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Seismic Isolation Technology Analysis of Heavy Liquid Metal Cooled Reactor

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ABSTRACT

Heavy liquid metal cooled reactor usually adopts the integration of pool type structure. Owing to the reactor vessel dimensions, the large free surface and the high density of the coolant, seismic loading and sloshing may become very important problem. Isolation technology would be an important way to improve the seismic safety of nuclear power engineering and site adaptability. Considering the seismic response of heavy liquid metal cooled reactor is much amplified, the research of isolation technology applied in heavy liquid metal cooled reactor is valuable and urgent.

Nowadays the isolation technology is limitedly employed in NPP construction. In this paper, a general analysis of the isolation technology development in present situation and its potential benefits and challenges of applying in design of liquid heavy metal cooled reactor are investigated. And the isolation technology and non-isolation technology are compared within China Lead-based Reactor (CLEAR). In addition, the results also give a guideline for the detailed foundation design of CLEAR plant, as well as provide reference for plant-based design of liquid heavy metal cooled fast reactor.

Key words: heavy liquid metal reactor; seismic safety; base isolation; lead-based reactor

INTRODUCTION

Background and preliminary results

Chinese Academy of Sciences had launched a Strategic Priority Research Program of "the Future Advanced Nuclear Fission Energy-ADS transmutation system" to develop ADS in China since 2011 (*Zhan Wenlong, 2012*). The ADS consists of a subcritical reactor coupled with a proton accelerator and liquid metal spallation target. Lead-based material has good neutronics, thermal-hydraulics and safety characteristics, which is chosen as the reactor coolant material. So the China LEAd-based Reactor (CLEAR) has been selected as the subcritical reactor for CAS ADS project (*Wu Yican, 2014*). Lead cooled fast reactor is a typical heavy liquid metal cooled reactor. Distinguished achievements have obtained by INEST in Generation IV reactor research during recent years, including low activation materials by *Huang et al. (2009, 2013)*, liquid metal by *Wu et al.(2012)*, sub-critical system *Wu et al. (2011, 2014)*, and advanced nuclear software *Wu et al. (2008, 2009)*.

Due to large static loading and wide free surface of heavy liquid metal in heavy liquid metal cooled reactor vibration and shaking problem is particularly prominent, especially in seismic exciting. (*Wen Jing 2010*)

After the Fukushima accident, people pay more attention on the seismic safety of nuclear installations. Experts and scholars focus on advanced nuclear energy systems, and also explore

the application of advanced seismic technology to improve the site suitability and safety of nuclear facilities (*Kong Xianjing, 2012*).

Improve the reliability and safety. To better protect human normal activities in the building at the time of earthquake, and to reduce the probability of mistakes during the earthquake, safe shutdown to prevent accidents from occurring should be achieved. Meanwhile, seismic isolation technology enables significantly reduce seismic response of the upper structure and internal equipment, it generally occurs only in the elastic deformation zone and reduces the computational complexity analysis in the design, but also further improve the security design reliability. In addition, the use of isolation technology can greatly reduce the seismic force transmitted upward, making the seismic design of nuclear power engineering superstructure of magnitude less sensitive seismic design, providing an important prerequisite for the standardization of seismic design of nuclear power.

Simplify the design procedure. The use of base isolation technology that enables systems, equipment and piping design of decoupling, to achieve the internal structure of the plant and the plant, facilities, standardization and modular design, and improve the seismic margin structure system degrees. Nuclear power engineering complex structure, different systems, components and various types of pipes, cables and other support criss-cross in a limited space, influence each other. Using seismic base isolation technology not only reduces transmission, while significantly reducing the coupling effect between each other, but also conducive to the standardization of nuclear power engineering design, significantly reducing design and construction costs, and speed up the design schedule, guarantee period.

Strong site adaptability. Adaptability of nuclear islands foundation is an important constraint for nuclear power plant site selection, site adaptability and seismic foundation is the key issue. Using isolation technology, the basis of the upper structure allows the acceleration response is greatly reduced, making it possible to build nuclear power plants in the area with higher seismic intensity.

Previous studies Problems

Application of base isolation technology is the most potential solution to heavy metal cooled pool-type reactor seismic and site adaptability. However, nuclear power engineering application cases and experiences are very little isolation technology, such as ALMR, S-PRISM, KALIMER, DFBR, STAR, EFR and other fast reactors, the series uses the isolation technology is still in the design of nuclear facilities stage, has not yet officially running, besides the lead-bismuth cooled fast reactors of this type of reactor is no more advanced examples of reference works (*Wang Yan, 2004*). China Lead-based Research Reactor (CLEAR-I) application of base isolation technology will face many problems and challenges, strengthen the research is imperative.

Purpose of this study and the specific studies

For lead alloy cooled fast reactors, what is the exactly impact applying isolation technology, how much of its influence and is it necessary? For preliminary answer these questions, this paper choose CLEAR-I as the research object for the study, the choice of typical confinement isolation design, from acceleration response of the structure, the structural displacement response, the maximum shear stress structure three aspects isolation scheme to analysis and compare with non-isolated solutions. Finally shows the conclusions.

METHODS

In this study, it applied numerical simulation methods for analysis. Subjects were selected to simplify the process, use of conventional isolation system program and then make a typical model for calculation. Then analysed the simulation results and gave the preliminary conclusions.

(1) The basic parameters of confinement

CLEAR-I has double confinement system, the outer layer is the reactor building, outside of the container is also provided with a top of the heap inclusive small rooms, which is the second confinement. Across the bottom of the reactor building is a 3 meters thick concrete raft foundation base. Reactor building exterior wall is thickness of 1 m, inner and outer length is 33 m and 35 m.

(2) Preliminary analysis of confinement isolation dampening

Dynamic response of isolated structure system transfer function is seismic acceleration *Xs* and surface seismic acceleration *Xg* ratio under earthquake isolation structure. Describe the isolation structure surface seismic attenuation response, the formula is:

$$H(\omega) = \frac{\ddot{X}_s}{\ddot{X}_g} = \sqrt{\frac{1+(2\zeta\omega/\omega_n)^2}{\left[1-(\omega/\omega_n)^2\right]^2+(2\zeta\omega/\omega_n)^2}}$$

Where, ω_n is the natural frequency of the structure of the system, ζ is the damping ratio, ω is the characteristic frequency of the floor space: k structural rigidity, m is the structural quality.

When $H(\omega) < 1$, the structure of the system for the isolation system; on the contrary, the structural system response amplification. In theory, for isolated structure reasonable design, it must be able to ensure that the conversion function is less than 1, to achieve the effect of isolation.

(3) Isolation system design of the confinement

Isolator bearing

Based on the principle of isolation technology requires low horizontal stiffness of isolation layer, so increasing the natural vibration period of the building. By optimizing the design and reference to foreign materials, the use of model the Same Isolated means HDS.A900 of. In the design of the main design considerations make the following three aspects (Yonezawa 2003):

1) Select the optimal damper parameters;
2) Optimal yield isolation bearing force calculation;
3) Optimize the arrangement of the seismic isolation device.

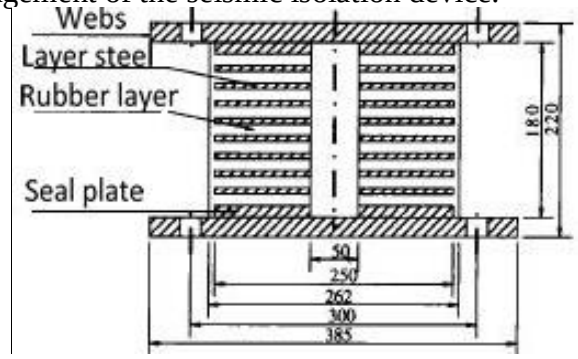

Figure 1 Typical isolation bearing design schematic

Isolation bearing arrangement

Isolators at the bottom of the reactor building of reinforced concrete raft foundation base plate at the bottom and provided a total of 12 * 12, 144. Arrangement is as shown below.

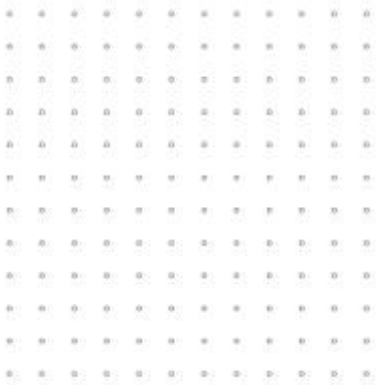

Figure 2 Isolators schematic arrangement

Simplified model parameter analysis

Mechanics model simplification isolation bearings by horizontal non-linear elastic and viscous dampers, linear spring vertical composition.

Simplified model of confinement system: concrete finite element analysis of concrete units, reinforced material properties bilinear stress-strain relationship.

(4) Confinement isolation attenuation calculation and analysis

Through structural acceleration response, structural displacement response, maximum shear stress three aspects of the structure of the isolated structure with non-isolated structure were compared. Preliminary calculations show that the use of isolated structures, can effectively reduce the structure acceleration, shear value and the relative displacement (HOU Gang-ling,2011).

PRELIMINARY RESULTS

Expected results showed that the use of isolated structure for the purposes of confinement system, can significantly reduce the seismic response. Select the appropriate isolation level optimization stiffness and damping ratio, can effectively reduce the structure acceleration, shear value and the relative displacement. Through the analysis of the optimum design for isolated structures to provide reference and guidance.

CONCLUSIONS

This paper describes the background of lead-based reactor application to isolation technology and choose the CLEAR-I reactor as the research object, compared to its confinement system using isolated structures with non-isolated structures acceleration, maximum shear stress and relative displacement structure were analyzed. Conception given further optimization of isolation scheme based progress needs, yet carry out detailed calculations. In this paper, methods, ideas and the expected results take the initial reports, in order to carry out follow–up work and communication.

This work only make typical isolated structure programs with non-isolated solutions analysis, preliminary assessment of the use of isolation scheme for the seismic response of confinement. In design of the isolated structure, is optimized for only isolator damper parameters. In a further isolation structure optimization, the use of engineering structural optimization technology, will be able to be more scientific and efficient way to select the best design.

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