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Seismic Isolation Studies and Applications for Nuclear Facilities

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1. Introduction

Seismic isolation, which is being used worldwide for buildings, is a well-known technology to protect structures from destructive earthquakes. In spite of the many potential advantages of a seismic isolation, however, the applications of a seismic isolation to nuclear facilities have been very limited because of a lack of sufficient knowledge about the isolation practices. The most important advantage of seismic isolation applications in nuclear power plants is that the safety and reliability of the plants can be remarkably improved through the standardization of the structures and equipment regardless of the seismic conditions of the sites. The standardization of structures and equipment will reduce the capital cost and design/construction schedule for future plants. Also, a seismic isolation can facilitate decoupling of the design and development for equipment, piping, and components due to the use of the generic in-structure response spectra associated with the standardized plant. Moreover, a seismic isolation will improve the plant safety margin against the design basis earthquake (DBE) as well as a beyond design basis seismic event due to its superior seismic performance [1,2].

A number of seismic isolation systems have been developed and tested since 1970s, and some of them have been applied to conventional structures in several countries of high seismicity. In the nuclear field, there have been many studies on the applicability of such seismic isolation systems, but the application of a seismic isolation is very limited. Currently, there are some discussions on the application of seismic isolation systems to nuclear facilities between the nuclear industries and the regulatory agencies in the U.S. [2]. In the future, a seismic isolation for nuclear facilities will be one of the important issues in the nuclear industry. This paper summarizes the past studies and applications of a seismic isolation in the nuclear industry.

2. Seismic Isolation of Advanced Nuclear Reactors

Several countries have initiated programs to develop seismic isolation systems for advanced nuclear applications.

Until now, six large Pressurized Water Reactor (PWR) units have been isolated in France and South Africa. At the Cruas plant in France, where the site safe shutdown earthquake (SSE) acceleration was 0.2g, four units were constructed on seismic isolation devices. Each of the four units is supported on 1,800 neoprene pads measuring 50×50×6.5cm. At the Koeberg nuclear power station in South Africa, where the site SSE acceleration was 0.3g, two units were isolated. A total of 2,000 neoprene pads with friction plates measuring 70×70×10cm were used.

In Japan, the Central Research Institute of Electric Power Industry (CRIEPI) carried out a ten-year research and development program (1987-1996) to develop design guidelines for base isolated Fast Breeder Reactors (FBR). The guidelines were issued in 1997 and revised to make them applicable to Light Water Reactors. Recently, a research program for applying a seismic isolation to the International Thermonuclear Experimental Reactor (ITER) has been underway.

In Canada, the Atomic Energy of Canada Limited (AECL) actively explored the use of a seismic isolation during its bid for the Akkuyu nuclear power project in Turkey. AECL's engineers considered a base mat isolation as a necessity for any DBE over 0.3g, enabling the CANDU-6 design to be used on sites requiring up to 0.6g DBE or more.

In the U.S., among the Generation IV (Gen IV) reactors, the Secure Transportable Autonomous Reactor-Liquid Metal (STAR-LM) reactor, Advanced Fast Reactor (AFR300), Power Reactor Innovative Small Module (PRISM) and the Super-PRISM reactors that use liquid metal coolants were designed to use a seismic isolation. The Department of Energy (DOE) sponsored Advanced Liquid Metal Reactor (ALMR) adopted a seismic isolation to simplify the design, enhance safety margins, and support the development of a standardized design for the majority of the available U.S. reactor sites. The nuclear island was designed for a SSE with a maximum horizontal and vertical acceleration of 0.5g. The total isolated weight is about 23,000 tons and it is supported on 66 high damping rubber bearings. The horizontal isolation frequency is 0.7 Hz, and the vertical frequency is greater than 20 Hz.

Another DOE-sponsored project, the Sodium Advanced Fast Reactor (SAFR), which weighs 31,000 tons, is supported on 100 elastomeric isolators that provide a vertical as well as a horizontal isolation. The design horizontal frequency is 0.5 Hz and the vertical frequency is 3 Hz.

Westinghouse also conducted a study of a horizontal seismic isolation for its AP600 plant. This study was directed primarily to determine if the AP600 standard design could be applied to sites in Japan where the design ground motion exceeds the 0.3g design basis for the AP600.

Recently, the Idaho National Engineering and Environmental Laboratory (INEEL) and Bechtel studied the application of a seismic isolation to a US NPP. Discussions with the utilities and NRC staff indicated that any move to implement a seismic isolation on a

NPP will require an extensive investigation of issues such as long-term behavior of isolators, in-service/pre-service inspection and testing isolators, and the basis for choosing an adequate isolation gab based on some beyond-design-basis considerations.

In Korea, Korea Advanced Liquid Metal Reactor (KALIMER) was designed to use a seismic isolation system. The total isolated weight is about 51,000 tons and it is supported on 182 lead rubber bearings (LRB) with a height of 1.2m and a diameter with 1.9m. The horizontal isolation frequency is 0.48 Hz. Seismic isolation design guidelines for KALIMER were developed by the Korea Atomic Energy Research Institute (KAERI).

3. Seismic Isolation of Equipment and Components

Seismic isolation of individual components is very beneficial in a situation where existing components and their supports have to be requalified for higher seismic loads. By using a seismic isolation, it may be possible to avoid an expensive retrofitting of the supporting facility and foundation.

In Japan, the Japan Atomic Energy Research Institute (JAERI) has conducted a ten-year research program (1991-2000) to provide the technical base of the seismic isolation of nuclear components [3]. A methodology and a computer code, Equipment Base Isolation System Analysis (EBISA), for evaluating the effect of a seismic isolation of nuclear components were developed. Verification test for real earthquake ground motions and a shaking table test were also carried out.

Under certain conditions, it may be considered adequate and safe to isolate only some of the important safety-related equipment and components within the nuclear structures. A recent study shows that the application of a seismic isolation to three or four equipments that have a significant contribution to the core damage frequency (CDF) will improve the seismic safety of a NPP by more than 60% [4]. The Korea Atomic Energy Research Institute (KAERI) has carried out the design and test of a three-dimensional isolation system for isolating the Emergency Diesel Generator in NPPs. The isolation system was designed to reduce the equipment vibration as well as the seismic load.

Most electrical or mechanical equipment and components are rigidly secured to the floor or are supported on wheels, thus allowing a sliding or rocking to occur. To prevent an overturning and a functional failure of this equipment and components during a seismic event, a seismic isolation is adopted. The Korea Electric Power Research Institute (KEPRI) has been developing a three-dimensional isolation system for the Main Control Room (MCR) in NPPs. A combination of an air spring and the Friction Pendulum System (FPS) is considered.

4. Considerations for Seismic Isolation Applications to Nuclear Facilities

Recently, there is an active movement to apply a seismic isolation to nuclear facilities in the U.S. To attain the goal, the following issues are suggested for the further discussions [2]:

· Quality Assurance/Quality Control capabilities of isolator vendors
· Production capabilities of isolator vendors
· Development of an appropriate testing protocol for isolators, including testing for demonstration of long service life in a potential radiation environment with somewhat elevated service temperatures
· Development of appropriate qualification/in-production testing requirements for isolators
· The need/extent for isolator surveillance, maintenance, and in-service testing during service life
· Development of specific codes, standards, and regulatory documents for addressing design and construction of isolated nuclear facilities
· Development of suitable performance criteria, especially with inputs from equipment vendors
· Determination of the division of the responsibility between the owner, engineer/constructor, and NSSS supplier
· Ability to provide suitable isolation joints for systems connected across isolated and non-isolated facilities
· Constructability issues associated with isolation diaphragm, clearance/moat, and access space for surveillance/inspection of isolators
· Need for further isolation research, industry education and regulatory participation/acceptance

5. Conclusions

The application of a seismic isolation to nuclear facilities is very limited at present. Nevertheless, many studies to develop seismic isolation systems applicable to nuclear facilities have been conducted, and several advanced reactors, equipment, and components have been designed to use a seismic isolation. The efforts of the isolation experts, regulators, utility companies, equipment suppliers, and isolator vendors are necessary for applying a seismic isolation to nuclear facilities.

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