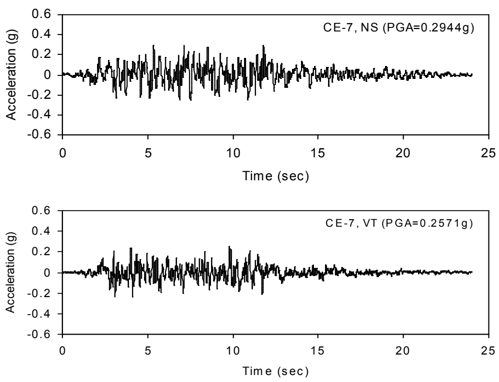

Figure 2. Seismic input motions specified on the ground surface convolved using the SHAKE

3. Results

The detailed seismic SSI and fixed-base analyses of the MACSTOR /KN-400 module have been carried out. Table 2 contains a summary of the maximum floor accelerations at various locations of structure for horizontal and vertical components of an earthquake motion, while Figure 3 shows the floor response spectrum at some typical locations. As can be seen from the results, the SSI effect should be an important factor in seismic design because it could give a great change in the overall structural response motions; a great deal of amplification arises in the floor acceleration amplitude, and the frequency contents of floor response spectrum are concentrated with shift to the SSI system frequency which might give appreciable impacts on the seismic qualification of secondary systems.

Table 2. Comparison of maximum floor accelerations

Elev.(m)	Horizontal Acc.(g)		Vertical Acc.(g)		Remark
	SSI	FIXED	SSI	FIXED	
7.518	0.506	0.2820	0.328	0.2081	Roof Slab
6.438	0.487	0.2692	0.328	0.2080	
4.775	0.457	0.2520	0.327	0.2079	
2.515	0.404	0.2322	0.320	0.2064	
0.457	0.372	0.2273	0.317	0.2058	
0.0	0.367	0.2269	0.317	0.2056	Bottom Slab
-1.0	0.357	0.2264	0.316	0.2054	Ground

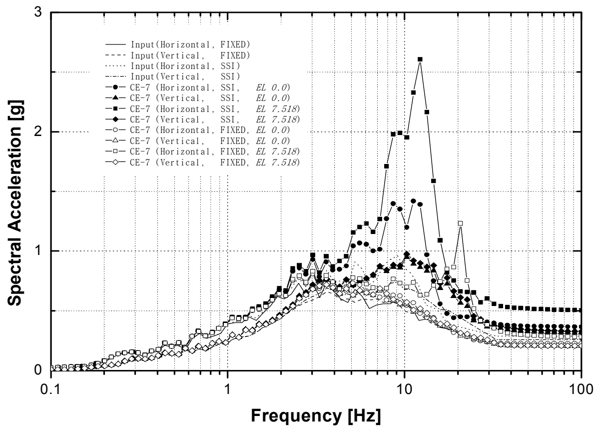

Figure 3. Acceleration floor response spectra at key locations

4. Conclusion

The seismic SSI analysis results for the MACSTOR /KN-400 module have concluded that the SSI effect necessarily be considered to correctly reflect and not to underestimate a dynamic response of the structure into the structural design.

REFERENCES

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

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