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Incoherent SSI Analysis of Reactor Building using 2007 Hard-Rock Coherency Model

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1. Introduction

Many strong earthquake recordings show the response motions at building foundations to be less intense than the corresponding free-field motions. To account for these phenomena, the concept of spatial variation, or wave incoherence was introduced. Several approaches for its application to practical analysis and design as part of soil-structure interaction (SSI) effect have been developed [1-3]. However, conventional wave incoherency models didn't reflect the characteristics of earthquake data from hard-rock site, and their application to the practical nuclear structures on the hard-rock sites was not justified sufficiently.

This paper is focused on the response impact of hard-rock coherency model proposed in 2007 on the incoherent SSI analysis results of nuclear power plant (NPP) structure. A typical reactor building of pressurized water reactor (PWR) type NPP is modeled classified into surface and embedded foundations. The model is also assumed to be located on medium-hard rock and hard-rock sites. The SSI analysis results are obtained and compared in case of coherent and incoherent input motions. The structural responses considering rocking and torsion effects are also investigated.

2. Methodology

2.1 2007 Hard-Rock Coherency Model

The spatial variation of ground motions can be quantified by coherency function. Based on the assumption that the ground motions can be represented by a stationary random process, the coherency function is defined by the ratio of the cross spectrum to the geometric mean of the auto power spectra as follows.

$$\gamma_{ij}(\omega) = \frac{S_{ij}(\omega)}{\sqrt{S_{ii}(\omega) S_{jj}(\omega)}} \tag{1}$$

Mathematically, the coherency function is a complex function of frequency ω . Practically, however, empirically developed functions are more frequently used in engineering problems of NPP structures.

Abrahamson proposed a new coherency function for hard-rock site using Pinyon Flat array data [2]. The Pinyon Flat array is located in southern California around the San Andreas Faults, and the array was deployed as part of PASSCAL experiment to study wave propagation, scattering, and spatial variations. The functional form for the coherency model is completed by regression analysis and is defined as follows.

$$\gamma(f,\xi) = \left[1+\left(\frac{f\tanh(a_3\xi)}{a_1 f_c(\xi)}\right)^{n1(\xi)}\right]^{-1/2} \left[1+\left(\frac{f\tanh(a_3\xi)}{a_2}\right)^{n2}\right]^{-1/2} \tag{2}$$

The main factors of the coherency model are the separation distance and frequency. The coherency goes to unity at zero separation distance and zero frequency and goes to zero at very large frequency and very large separation distances.

2.2 Analysis Procedure

Case studies are performed to investigate the effects of site condition, location, foundation type and spatial variation of input motion. The ground condition represents typical medium-hard rock and hard-rock sites that have shear wave velocity of 3,500 ft/s and 8,000 ft/s, respectively. And a three dimensional beam-stick model of PWR type reactor building is considered as shown in Fig. 1. To identify the responses of rocking and torsion behavior, a couple of edge points and rigid beam elements are added to the model. The foundation of the model is placed on the surface and embedded into the ground, respectively. For input motion, acceleration time histories composed of two horizontal components and one vertical component are artificially generated. The input motions comply with Regulatory Guide (RG) 1.60 spectrum in low frequency range and are enriched in high frequency range. Each ground motion has total duration of 20.48 seconds, strong motion of 7.5 seconds and intervals of 0.005 seconds. Their peak ground accelerations are anchored to 0.3g as shown in Fig. 2.

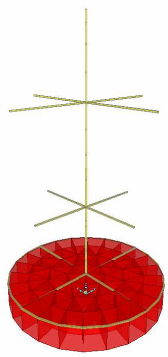


Fig. 1. A typical reactor building model

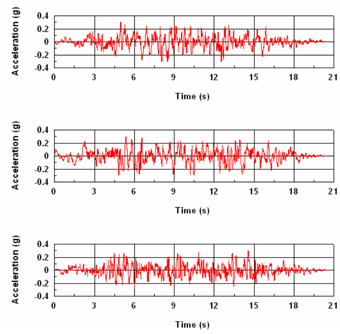


Fig. 2. Time histories of input motion (EW, NS, VT)

Incoherent SSI analysis is carried out by ACS-SASSI program, in which each mode of SASSI frequencies is solved explicitly and summed linearly only changing phase angle of the each mode.

3. Results

Responses are obtained for both the surface-supported and embedded foundation cases at six locations, i.e., the center and edge points of the basemat at El. 0.0 ft, containment shell at El. 143.8 ft and internal structure at El. 61.0 ft. For each location, responses are also computed for medium-hard rock and hard-rock sites.

3.1 Foundation Type

As for horizontal response, conventional embedment effect is observed similarly through incoherent analysis as well as coherent analysis. Peak from the model with embedded foundation decrease compared to the surface-supported foundation case. And simultaneously, location of the peak moves to higher frequency range at embedded foundation. However, this effect is not found for vertical direction under the given embedded depth.

3.2 Location

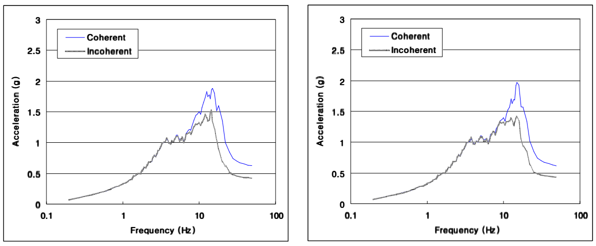
For containment shell, the peaks of horizontal and vertical directions appear around 4.5-5.5 Hz and 14-15 Hz, respectively. Response reduction at high frequency range for horizontal direction is not found, whereas peak values from surface and embedded foundation cases decrease by 11-19% and 17-28% respectively for vertical direction. For internal structure, the peak of horizontal direction appears around 10-12 Hz. Response reduction by wave incoherence is obvious for the embedded foundation model, but not always for the surface foundation case. At the edge points of containment shell and internal structure, the vertical responses are largely affected by their horizontal vibration modes.

Consequently, response reduction at high frequency range due to the wave incoherence is observed more distinctly from embedded foundation model than surface foundation case.

Additional rocking and torsion behavior by incoherent motion is observed and it can increase the peak level of responses. But the effect is not significant to affect the entire responses.

3.3 Site Condition

Hard-rock media with shear wave velocity of 8,000 ft/s can be assumed to be a fixed base. Analysis results show that response reduction above 10 Hz due to wave incoherence is still observed to the given hard-rock site.



(a) Surface foundation (b) Embedded foundation

Fig. 3. Vertical direction floor response spectra of reactor building on medium-hard rock site.

4. Conclusions

Incoherent SSI analysis of reactor building located on rock media was performed using the newly proposed hard-rock coherency model. Following conclusions can be derived from the case study results.

(1) Response reduction by wave incoherence is more obvious for embedded foundation model than surface foundation case.

(2) The response caused by rocking and torsion effect due to incoherent motion does not increase remarkably compared to the coherent case.

(3) Response having the unique peak at lower than 10 Hz does not show response reduction at even higher than 10 Hz range.

(4) Response reduction effect at high frequency range due to incoherent motion can be expected under hard-rock site as well as medium-hard rock site.

REFERENCES

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