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COMPUTATIONAL RESEARCH OF BASE-ISOLATION FOR NUCLEAR POWER PLANT

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ABSTRACT

Base isolation technique is able to standardize the seismic design of nuclear power plants, shorten design and construction period, and improve economic benefits. Moreover, it provides nuclear power plants a larger seismic margin to protect structures, and facilities from potential huge earthquakes with larger intensities than fortification earthquakes. The base-isolated model and non-base-isolated model ware build depend on Hualong One, and the dynamic characteristics, the response spectrum analysis as well as elastic time-history response of nuclear containment model has been done respectively. The result verifies that base-isolation technique is effective in reducing acceleration and stress response of nuclear containment and internal structure under seismic load.

INTRODUCTION

Previous nuclear accidents have shown that earthquakes and their secondary disasters can have a significant impact on the normal operation and safety of nuclear power plants, and can also cause serious environmental problems and economic losses. Although most nuclear power units are able to safely shut down in an earthquake, there are exceptions that can lead to extremely serious nuclear accidents or more dangerous nuclear safety incidents. On March 11, 2011, the Fukushima Daiichi Nuclear Power Plant was hit by a tsunami triggered by the Great East Japan Earthquake measuring 9 on the Richter scale, destroying all emergency power sources and losing cooling capacity. The accident is classified as the highest level of 7 according to the International Nuclear Event Scale (INES), which is the same as the accident at the Chernobyl nuclear power plant in the Soviet Union. The accident not only had an incalculable adverse impact on the surrounding environment and residents of Fukushima, but also had an extremely strong impact on the global nuclear industry.

In contrast, although some nuclear safety incidents are under human control, they can still cause significant economic losses. For example, on July 16, 2007, an earthquake measuring 6.8 on the Richter scale and several aftershocks below a magnitude of 6 struck the coastal area of Kashiwazaki City, Niigata Prefecture, Japan. The intensity of the earthquake exceeded the 6.5 magnitude specified in the nuclear power plant safety design standards, triggering a number of nuclear power plant safety incidents. Although the four reactors at the Kariba Nuclear Power Plant were automatically and safely shut down during the earthquake, TEPCO stated that the economic losses would amount to 700 billion yen, or about $5.79 billion, due to the closure of the nuclear power plant[1].

The nuclear safety incidents caused by these earthquakes tell us that in the construction and design of nuclear power plants, it is not only necessary to select and develop reasonable nuclear power construction technologies, but also to improve the seismic resistance of nuclear power plants to ensure the safety and reliability of nuclear power plant operation and avoid the recurrence of the tragedy of the Fukushima nuclear accident. At the same time, the performance design method should be introduced into the design of nuclear power plants, considering the seismic performance requirements of equipment and pipelines, reducing their response to earthquakes as much as possible, and reducing damage and damage, so as to improve the overall seismic performance of nuclear power plants, reduce unnecessary shutdown operations, and avoid huge economic losses caused by shutdown and other operations.

Therefore, it is necessary to develop and design a new nuclear power construction technology to improve the seismic resistance of nuclear power plants under seismic action, and also to meet the economic requirements in the design, construction and operation of nuclear power plants.

STRUCTURE

There are three main parts of the reactor building structure, the raft foundation, the containment structure and the internal structure. A cross-sectional view of the reactor building structure is shown in Figure 1.

Among them, the internal structure weighs about 43,500 tons, the inner containment weighs about 37,100 tons, the outer containment weighs about 59,100 tons, the valve plate foundation weighs about 31,000 tons, and the total mass of the reactor plant is about 170,700 tons. The valve plate is circular with a diameter of about 56 meters, and the reactor building is 73.38 meters high.

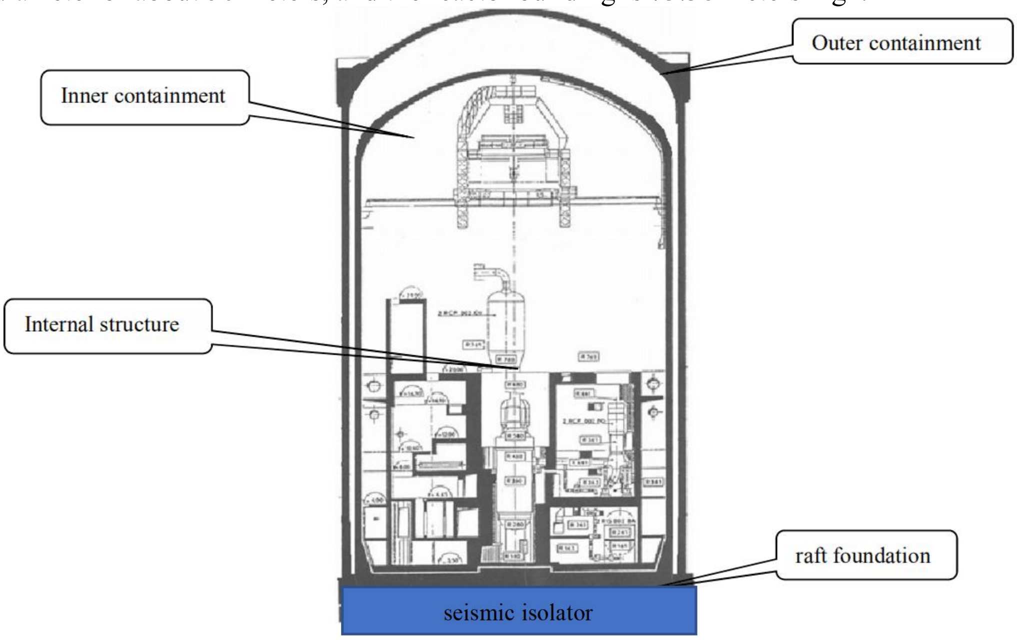

Figure 1. A cross-sectional view of the reactor building structure

LOAD

In this analysis, the acceleration time history of the bedrock spectrum generation with a damping ratio of 2% was used to generate artificial simulation, and the horizontal and vertical spectral values are shown in Table 1. Fig. 2 shows the artificial simulation acceleration time history in the three orthogonal directions of X, Y, and Z and the envelope of the response spectrum to the bedrock spectrum.

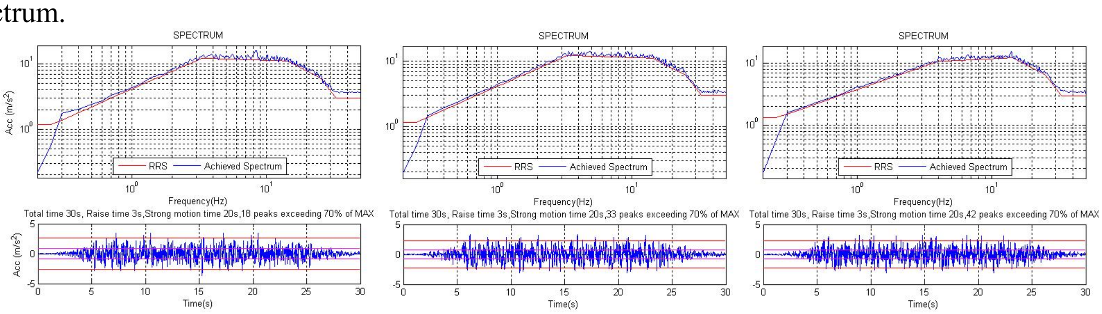

Figure 1. Seismic time history

Table 1 Bedrock spectrum

Horizontal		Vertical	
Frequency (Hz)	Acceleration (m/s^2)	frequency (Hz)	acceleration (m/s^2)
0.2	1.17	0.2	1.32
0.25	1.17	0.25	1.32
3.33	12.3	4	10.68
14.29	11.16	14.29	12.27
25	6.21	25	6.54
33	3	33	3

MODEL

The non-seismic isolation model and the seismic isolation model are shown in Figure 3. The position of the seismic isolation bearing at the bottom of the seismic isolation structure is shown in Figure 3. Considering that the diameter of the seismic isolation bearing is 1m and the bottom raft structure is 28m, ignoring the non-uniformity of the mass distribution of the reactor plant, and considering that there is enough gap between the bottom supports, the seismic isolation bearing is arranged with the center of the bottom plate as the center of the circle, as shown in Figure 4. According to the results of static analysis and considering that the vertical load will increase during the earthquake, considering that the total gravity of the containment structure is 1.25 × 109N, and the vertical acceleration is conservatively estimated to be 0.3g, the average stress of each seismic isolation bearing is considered.

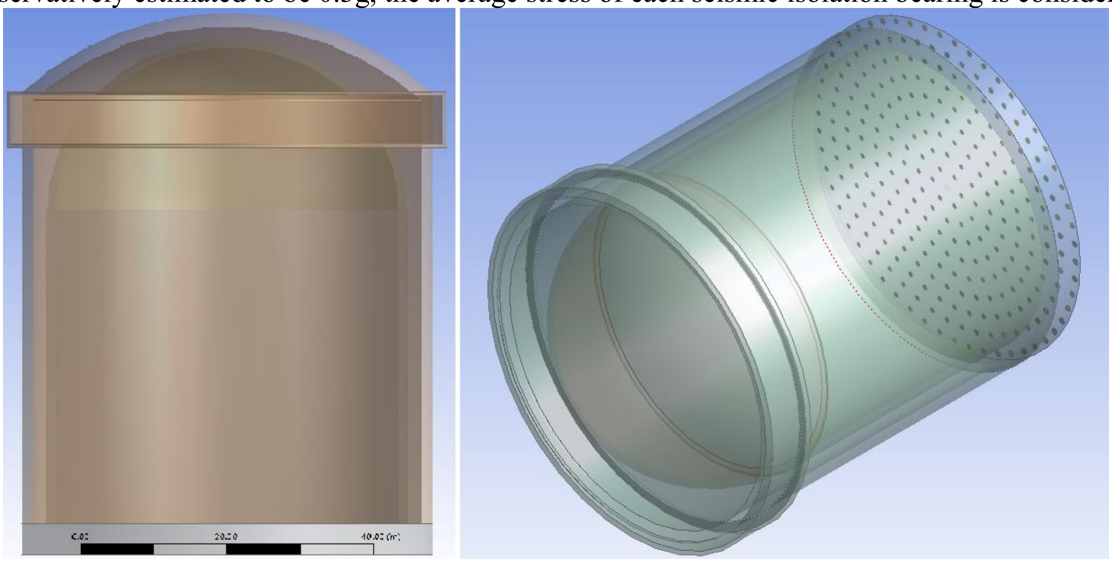

Fig. 3 No-isolation and base-isolation structure

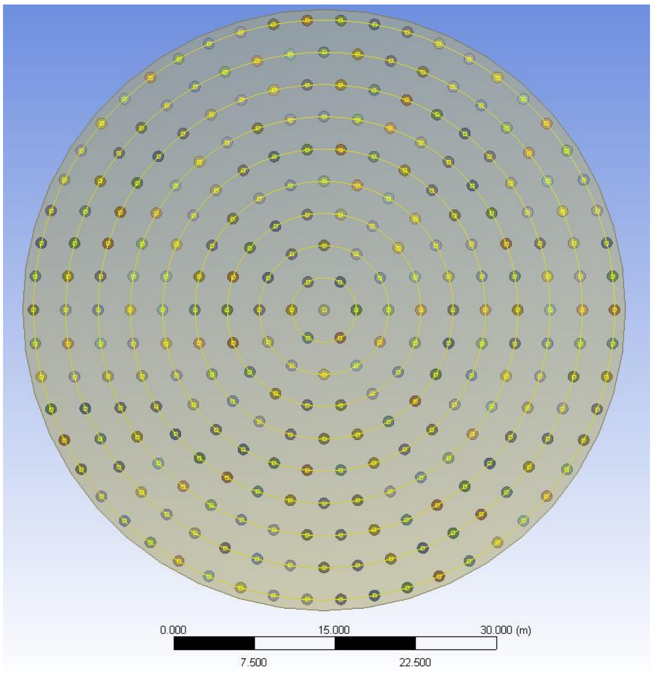

Fig. 4 Arrangement of isolator

RESULT

Modal analysis results

In the case of no seismic isolation, the modal analysis results of the reactor plant are shown in Table 2~Table 3, from which it can be seen that the low-order natural frequencies of the first three orthogonal directions (X, Y, Z) of the overall seismic isolation of the reactor plant are 3.66Hz, 3.66Hz and 9.28Hz. The low-order natural frequencies that rotate around the three axes (X, Y, Z) are 3.66 Hz, 3.66 Hz, and 7.70 Hz, respectively.

In the case of seismic isolation, the modal analysis results of the reactor plant are shown in Table 4~Table 5, from which it can be seen that the first-order natural frequencies of the first three orthogonal directions (X, Y, Z) of the overall seismic isolation of the reactor plant are 0.34Hz, 0.34Hz and 7.46Hz respectively; The first-order natural frequencies rotating around the three axes (X, Y, Z) are 3.68 Hz, 3.68 Hz, and 0.29 Hz, respectively. The calculation results show that the horizontal to translational first-order natural frequency of the reactor plant is significantly reduced after the substrate isolation is adopted, and the seismic isolation effect is significant.

Table 2 Result of modal analysis for non-isolation power plant (translation)

Frequency (Hz)	cycle (s)	Effective mass X	Effective mass Y	Effective mass Z
3.66	0.27	4.61E+07	7.74E+05	3.50E-02
3.66	0.27	7.74E+05	4.61E+07	4.94E-05
9.28	0.11	3.92E-01	1.05E-01	3.93E+07

Table 3 Result of modal analysis for non-isolation power plant (rotate)

Frequency (Hz)	cycle (s)	Effective mass X	Effective mass Y	Effective mass Z
3.66	0.27	2.41E+09	1.43E+11	1.42E+00
3.66	0.27	1.43E+11	2.41E+09	5.94E+00
7.70	0.13	3.47E+01	7.11E+00	3.59E+10

Table 4 Result of modal analysis for base-isolation power plant (translation)

Frequency (Hz)	cycle (s)	Effective mass X	Effective mass Y	Effective mass Z
0.34	2.98	5.74E+07	6.98E+07	1.31E-02
0.34	2.98	6.98E+07	5.74E+07	1.97E-04
7.46	0.13	2.52E-04	1.14E-05	8.55E+07

Table 5 Result of modal analysis for base-isolation power plant (rotate)

Frequency (Hz)	cycle (s)	Effective mass X	Effective mass Y	Effective mass Z
0.29	3.50	1.66E+05	6.64E+05	7.13E+10
3.68	0.27	2.60E+08	6.39E+10	3.93E+00
3.68	0.27	6.39E+10	2.60E+08	1.56E+00

Acceleration time history analysis results

The time history of the acceleration response before and after isolation at each reference point was obtained through seismic acceleration time history analysis. The results show that the horizontal acceleration response after isolation is reduced by more than 65%. The peak of the response spectrum drops by more than 60%. After the isolation, the maximum relative displacement of the inner containment shell was reduced by 87.79% compared to before the isolation, and it had a significant horizontal isolation effect on the internal structure.

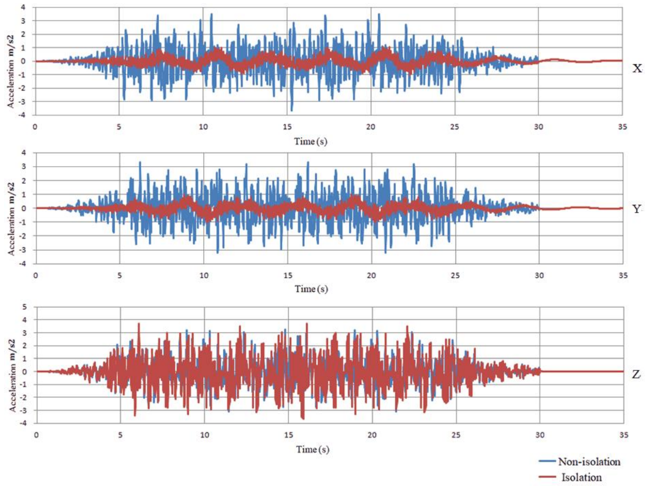

Figure 3. The acceleration response before and after isolation

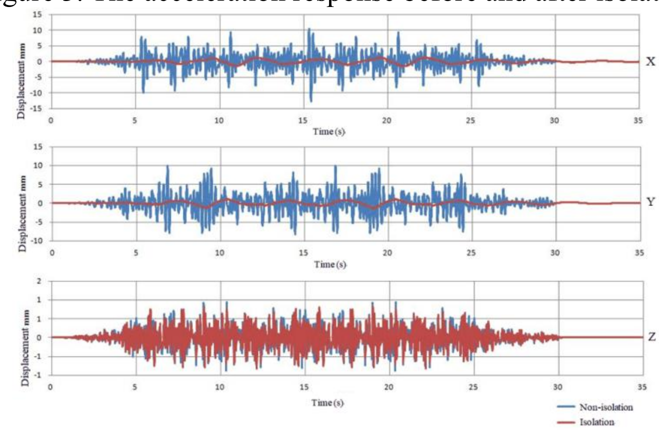

Figure 4. Relative displacement of inner containment

CONCLUSION

A three-dimensional finite element model was established for the reactor building, and the modal analysis and elastic time history analysis were carried out under the conditions of no seismic isolation and foundation isolation: the first-order frequency data of the three-dimensional model under the condition of no seismic isolation and seismic isolation were obtained, and the first-order natural frequency of the reactor plant after seismic isolation was much smaller than that without seismic isolation, and the seismic isolation bearing could effectively isolate the vibration of the ground when suffering from the actual earthquake. Through the acceleration time history analysis, the results show that the horizontal acceleration of the structure of the reactor building after the seismic isolation of the basement greatly decreases with the increase of floor height, and the horizontal relative displacement of the containment cylinder wall also decreases significantly, which effectively improves the seismic margin of the main structure of the reactor building of the nuclear power plant.

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