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Safety review and action for earthquake in nuclear power plants

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1. Introduction

After the accident in Fukushima Daiichi nuclear power plants (NPPs) and the earthquakes in Gyeongju and Pohang, there has been an increase in public interest in the safety of NPPs under seismic conditions. Thus, it is important to review the influence of seismic event on the safety of NPPs. Therefore, the regulatory guidelines of seismic design, design procedure, and seismic monitoring system of NPPs were reviewed in this study. In addition, the system, structure, and components (SSCs) of NPPs and operating parameters affected by the earthquake were identified, and the responses of the SSCs and parameters during the earthquake event were reviewed from the earthquake experiences of NPPs in Korea and Japan. Based on these, appropriate reviews and actions were proposed to ensure the safety of NPPs in the events of an earthquake.

2. Guidelines and procedures for seismic design

In the United States, until the 1960s, there were no specific guidelines and procedures for seismic design of NPPs, and general guidelines were used for seismic design of NPPs. However, after the occurrence of the San Fernando earthquake in 1971, which was greater than the magnitude considered in the design of some NPPs, the procedure and guidelines for seismic design of NPPs have been established and applied since 1973 [1]. Korean NPPs have also been designed in accordance with these procedures and guidelines.

2.1 Design guidelines and standards

Site survey, seismic design, and operation of seismic monitoring system are conducted in accordance with the "Regulations on Technical Standards for Reactor Facilities, etc." and “Notice” of the Nuclear Safety and Security Commission [2], which adopts the Regulatory Guidelines of US NRC and industry standards. According to these guidelines, the largest earthquake that can occur every 1,000 to 10,000 years within a site radius of 320 km should be regarded in the design of NPPs [3].

In the design of Hanbit NPPs, the earthquake of magnitude 6.75 occurring at 90 km from the site was considered as a design earthquake. The magnitude of 6.75 was based on the Hwanghae earthquake occurring at about 405 km from the site in 1910. Based on this earthquake, the acceleration level of Hanbit site was calculated as 0.165 g, but conservatively 0.2g was applied to the design of the NPPs [3].

2.2 Design procedure

The key procedure of seismic design is consisted of decision of design earthquake, dynamic seismic response analysis, seismic design of structures and equipment, and seismic verification of equipment. In the dynamic seismic response analysis, the ground-structure interaction analysis should be added if the ground condition is not sound compared to the reference value [4].

2.3 Seismic monitoring system

The occurrence of earthquake should be monitored for safe operation and shutdown of NPPs during the seismic event. Thus, the seismic monitoring system monitors the vibration of a Seismic Category I system and their parts caused by earthquake, tsunami, bombardment, and so on [3,5]. Also, when the vibration exceeds the setting value, the monitoring system automatically trips the NPPs and alarms according to the level of the earthquake. In addition, the system records the vibration data and the operation of NPPs is decided through the analysis of these data.

3. Responses of NPPs under seismic conditions

For the safe operation of NPPs during the seismic event, it is important to understand the responses of structures and equipment of NPPs under seismic condition and to take appropriate action to mitigate the abnormal responses. Thus, this section reviews the expected responses and analyses the effects of the responses on the safe operation of the NPPs.

3.1 Frequency of electricity system

During the large earthquake event, the frequency of the electricity system suddenly rises due to the destruction of urban, industrial complexes, and the electricity grid. In this case, the governor droop factor set on the turbine generator of NPPs is operated and automatically reduces the output of NPPs. Therefore, the facilities of NPPs and the frequency of electricity grid can be stabilized.

3.2 Reactor power and behavior

In the earthquake event, the flow rate of primary coolant and secondary feedwater can increase due to the increase in reactor coolant pump (RCP) speed and feedwater pump speed, respectively. These enhance the cooling of reactor core, which leads to the rise in reactor power induced by the moderator temperature coefficient (+MTC). However, the effect is expected to be minimal; in particular, the effect is negligible for the initial core (BOL) [6]. In case of the end of core (EOL), the effect may be somewhat larger, but the rise in rector power does not reach the set-point of reactor trip (109%).

3.3 Bearing vibration of turbine generator

Turbine generator vibration is the most sensitive to the NPPs when an earthquake occurs. In Japan, the automatic trip of NPPs has been experienced due to the rise of turbine vibration and the damages of the turbine blades during the earthquake event. The domestic NPPs also experienced a rise in turbine vibration, even though the vibration level did not reach the trip requirement. In the event of a large earthquakes, this effect may require manual shutdown of the NPPs.

3.4 Revolution and vibration of large rotating equipment

Large-sized rotary equipment such as RCP, charging pump, condensate pump, circulating water pump, can rise rotation speed and vibration when an earthquake occurs. The increase in revolution of these components may increase the reactor power due to the increase in flow rate of primary coolant and secondary feedwater. However, it is expected from the operating experience that the effect is insignificant.

3.5 Damage of circuit breakers, transformers and transmission lines, transmission tower

During the large earthquake event, the main transformer and circuit breaker may be damaged and fire may occur. Transmission lines and towers may also be damaged [7,8]. In a large-scale NPP site, thus, countermeasures should be taken by comparing the capacity of the transmission line with the maximum transmission capacity of all generators within the site. That is, the priorities of power reduction and shutdown and the amount of power reduction and reduction rate should be specified in advance.

3.6 Malfunction of protective relay

The impact pressure relays (Buchholz relays) and differential relays of transformers may cause malfunctions due to dynamic impact induced by accident in transmission line and direct or indirect effects of the earthquake. Actually, NPPs have experienced trip due to these malfunctions. Therefore, individual seismic verification of each relay is necessary.

3.7 Major tank level fluctuation

The water level of the main tanks of NPPs such as refueling water storage tank, condensate storage tank, fresh water tank, spent fuel pool, dousing tank and fuel oil tank can be fluctuated by earthquake [8]. A malfunction of the level gauge can also cause high or low level alarms. Thus, barriers were already installed to protect radioactive materials and oil leakage

3.8 Possibility of tsunami

In 1983, the sea level in imwon, 15 km north of the Hanul NPPs site, has risen about 4 m due to the tsunami. The tsunami was caused by the earthquake of magnitude 7.7 in the western coast of Japan. Thus, the eastern coast of Korea is the most likely place for a tsunamis [3]. With the exception of the Kori NPPs, the level of ground is more than 10m over sea level, which is sufficient to prevent damage from the tsunami. Kori NPPs have increased the coastal barrier from 7.5m to 10m, to enhance the safety of NPPs against tsunami.

4. Conclusions

Based on the reviews of guidelines of seismic design and responses of NPPs under seismic events, it was concluded that the current design of Korean NPPs has no critical problems in terms of safe operation and safe shutdown during the earthquake event. To further enhance the safety of NPPs under seismic events, however, it is necessary to manage the lifetime of affected equipment and seismic verification of spare parts. Also, repeated training and emergency training on the response of NPPs in the event of earthquake are required.

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