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Effect of floor response spectrum generation methods on secondary system fragility

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ABSTRACT

Floor response spectrum(FRS) is widely used to analyze a secondary structure in a nuclear power plant. While it is a common practice to generate the FRS with a separate primary structure, this may be inaccurate in some cases. A measure to incorporate dynamic interaction was investigated. As an illustrative example the FRS was generated with a simple two degree of freedom model. The peak response near resonant region decreased as the mass ratio of secondary structure to primary structure increased. Such differences in the FRS further propagated through a fragility analysis.

In a practice of seismic probabilistic risk assessment, seismic fragility analysis of a component is required. The purpose is to evaluate probability of failure with an exerted demand and a capacity of certain failure mode. For the secondary structure fragility analysis, aforementioned FRS is used to estimate the demand. Gupta et al.(2017) noted that in many practice FRS by default, is generated without considering the dynamic interaction effect, despite its possible inaccuracy. It can be expected the FRS of coupled analysis could be comparatively reduced and eventually estimate lower risk. This was studied in the previous example with the FRS considering the dynamic interaction and the secondary structure fragility was greater.

1. INTRODUCTION

1.1 Floor response spectrum method

A nuclear power plant(NPP) houses numerous equipment. Including a reactor, one of the most important features, there exists many safety-related mechanical, electrical equipment located in the NPP. In order to operate the NPP safely and avoid a catastrophic event, not only structural survivability but also equipment functionality should be guaranteed. Hence seismic analysis and design methods of the equipment or

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more generally secondary structures have been consistently studied. Common practice is the so-called floor response spectrum(FRS) or in-structure response spectrum(ISRS), which are extensively used in the nuclear engineering field. Generating FRS procedure is identical to that of the typical response spectrum except input is response of the structure instead of the ground motion. Once FRS at a point is required one can calculate the demand of the equipment. When generating FRS the dynamic analysis is usually performed with the decoupled model, or the structure and the equipment separately. Villaverde(1997) reported several reasons lying behind. One is that the properties, especially damping ratio, differ greatly between the primary and secondary structures so that computation of the combined analysis is difficult. For instance modal analysis yields complex eigenvectors and eigenvalues as a non-classical damping matrix is formed even though individual damping matrices are classical. Number of researchers suggested methods to overcome this problem and approximate dynamic properties of coupled structure with those of separate structures.

1.2 Seismic fragility analysis

Fragility is a conditional probability of failure and it can be computed with various methods. EPRI(2018) uses a safety factor method where the fragility curve is expressed as a cumulative lognormal distribution function. It can be acquired with two parameters, namely a median capacity and a logarithmic standard deviation. The FRS, input demand for the secondary structure is required to calculate the former. Therefore as the dynamic interaction alters the FRS, it is expected that the fragility curve would be affected as well.

2. FLOOR RESPONSE SPECTRA GENERATION

2.1 Uncoupled analysis

Conventional FRS generation scheme follows: 1) dynamic analysis of the primary structure alone, 2) generate response spectrum with the acceleration response time-history at the secondary structure location as an input.

2.2 Coupled analysis

Many researchers proposed methods to refine conventional uncoupled FRS. Igusa et al. (1985) suggested a method to account for tuned-frequency, dynamic interaction and non-classical damping based on random vibration theory. Gupta et al.(1986) applied a perturbation method to generate FRS based on a response spectrum method along with complex modal properties of the combined structure. Researchers agreed on the result that the peak decreases when the secondary structure is tuned and its mass increases. This was verified with a simple numerical example with a SDF primary – SDF secondary structure. The damping ratios were 4% for the primary and 3% for the secondary structure. Natural frequency of the primary structure was set to 5 Hz. As shown in Fig. 1, the FRS peaks occur near 5 Hz. Six mass ratios were used from 0.001 to 0.1 and clearly the peaks decreased corresponding to the mass ratios.

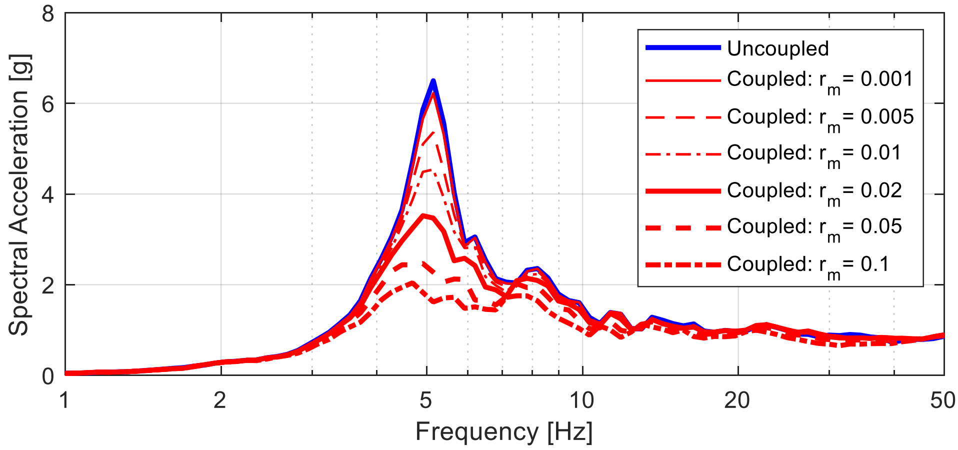

Fig. 1 Comparison of uncoupled and coupled FRS with different mass ratios

3. SEISMIC FRAGILITY ANALYSIS

Once the FRS is prepared fragility analysis for the secondary structure could be proceeded. The median capacity used to define the fragility curve is calculated as below Eq. 1.

$$A_m = F_c F_{RS} F_{ER} A_{RE} \quad (1)$$

$F_C: strength\ factor$
$F_{RS}: structure\ response\ factor$
$F_{ER}: equipment\ response\ factor$
$A_{RE}: ground\ motion\ parameter\ of\ reference\ earthquake$

The strength factor by definition is capacity over demand. Other factors being unchanged it can be expected that the median capacity would increase with the decreased FRS. To verify, the same example was used and showed higher fragility when the mass ratio was higher.

4. CONCLUSIONS

A simple example was studied to verify the effect of FRS change on the secondary structure fragility. FRS was generated considering the dynamic interaction and the non-classical damping. With the decreased demand, the fragility of the secondary structure was estimated higher than that calculated without coupling effects.

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