

The Effects of Seismic Spectrum on Seismic Analysis

Tian Jinmei^a Liu Shubin^a

^aChina Nuclear Power Engineering Co.,Ltd. Beijing, China,
email:jmtian_2000@sohu.com

Keywords: seismic analysis, seismic response, inherent frequency,;

1 ABSTRACT

In this paper, the basic principle of seismic analysis is explained and the factors which affect the seismic response are analyzed. In the seismic computation of regenerative heat exchanger of Lingao II nuclear power plant, one problem occurs, which is there's only a little difference between the seismic spectrum of the same component, but there is great difference between the seismic response of the same component in different plants, so the effects of the peak change of seismic spectrum and the magnitude of the seismic spectrum on results of seismic analysis are analyzed.

The results show that if the first few frequencies of the component are close to the inherent frequency of the plant, then the modal response of this mode is magnified remarkably, and these modal responses will contribute most to the whole structure response. Also, as to the same component, the principle of the seismic spectrum value change is identical to that of the results of the seismic responses. So this paper can be served as a reference of analyzing and solving those problems concerned with seismic analysis.

2 INTRODUCTION

In nuclear power plant design, response spectrum analysis is included in the seismic computation. The spectrum analysis is mainly related to the response of structures to earthquake and other random excitement. Many structures, such as building frames, bridges, satellite components, airplane components and other structures under unstable loadings all need response spectrum analysis. Meanwhile, response spectrum analysis is a very important job in nuclear power plant design.

In the seismic computation of regenerative heat exchanger of Lingao II nuclear power plant, it is found that although two components are the same in structures, while they are put in different plants, the results differs far from each other. When analyzing these phenomenon in former time, we may think it's caused by model itself, but the fact is not so. What kind of effect will the magnitude of seismic spectrum and the location change of the seismic spectrum peak value be on seismic computation results? In order to know these problems clearly, it is indispensable to analyze seismic computation results reasonably and heighten working efficiency.

In fact, each physical phenomenon has its inner basis. In order to analyze these problems, the basic theory of seismic computation should be used. So in this paper, the basic theory of response spectrum analysis of ANSYS programme are explained first, and then in order to solve those seismic computation problems of regenerative heat exchanger of Lingao II nuclear power plant, the effects of the changes of seismic spectrum peak and seismic spectrum magnitude on seismic computation results are analyzed.

3 THEORY OF SEISMIC COMPUTATION

Before doing the seismic spectrum analysis, the modal analysis should be done first to get the participation factors of each mode, which represents in which degree some mode takes part in vibration in a given direction. The participation factor of each mode can be got through the modal analysis of ANSYS. Here the participation factor of the i th mode is defined as γ_i .

Then according to different excitation types, the mode coefficients of each mode A_j can be obtained. Acceleration excitation is usually used during the computation of components of nuclear power plant, and the formula is listed below:

$$A_i = \frac{S_{ai}\gamma_i}{\omega_i^2} \quad (1)$$

Where: γ_i is the participation factor of the i th mode, S_{ai} is the spectrum acceleration of the i th mode, ω_i is the natural circular frequency, $\omega_i = 2\pi f_i$, and f_i is the natural frequency of the i th mode. So we can know the mode coefficient is inversely proportional to the square of the frequency, moreover, the contribution of the higher frequency is much smaller.

After the mode coefficient is got, the displacement vector of each mode can be obtained by :

$$\{R_i\} = A_i \{\phi_i\} \quad (2)$$

Where: ϕ_i is eigenvector, namely mode, $\{R_i\}$ represents the maximum response of this mode.

In order to get the whole response of the structure, the mode response $\{R_i\}$ of each mode response needs to be combined by a certain manner which is the so-called mode combination, namely the Mode Combination of ANSYS programme. Then the whole response of the structure can be got by:

$$R_a = \left(\sum_{i=1}^N \sum_{j=1}^N \varepsilon_{ij} R_i R_j \right)^{\frac{1}{2}} \quad (3)$$

Where: R_a is the mode response, N is the expansion number of the mode in spectrum analysis, ε_{ij} is the coupling coefficient.

According the different values of ε_{ij} , different formula can be obtained. The two common methods in the seismic spectrum analysis of nuclear power plant are explained in the followings:

If the mode is non-closely spaced mode, the following formula should be used:

$$R_a = \left(\sum_{i=1}^N (R_i)^2 \right)^{\frac{1}{2}} \quad (4)$$

This is the Square Root of the Sum of the Squares, namely the SRSS method in ANSYS programme.

If the mode is closely spaced mode, the following should be used:

$$R_a = \left(\sum_{i=1}^N \sum_{j=1}^N \varepsilon_{ij} |R_i R_j| \right)^{\frac{1}{2}} \quad (5)$$

Where: if $\left| \frac{\omega_i - \omega_j}{\omega_i} \right| \leq 0.1$, then $\varepsilon_{ij} = 1.0$; if $\left| \frac{\omega_i - \omega_j}{\omega_i} \right| > 0.1$, then $\varepsilon_{ij} = 0.0$, this is the so-called

Grouping Method, namely the GRP method in ANSYS programme.

Generally speaking, the flow chart of the seismic spectrum analysis is listed below:

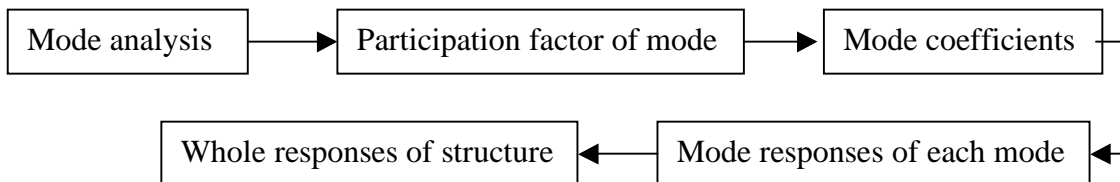


Fig. 1 Flow chart of seismic spectrum analysis

From the former computation theory of the seismic analysis, we can conclude that the whole response of structure is the function of the participation factor of each mode, frequency, spectrum value and mode, namely, the whole response of structure is the result of the common effects of these physical quantities.

4 ANALYSIS OF SEISMIC COMPUTATION RESULTS

In the following part, the seismic computation of the regenerative heat exchanger of the Steam Generator letdown system of Lingao II will be used as an example to analyze the seismic results. Two identical components are located in building W1 and W2 respectively, and the elevation are both +6.05m. The main material of the components is 20HR-B. The finite element model set up using ANSYS programme is shown in Figure 2.

When we do the computation, it's found that as to the seismic spectrum response of x and z direction, the stresses of the two components both are small, but when the seismic spectrum response of the y direction is different, namely, the responses of the two components differs greatly from each other. So here the seismic spectrum responses of y direction of these two components will be analyzed in the followings. The seismic acceleration spectrums of the y direction of the OBE earthquake of the two buildings are shown in Figure 3. Then the responses of the two components under similar conditions can be got.

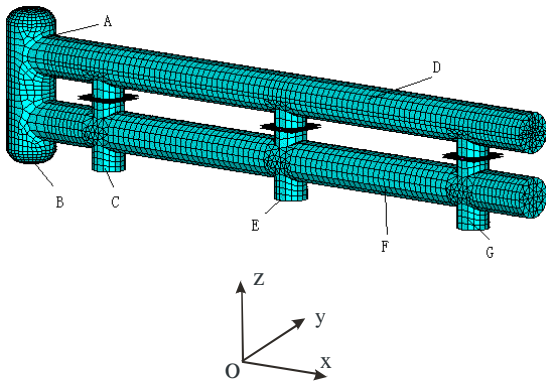


Fig. 2 The finite element model

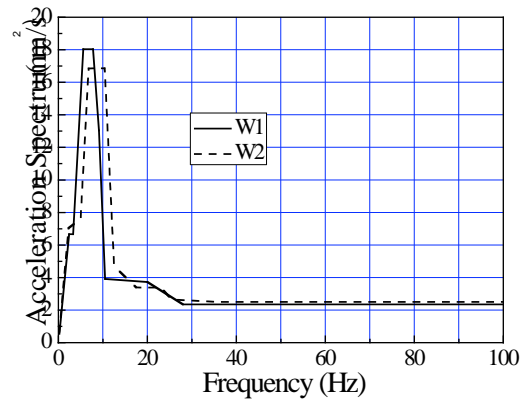


Fig. 3 Acceleration spectrum of the building

4.1 Effect of location of seismic spectrum peak value

The first 5 natural frequencies are listed in Table 1.

Table 1 The first 5 natural frequencies of the component

| Mode | 1 | 2 | 3 | 4 | 5 |
|------|--------|--------|--------|--------|--------|
| Fre. | 10.623 | 18.731 | 21.791 | 28.117 | 33.211 |

The membrane stress contours of the areas A and areas C of the two components are shown in Figure 4 and Figure 5 under spectrum of y direction.



Fig. 4 Membrane stresses of the component in building W1



Fig. 5 Membrane stresses of the component in build W2

From Figure 4 and Figure 5 , it can be seen that the maximum membrane stresses of areas A and areas C of the component located in building W1 are only 8.68MPa and 32.7 MPa respectively, but the corresponding stresses of the component located in building W2 are 32.2MPa and 122MPa, which are about 3.7 times of those of the component in building W1. From Figure 3 it can be seen that the peak of the seismic spectrum of building W1 is larger than that of the building W2, but the computed stresses of the component in building W1 are much smaller than that of the component in building W2. Why does this phenomenon occur as to the same component with the same elevations of installation?

From the seismic spectrum of the two buildings, it can be seen that though the peak of the seismic spectrum of building W1 is larger than that of the seismic spectrum of building W2, the area where the peaks of the seismic spectrum occur differs from each other, namely, the natural frequencies of the two buildings are different. The peak of the seismic spectrum of building W1 occurs this frequency area from 5.58 Hz ~7.8 Hz, but the peak of the seismic spectrum of building W2 occurs this frequency area from 6.8 Hz ~10.4 Hz. From the results of modal analysis, it can be known that the first frequency of the component is 10.623 Hz, which is very close to the frequency where the peak of the seismic spectrum occurs. After linear interpolation of the seismic spectrum of building W2, it can be got that the seismic spectrum corresponding to the first frequency is 15.58 m/s². As to the component located in building W1, the first frequency of which is far from the natural frequency of the building, and after linear interpolation of the seismic spectrum, we can get that the seismic spectrum is only 3.82 m/s².

The participation factors, mode coefficients and effective masses of the first 5 modes of components located in W1 and W2 buildings are listed in Table 2 and Table 3. Because the two components are identical, the participation factor and effective mass of each mode are the same. Also, because the seismic spectrums are different, from formula (1) and (2), it can be known that the mode coefficients and the responses of each mode are different. As to the first mode, the ratio of the first mode coefficients of the two components is approximately equal to that of the seismic spectrum of the two components. Because the eigenvectors namely the modes are identical, the ratio of the responses of the two components is equal to that of the spectrum of the two components.

Table 2 Factors of the component in building W2

| mode | 1 | 2 | 3 | 4 | 5 |
|----------------------|---------|-----------|-------------|------------|--------------|
| participation factor | -105.2 | -7.115 | 0.0469 | -4.431 | 0.01412 |
| mode coefficient | -0.3434 | -0.001737 | 0.000008452 | -0.0003696 | -0.000000821 |
| effective mass | 11062.7 | 50.6273 | 0.002197 | 19.6336 | 0.0001974 |

Table 3 Factors of the component in building W1

| mode | 1 | 2 | 3 | 4 | 5 |
|----------------------|----------|-----------|-------------|------------|---------------|
| participation factor | -105.2 | -7.115 | 0.0469 | -4.431 | 0.01412 |
| mode coefficient | -0.09246 | -0.001923 | 0.000008278 | -0.0003339 | -0.0000007628 |
| effective mass | 11062.7 | 50.6273 | 0.002197 | 19.6336 | 0.0001974 |

From the results of the modal analysis, it can be known that the participation factor and effective mass of the first mode are much larger than those of other modes. Only the results of the first 5 modes are presented in this paper, but the same conclusion can be got as to other modes. From the formula (1), it can be seen that the mode coefficient of the first mode are much larger than that of the other modes, so the contribution of the first mode to the response of the whole structure are much larger than that of the other modes, which is the same as to the two components in two buildings. But because the first frequency of the component in building W2 is very close to the frequency which corresponds to the peak of the seismic

spectrum, the response of the whole structure is much larger. As to the component in building W1, the response of the first mode also contributes the most to the whole response of the component, but because the corresponding seismic spectrum is smaller, so the whole response of the component is smaller. So from the above analysis, it can be got that the ratio of the whole responses of the two components is approximately equal to that of the seismic spectrum corresponding to the first mode. The ratio of the two seismic spectrums is $1.59/0.39=4.08$, which is approximately equal to the stress results. So, the results can be explained comprehensively, the differences between the results are caused by the different location of the peak of the seismic spectrums, namely the different natural frequencies of the two buildings.

In fact, the response of each mode of the structure will be magnified under the seismic spectrum. If some frequency of the structure just corresponds to the peak of the seismic spectrum, namely, the frequency is very close to the natural frequency of the building, moreover, the participation factor and the effective mass of this mode are much larger than other modes, then the magnifying effect of the seismic spectrum on the response of this mode is remarkable, and the response of this mode will contribute most to the response of the whole structure, which is resonance phenomenon. So when doing the seismic analysis, if the response of the structure is very large, after the above reason is determined, not only can we determine which mode contribute most to the whole response of the structure, but can we adopt some measures to avoid that the natural frequency of the structure meets the peak of the seismic spectrum, such as changing the mass distribution of the structure and so on.

4.2 Effect of the magnitude of seismic spectrum

The effect of the location change of the peak of the seismic spectrum on seismic computation results is analyze in 3.1 of this paper. Then the change of the seismic computation results with the change of the magnitude of the seismic spectrum will be explained. The results of area A and area C of the components located in building W1 are listed in Table 4 after the seismic spectrum is multiplied by a factor. From the data in Table 4, it can be known that the principle of the change of the stress results is consistent with that of the change of the seismic spectrum. And this phenomenon can be explained easily and clearly from the theory of the seismic computation. As to the same model, the frequency, mode, and participation factor of each mode are all identical, so the change principle of the mode coefficients is the same to that of the change of the seismic spectrum, the change principle of the response is also identical to that of the change of the seismic spectrum.

From the analysis above, it can be known that if the other loads are not considered (such as the internal pressure) and only the magnitude of the seismic spectrum is changed, for example the SSE spectrum value is two times of the OBE spectrum value, if the response of the component under OBE earthquake has been obtained, two times of the corresponding results are the response results under SSE earthquake. So the seismic computation of the component under SSE earthquake needn't be done any more, which can improve the working efficiency greatly.

Table 4 Stress change with the changes of spectrum and mode coefficient

| factor | 0.5 | 1.0 | 1.25 | 1.5 | 1.75 |
|-------------------------------|------------|------------|-------------|------------|-------------|
| Mode coefficient (first mode) | -0.04623 | -0.09246 | -0.1156 | -0.1387 | -0.1618 |
| Stress at area C (MPa) | 21.2 | 42.5 | 53.1 | 63.7 | 74.3 |
| Stress at area A (MPa) | 4.34 | 8.68 | 10.8 | 13 | 15.2 |

5 CONCLUSION

In this paper, in the seismic computation of the heat exchanger of the steam generator letdown system of Lingao II, as the problem in which the seismic response differs greatly with only a little difference of the seismic spectrum of the same component, the theory of seismic analysis is explained and the relationship between the change of the seismic spectrum peak and the seismic result and between the magnitude change of the seismic spectrum and the seismic result are also analyzed. Then the following conclusions can be got from the computation and analysis in this paper:

(1) If one of the frequencies of the component is close to the frequency corresponding to the peak of the seismic spectrum in some direction, namely the building frequency, moreover, the participation factor and effective mass of this mode are much larger than those of the other modes, then the magnifying effect of the seismic spectrum on this mode response is remarkable, and the response of this mode contributes most to the response of the whole structure.

(2) The seismic response of the structure is the function of mode participation factor, spectrum value, frequency and mode. As to one component, if the input seismic spectrum is multiplied or reduced by some factor, the obtained result will be multiplied and reduced by the same factor. Based on this, some concerned seismic problem will be simplified remarkably.

Altogether in this paper, the concerned problems in seismic computation are explained comprehensively, which can serve as a reference for analyzing the similar problem, moreover, can also supply a shortcut to solve some seismic computation problem.

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