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Potential Seismic Safety Issues associated with Small Modular Reactors (SMRs)

Jeong-Gon Ha [a*], Minkyu Kim[a]
[a]*Structural and Seismic Safety Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-Daero 989 beon-gil, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: jgha@kaeri.re.kr*

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1. Introduction

Conventional commercial nuclear power plants have consistently supplied electrical energy to our society. Nonetheless, utilizing large nuclear power plants demands substantial capital investment for their construction and integration with diverse power grids to ensure smooth operation and supply. Furthermore, the occurrence of unforeseen incidents, such as the Fukushima nuclear power plant accident, underscores the potential for significant losses associated with large-scale nuclear facilities.

Motivated by these apprehensions, Small Modular Reactors (SMRs) have emerged as a viable alternative. SMRs present a range of advantages, including heightened safety features, cost-efficiency, and competitive scalability, thereby prompting numerous countries to channel their research and development efforts into exploring these innovative solutions.

In the present context, SMRs are defined as nuclear reactors with power outputs ranging from 10 megawatts electric (MWe) to 300 MWe. They are deliberately designed with greater emphasis on modularity, standardization, and factory-based construction to capitalize on economies of scale. This approach allows various modules to be fabricated off-site and subsequently transported and assembled on location, leading to enhanced predictability and efficiency in construction timelines [1]. However, the reduced dimensions and distinct configurations of SMRs can introduce seismic safety challenges that diverge from those encountered by conventional nuclear power plants.

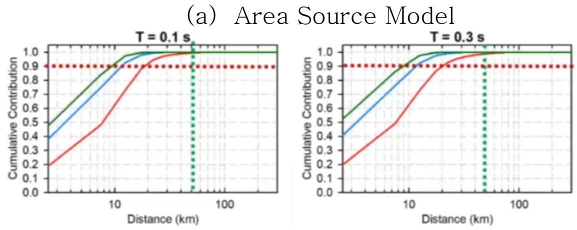
Within this paper, we extract potential SMR-related issues, distinct from those associated with existing commercial nuclear power plants, from the perspective of seismic safety. These insights are drawn from a comprehensive literature review and discussions among the authors.

2. Potential Issues related to Seismic Safety

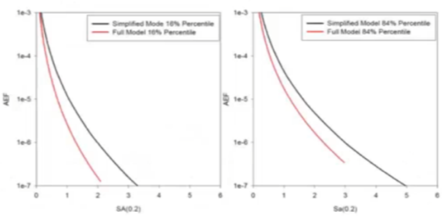
- Graded PSHA Methodology: Probabilistic Seismic Hazard Assessment (PSHA) serves as the first phase in evaluating seismic safety. It computes the likelihood of ground motion intensities exceeding specified thresholds at a target site, accounting for potential seismic sources in proximity. Established commercial nuclear power plants conduct the PSHA considering potential earthquake sources within an approximately 300 km radius of the site, a task demanding considerable resources and effort.

A more flexible approach might be chosen when it comes to Small Modular Reactors (SMRs), which have relatively higher safety systems compared to existing nuclear power plants. In such instances, the PSHA requirement of SMR could gradually be eased compared to conventional nuclear power plants. For instance as described in Fig. 1, if an earthquake source within a 50 km radius of the site contributes over 90% to the hazard, it is possible to simplify the seismic source identification and ground motion prediction equation selection [2]. However, to apply this Graded PSHA Methodology, it is necessary to conduct research to determine the appropriate and conservative evaluation parameters and earthquake models.

(a) Area Source Model



(b) Cumulative Contribution



(c) Comparison of Hazard Curves

Fig. 1. Example of graded PSHA approach by Aybars Gurpinar [2]

- Effect of Reactor Size: One of the defining characteristics of SMRs is their comparatively reduced size, measuring approximately 1/10 to 1/4 of conventional nuclear plants. Reactor buildings of relatively small size and mass can give rise to several issues. First, in estimating a structure's floor response during an earthquake, the widely used square root of the sum of square method (SRSS) for combining responses may not be effective [3]. Particularly, variations in floor response may occur due to interactions between structures and internal equipment, which may be difficult to reflect using traditional methods. In addition, the boring distance required for site investigation of existing commercial nuclear reactor foundations may need to be reduced for SMRs [3].

- Effect of Embedment: In existing commercial nuclear power plants, main buildings and equipment are located on the upper structure on the foundation, but some SMRs can be built in a form buried in the ground to improve safety as Fig. 2 [4]. The following issues may arise when the reactor buildings and equipment are buried in the ground. First, the impact of soil-structure interaction can be significant when evaluating the safety of structures and equipment. Relatively small structure masses and large embedment depths can cause large interaction effects, which can cause changes in the floor response and external pressure of the structure. In addition, re-consideration is required for the assumption that the incident wave due to the earthquake propagates vertically, and wave propagation through the soil surrounding the structure is carefully assessed when calculating the ground motion response spectrum [3]. Moreover, it is judged that the influence of ground deformation, such as the liquefaction of the ground around the SMRs, should be considered more closely.

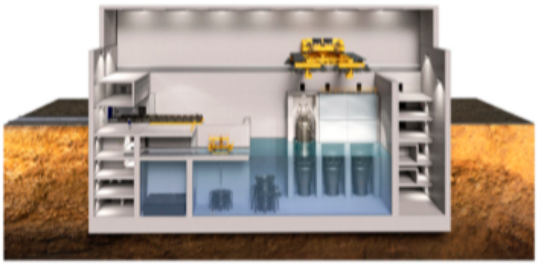


Fig. 2. Embedded Small Modular Reactor (NuScale Reactor Building Cutaway [4])

3. Conclusion

This study summarizes potential issues that may arise concerning seismic safety during the construction and operation of SMRs in the future. Most of the regulations and evaluation methods related to seismic safety will be applied without significant differences. However, since the SMRs has a different shape and size from existing commercial reactors, various issues described above may occur. Although there is no guarantee that the issues presented in this study will necessarily happen, we hope that it will serve as a starting point for researchers and practitioners to thoroughly consider before applying SMRs.

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