A MULTIPLE SUPPORT APPROACH FOR SEISMIC ANALYSIS OF STEAM GENERATORS IN CANDU 600MWe NPP

by

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SUMMARY

Typical CANDU-PHW 600MWe Nuclear Power Plants (NPP) contain four indentical Steam Generators (SG). Each Steam Generator is housed in an internal box concrete structure. Seismic restraints and/or snubbers are used to support the SG laterally from this internal box structure. Conventionally, these SG's are designed by the use of an envelope single floor response spectrum for the internal structure; as an upper bound on the seismic response of light secondary systems. This paper presents a new substructuring technique to perform the seismic analysis of a Steam Generator in isolation from a Reactor Building (RB). The technique accounts properly for the different input motions at SG supports and leads to a substantial reduction in SG seismic response.

INTRODUCTION

Typical CANDU-PHW 600MWe Nuclear Power Plants (NPP) contain four identical Steam Generators (SG). Because of space limitations around the Fuelling Machine area, each one of these SG's is supported by a single column of approximately 45ft long which is anchored to the base slab at the bottom. The SG is housed in an internal box concrete structure. Seismic restraints and/or snubbers are used to support the SG laterally from the internal box structure. Conventionally, these SG's are designed by the use of an envelope single floor Response Spectrum (FRS) for the internal structure, as an upper bound on the seismic response of light secondary systems. Nevertheless, mass coupling effects between the SG and the internal structure may be important since the SG has a considerable mass and is supported almost the full height of the internal structure (Figure 1). An obvious solution to account for the coupling effects for the primary system (Reactor Building) and the secondary system (SG) is to utilize an elaborate dynamic model which incorporates the different steam generators, the reactor, and the Reactor Building (RB) in one dynamic model. This approach may have some drawbacks as discussed in Reference 1 and 2 by the authors.

The objective of this paper is to develop a substructuring approach to quantify the seismic interaction effects for steam generators as those found in a CANDU 600MWe <u>without</u> resorting to a fully coupled dynamic model. By definition, a substructuring approach as used herein would involve analyzing the SG in isolation from the RB and vice versa without neglecting the true nature of the seismic interaction effects present.

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NATURE OF THE SEISMIC INTERACTION

The nature of seismic interaction between the RB and the SG was found in Reference (6) not to be of the inertial type (feedback due to large modal mass effects). The seismic interaction present is primarily because of the differences in input motions at points of the SG supports. Thus a multiple support approach, as presented in the following section, is considered the most suitable technique to analyze the SG in isolation. While the formulation as presented is applicable to time-history as well as spectrum solutions, only the later results will be presented because of space limitations.

SG ANALYSIS USING A MULTIPLE SUPPORT APPROACH

The equation of motion of the SG itself subjected to input at points a, b and c (Fig. 3) are as given below:

$$\left[M_{rr}\right]\left\{\ddot{X}\right\} + \left[C_{rr}\right]\left\{\dot{X}\right\} + \left[K_{rr}\right]\left\{X\right\} = -\left[K_{rs}\right]\left\{U_s\right\} - \left[C_{rs}\right]\left\{\dot{U}_s\right\} \quad (1)$$

where

$\left\{X\right\}\left\{\dot{X}\right\}\left\{\ddot{X}\right\}$ = Absolute displacement, velocity, and acceleration vectors of the unsupported nodes of the system (free nodes)

$\left\{U_s\right\}\left\{\dot{U}_s\right\}\left\{\ddot{U}_s\right\}$ = Absolute displacements, velocity, and acceleration vectors of the supported nodes of the system (deriving points)

$\left[M_{rr}\right]\left[C_{rr}\right]\left[K_{rr}\right]$ = Mass, damping, and stiffness matrices when points a, b and c are fixed in space

$\left[K_{rs}\right]$ $= \left[\left\{A\right\}\ \left\{B\right\}\ \left\{C\right\}\right]$ = stiffness coupling between the supported and the unsupported nodes

Choosing a reference motion $\left\{S\right\}$, such that it represents the displacements at the unsupported nodes due to displacements of the supported nodes, the relative motion $\left\{Y\right\}$ of the unsupported nodes will be given by:

$$\left\{Y\right\} = \left\{X\right\} - \left\{S\right\} \quad (2)$$

$$\left\{S\right\} = -\left[K_{rr}\right]^{-1}\left[K_{rs}\right]\left\{U_s\right\} \quad (3)$$

$$\left[M_{rr}\right]\left\{\ddot{Y}\right\} + \left[C_{rr}\right]\left\{\dot{Y}\right\} + \left[K_{rr}\right]\left\{Y\right\} = -\left[M_{rr}\right]\left\{\ddot{S}\right\} = \left[M_{rr}\right]\left[K_{rr}\right]^{-1}\left[K_{rs}\right]\left\{\ddot{U}_s\right\} \quad (4)$$

Equation 4 can be solved in the time domain or alternatively transformed into its modal coordinates utilizing conventional modal analysis and widely used conventional notations:

$$\left\{Y\right\} = \left[\phi\right]\left\{q\right\} \quad (5)$$

$$\left\{\ddot{q}\right\} + \left[2\beta\omega\right]\left\{\dot{q}\right\} + \left[\omega^2\right]\left\{q\right\} = \left[\phi\right]^T\left[M_{rr}\right]\left[K_{rr}\right]^{-1}\left[K_{rs}\right]\left\{\ddot{U}_s\right\} \quad (6)$$

The stiffness coupling terms $\left\{A\right\}$, $\left\{B\right\}$ and $\left\{C\right\}$ for the case in hand (Fig. 3) with lateral support K_n and K_m at nodes 'n' and 'm' respectively are given by:

$$\{C\} = \begin{Bmatrix} o \\ o \\ o \\ -k_m \\ o \\ o \end{Bmatrix} \quad \{B\} = \begin{Bmatrix} o \\ o \\ -k_n \\ o \\ o \\ o \end{Bmatrix} \quad \{A\} = [K_{rr}]\{J\} - \{B\} - \{C\} \tag{7}$$

$\{J\}$ = a vector whose elements are all unity

It can be shown that

$$\{\ddot{q}\} + [2\beta\omega]\{\dot{q}\} + [\omega^2]\{q\} = [1/\omega^2]\,[\phi]^T\,[K_{rs}]\,\{\ddot{U}_s\} \tag{8}$$

$$= \{\Gamma_a\}\ddot{U}_a + \{\Gamma_b\}\ddot{U}_b + \{\Gamma_c\}\ddot{U}_c \tag{9}$$

where:

$$\{\Gamma_a\} = \left[\frac{1}{\omega^2}\right][\phi]^T\{A\} \tag{10}$$

$$\{\Gamma_b\} = \left[\frac{1}{\omega^2}\right][\phi]^T\{B\} = \left\{\frac{-\phi_{in}}{\omega_{i}2}\,K_n\right\} \tag{11}$$

$$\{\Gamma_c\} = \left[\frac{1}{\omega^2}\right][\phi]^T\{C\} = \left\{\frac{-\phi_{im}}{\omega_{i}2}\,K_m\right\} \tag{12}$$

It can be shown that: $\{\Gamma_a\} + \{\Gamma_b\} + \{\Gamma_c\} = -\{\Gamma\}$ (13)

Where $\{\Gamma\}$ is the participation vector $= [\phi]^T[M_{rr}]\{J\} = \left[\frac{1}{\omega^2}\right][\phi]^T[K_{rr}]\{J\}$ (14)

Equation (9) is very similar to the basic equation of motion of a one degree of freedom system. The only difference being the redefinition of the participation vectors $\{\Gamma_a\}$, $\{\Gamma_b\}$, $\{\Gamma_c\}$ as given by equations 10, 11 and 12.

EXAMPLE AND CONCLUSIONS

A typical SG was analyzed utilizing the previous multiple support spectra approach (Fig.3). The input support spectra were developed from a dynamic model for the Reactor Building as shown in Fig.(2). Results for different modal combination rules are presented in Fig.(4) for a single input approach and the more realistic multiple support input approach. From the figure, it can be concluded that the multiple input spectrum approach, utilizing an SRSS rule for modal combination, leads to substantially lower and more realistic results compared to an envelope spectrum type approach.

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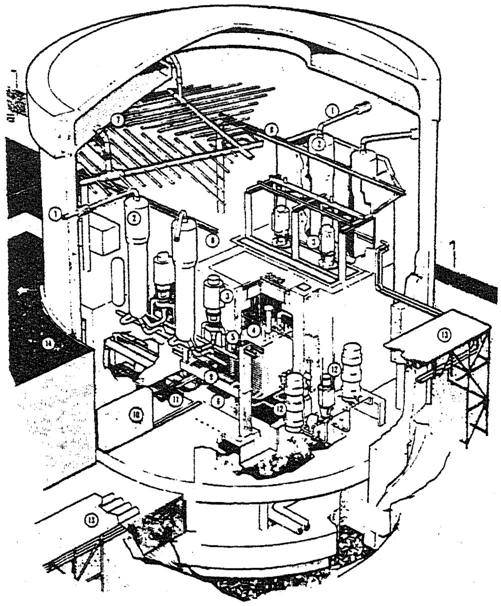

Fig. 1 CANDU 600MWe REACTOR BUILDING CUTAWAY

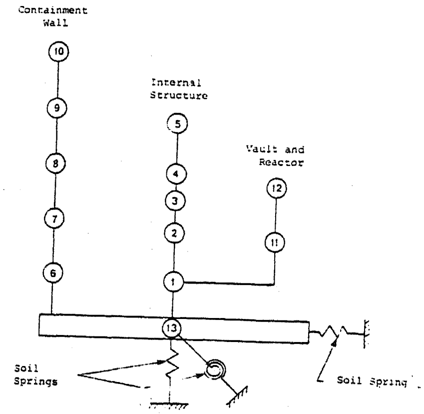

Fig. 2 CANDU 600MWe REACTOR BUILDING DYNAMIC MODEL

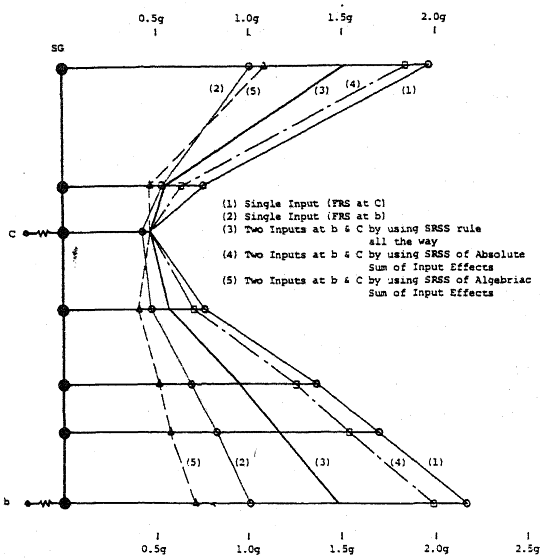

Fig. 4 SG ACCELERATION PROFILES USING DIFFERENT APPROACHES

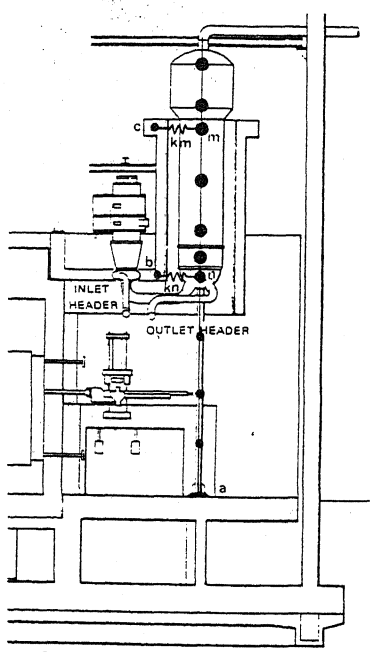

Fig. 3 SG ANALYSIS USING MULTIPLE SUPPORT INPUT APPROACH