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REANALYSIS AND EVALUATION OF SEISMIC RESPONSE OF REACTOR BUILDING

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ABSTRACT

For the Ling Ao phase-I (LA-I) Nuclear Power Plant (NPP), its' seismic analysis of nuclear island was in accordance with the approaches in RCC-G standard for the model M310 in France, in which the Simplified impedance method was employed for the consideration of SSI. Thanks to the rapid progress being made in upgrading the evaluation technology and the capability of data processing systems, methods and software tools for the SSI analysis have experienced significant development all over the world. Focused on the model of reactor building of the LA-I NPP, in this paper the more sophisticated 3D half-space continuum impedance method based on the Green functions is used to analyze the functions of the soil, and then the seismic responses of the coupled SSI system are calculated and compared with the corresponding design values. It demonstrates that the design method provides a set of conservatively safe results. The conclusions from the study are hopefully to provide some important references to the assessment of seismic safety margin for LA-I NPP.

Keywords: Seismic response, soil geotechnical parameter, soil-structure interaction (SSI), impedance function, floor response spectrum.

1. INTRODUCTION

There have been many activities[1~7] emphasizing on the re-evaluation of seismic design for the existing nuclear power plants in the world. Thanks to the rapid progress being made in upgrading the evaluation technology and the capability of data processing systems, methods and software tools for the SSI analysis have experienced significant development all over the world, it's necessary and possible to re-evaluate the seismic design for an existing nuclear power plant.

The definition of soil geotechnical parameters and calculation of soil's impedance function would have direct effects on the seismic analysis of nuclear power plant (NPP) structures with consideration of soil-structure interaction (SSI) effects. For the LA-I NPP, its' calculation of soil's impedance function was in accordance with the approaches in RCC-G standard for the model M310 in France, just based on the due parameters of DAYA Bay NPP site. Focused on the soil parameters of the LA-I NPP site, in this paper the more sophisticated 3D half-space continuum impedance method is used to analyze the functions of the soil, and then the seismic responses of the coupled SSI system involving the reactor building are calculated and just compared with the corresponding design values. It demonstrates that the design method provides a set of conservatively safe results.

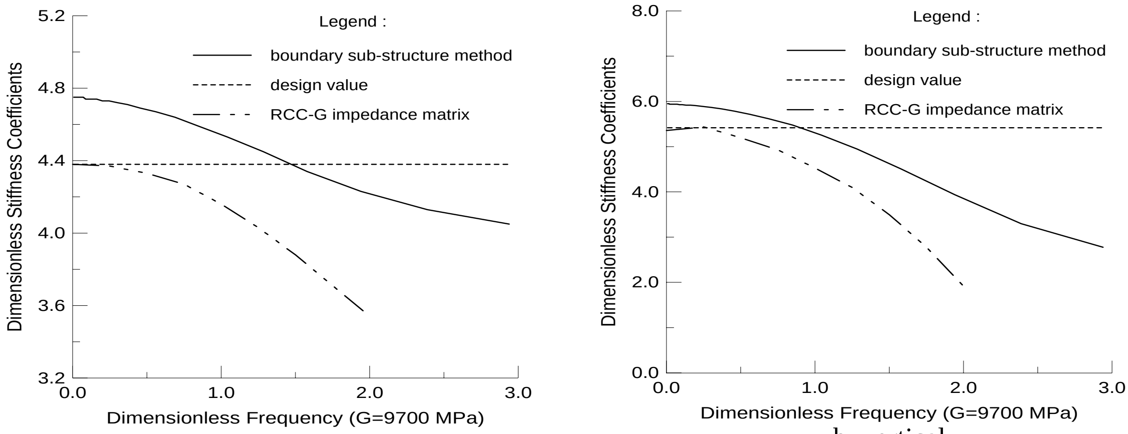
The conclusions from the study are hopefully to provide some important references to the assessment of seismic safety margin for the LA-I NPP and to the method selection of seismic analysis for the new project of LA-II.

2. COMPARISON OF SSI ANALYSIS AND CALCULATION OF IMPEDANCE FUNCTION

The seismic effects on a structure are related to many factors such as soil-structure interaction system and mathematical model, dynamic geotechnical parameters and impedance function of soil, and ground motion input etc,. For the calculation of impedance function of soil, the comparison of design and the new method will be made.

2.1 Simplified Impedance Method in RCC-G

Based on the impedance function method, the stiffness and damping coefficients functions with variability of frequency are developed in the standard of RCC-G. The impedance matrix with Poisson's ratio of 0.32 in RCC-G is shown in Fig.1.



a. horizontal b. vertical

Fig.1 Comparison of Stiffness Coefficients of Soil

Although the stiffness and damping coefficients in RCC-G standard are frequency-related, they keep constant in the SSI analysis and seismic design so that it can make analysis simple but could reduce the accuracy of analysis. And the stiffness and damping coefficients in the design are set as the corresponding values that are related to the 1st natural frequency of SSI system.

2.2 3D Half-Space Continuum Impedance Method

Based on the hypothesis of visco-elastic half-space, the Green function of rock-soil is calculated in the first step, and then impedance function of rock-soil can be developed with the boundary integral method. The obtained impedance functions are frequency-related and this feature can make the response analysis performed numerically in the frequency domain so that the response in the time domain can be obtained by inverse Fourier transformation. The code of CLASSI[9] is just based on the above-mentioned theory.

The CLASSI code is employed in this study. The soil parameters of nuclear island in LA-I are listed in Table 1 with the relevant parameters in DAYA Bay NPP site. It is shown that the differences of rock-soil characteristics between two sites are relatively clear. Based on the soil parameters of LA-I, the impedance functions are calculated with 3D half-space continuum impedance method and compared with the corresponding values in the original design.

Table 1 Geotechnical Parameters of Rock-soil

Site	Shear modulus	Shear wave velocity	Poisson's ratio	Damping ratio	Mass density
LA-I NPP	9700-13000MPa	1910-2210m/s	0.32	2%	2650kg/m^3
DAYA Bay NPP	7700-11500MPa	1720-2100m/s	0.31	2%	2600kg/m^3

2.3 Comparison of Calculation Results and Design Values of Impedances

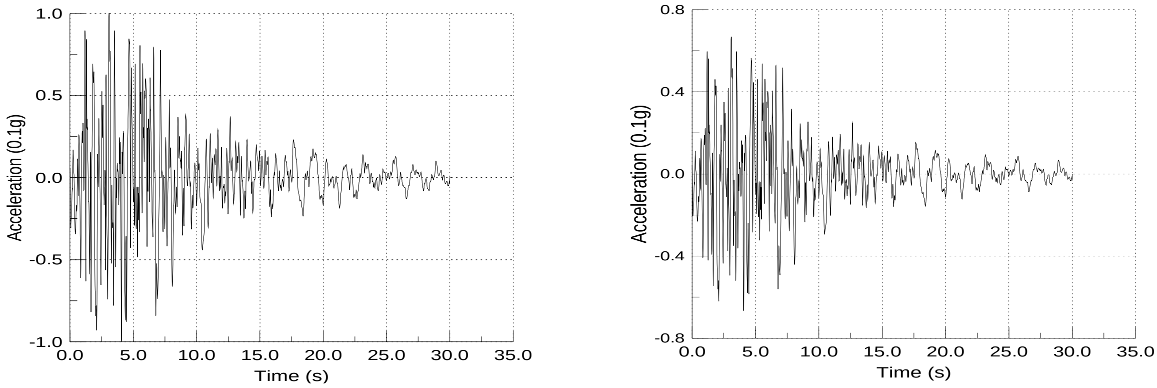
The stiffness coefficients curves with the shear modulus of 9700Mpa based respectively on the 3D half-space continuum impedance method, design method, and also the impedance matrix with Poisson's ratio of

0.32 in RCC-G are shown in Fig.1. It must be noted that the design values (dash line) in Fig.1 are directly copied from the corresponding design of DAYA Bay NPP just because the LA-I project is actually a “copy” one based on the design of DAYA Bay NPP, so the impedances in the design of LA-I are introduced from that of DAYA Bay NPP. The damping coefficients are not discussed in this paper.

From the comparison results in Fig.1, the stiffness coefficients in the design do not change with the frequency, and they are close to the maximum values of RCC-G impedance matrix curve and this feature could make the analysis conservative. While the calculated stiffness coefficients with 3D half-space continuum impedance method vary with frequency in the interesting domain. For the horizontal displacement component, the calculated stiffness coefficients are higher than the design values when the dimensionless frequency is less than about 1.5, otherwise the former are lower than the later. And for the vertical displacement component, the calculated stiffness coefficients are higher than the design values when the dimensionless frequency is less than about 1.0, otherwise the former are lower than the later. It’s demonstrated that in most cases the design method give the relatively more conservative results compared with the new method in this paper, especially for the vertical component. This conclusion can be found applied to damping coefficients. These differences could have effects on the seismic responses of structure and floor response spectra.

3. EARTHQUAKE INPUT

The given target response spectrum is standard one in US-NRC RG1.60[10]. The peak values of ground motion acceleration are 0.1g for the horizontal and 0.0667g for the vertical respectively, which are equivalent to the half SSE level for the LA-I NPP. To account for the uncertainty of the ground motion input, three groups of time histories are used in the seismic response analysis that is similar to the design at all. The responses can be calculated in each case, and then the average values are calculated and used for comparison. One group of time histories curves are shown in Fig.2.



a. horizontal　　b. vertical

Fig.2 Time Histories

4. STRUCTURE MODEL AND CALCULATION OF SEISMIC RESPONSE

The structure model is shown in Fig.3. The dynamic properties of structure material are listed in Table 2.

Based on the calculated impedances of rock-soil with 3D half-space continuum impedance method in this study, the seismic responses of SSI coupled system are calculated using time history analysis approach. For the floor response spectra (FRS), the calculation results can be compared with the corresponding design values in this paper. Because two set of parameters of rock-soil are involved in seismic analysis for the LA-I NPP, the analysis are implemented according to the following philosophy and steps for each floor: (1) the original FRS for each set of parameter is calculated; (2) the enveloped FRS is obtained for the two set of parameters; (3) to account for the uncertainty of the primary frequencies of structure due to the uncertainty of material properties, structure modelisation, and calculation method, the broaden FRS is developed with broaden factor of 0.15 according to the US-NRC RG 1.122[11].Just the broaden FRS are used to be compared with each other.

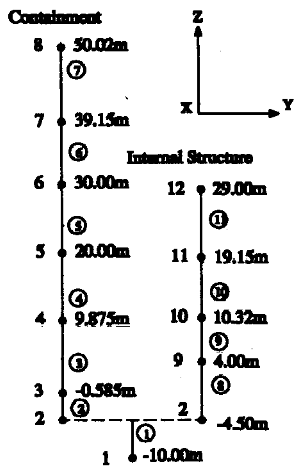


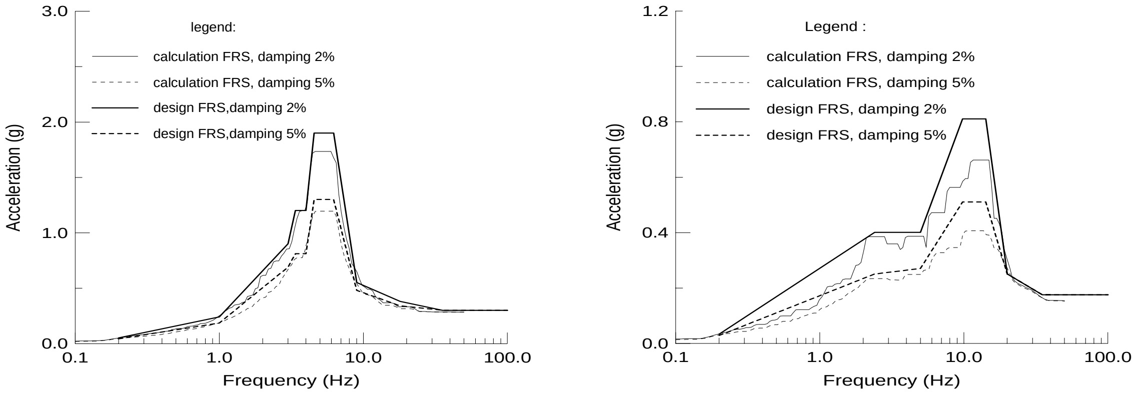
Fig.3 Model of Building

Table 2 Dynamic Parameter of Structure Material

Structure	Elastic modulus	Shear modulus	Poisson's ratio	Mass density	Damping ratio
Concrete	$4\times10^{10}N/m^2$	$1.6\times10^{10}N/m^2$	0.2	$2500kg/m^3$	7%
Prestressed concrete	$4\times10^{10}N/m^2$	$1.6\times1010^{N}/m^2$	0.2	$2500kg/m^3$	5%

5. COMPARISON OF CALCULATED FRS WITH DESIGN FRS

The comparison of FRS curves in absolute acceleration of Node 11 (level 19.15m for internal structure) is shown in Fig.4. The object-damping ratios are selected as 2%, 5% in FRS. It shall also be noted that the design FRS in the above figure are directly copied from the design FRS of DAYA Bay NPP just because the LA-I project is actually a "copy" one based on the design of DAYA Bay NPP.



a. horizontal b. vertical

Fig.4 Comparison of FRS at Node 11

From the figures, the outlines of the calculated FRS are close to the ones of the design FRS of LA-I NPP, and the former can envelope the later almost at all. The peak value and zero-period acceleration (ZPA) level of the calculated FRS are higher than those of the design FRS. Especially for the vertical design FRS with much more margins, their peak values are inclining to shifting toward high frequency range. And the above phenomena can be found to be applied to other Nodes. It demonstrates that the design method provides a set of conservatively safe results compared with the analysis in this study especially for the vertical component. The comparison of FRS just reflects the comparison of impedance of rock-soil.

6. RESULTS AND REMARKS

Based on the soil parameters of LA-I NPP nuclear island, the impedance function of rock-soil is calculated using 3D half-space continuum impedance method in this stud, and seismic response of structure and FRS are obtained. The calculated FRS is then compared with the design one and the seismic design margin of LA-I NPP are evaluated. Some conclusions can be made as follows:

The impedance of soil is set as constant in the design and this feature can make analysis simple and give a set of relatively conservative results. For the LA-I NPP, It's shown that the design is safer compared with the analysis results in this study.

For the soil parameters of nuclear island, although there are relatively clear differences between the two sites, the introduction of seismic design directly from DAYA Bay NPP is safe for the LA-I NPP with high modulus of rock-soil, according to analysis results in this research.

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