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A new design concept and seismic margin assessment for a spent fuel storage system

Jinho Oh, Shinyoung Kwag*, Jongmin Lee

Korea Atomic Energy Research Institute, 111 Daedeok-daero, Yuseong-gu, Daejeon 34057, Republic of Korea

A R T I C L E I N F O

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A B S T R A C T

The design and structural performance of a spent fuel storage system, which plays a role in storing irradiated and damaged fuel assemblies generated during the operation of a reactor, have been regarded as very important issues in relation to nuclear safety. The recent accident at the Fukushima Daiichi Nuclear Power Plant once again highlights the importance of the safe design of such a system. Thus, this paper proposes a new design concept of a spent fuel storage system composed of spent fuel storage racks (SFSR) and a support frame. The design of each SFSR is enhanced by increasing the natural cooling capacity of the pool water. The support frame is newly devised such that it physically prevents the overturning and sliding of racks and collisions among them during an earthquake event.

In addition, to verify the structural integrity of the proposed design and evaluate its seismic margin, static analyses, response spectrum analyses and nonlinear time history analyses are conducted. The response spectrum analyses provide the maximum response of the structures during and after seismic events. The nonlinear time history analyses were carried out to predict contact sliding, rocking, twisting, and turning between the floor of the pool bottom and the support frame. The numerical results were analyzed based on the allowable code limits to assess the structural integrity. The possibility of a collision between the support frame and the adjacent pool wall is investigated. The seismic margin of the proposed design is studied within the seismic fragility analysis framework.

The analysis results show that the maximum stress values of these SFSRs and their support frame under seismic loads are within the specified code limits. An impact between the support frame and the adjacent pool wall will not occur because the sliding distance calculated from the nonlinear time history analysis is less than the gap between the two elements. These results confirm that they cannot be overturned but will instead slide under an SSE event. Finally, the seismic fragility analysis results demonstrate that the designed spent fuel storage system has a sufficient seismic margin which exceeds the targeted seismic design level.

1. Introduction

After the accident at the Fukushima Daiichi Nuclear Power Plant, concerns over the safety, security, and/or the environment of the nuclear industry have greatly increased. In particular, a number of researchers have paid special attention to spent fuel storage and fuel handling systems because these areas experienced during that event a hydrogen explosion caused by the melting of Zircaloy surrounding the spent fuel assembly (Shozugawa et al., 2012). Consequently, such an accident demands evaluations of the seismic margin and risk assessments of spent fuel pools and related storage and handling systems in the event of a beyond-design-basis earthquake. In addition, given the increased number of annual spent fuel assemblies generated during the operation of nuclear reactors, the storage/management of spent fuel assemblies is recognized as one of the most important and urgent issues.

Current methods for the storing of spent fuel assemblies include dry and wet methods. A reactor facility essentially has a storage pool (wet storage) to provide adequate cooling and radiological shielding. Most storage pools are designed and built considering the storage capacity during the operation of the reactor. However, as the lifecycle of the reactor is prolonged, the storage pool at the reactor cannot accommodate all of the spent fuel assemblies. Thus, wet/dry storage facilities away from the reactor site as an alternative have been proposed. Dry storage technology has been intensive over the last decade. Initially, dry storage was developed in the form of single systems such as vaults, silos, and/or non-transportable casks without transport off site. With continuing research on the topic of dry storage, storage systems with multiple functions for storage and transport have been developed.

* Corresponding author.
E-mail address: skwag@ncsu.edu (S. Kwag).

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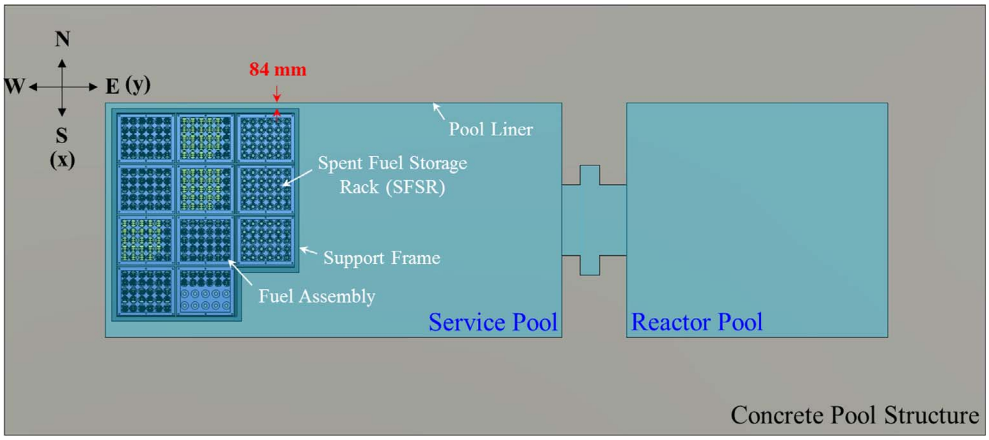

Fig. 1. Conceptual configuration of the proposed spent fuel storage system in two pools.

Table 1
Design classification of the SFSR and Support Frame.

Component	Safety Class(1)	Seismic Category(2)	Quality Class
SFSR	NNS	I	Q
Support frame	NNS	I	Q

NOTES
(1) Defined in American National Standard ANSI/ANS-51.1.
(2) Defined in Regulatory Guide 1.29.

In this study, the research emphasis is on wet storage at the reactor facility, specifically the design of a spent fuel storage system and a seismic safety assessment of the proposed design. A typical spent fuel storage system consists of a several rack modules which are submerged in the pool water (DeGrassi, 1992). Each rack module includes stainless storage cells arranged into a welded grid structure. In order to maximize the storage capacity within the spent fuel pool, the rack modules are installed as closely as possible to each other and to the concrete pool wall, which is lined with stainless steel. Typically, each module is

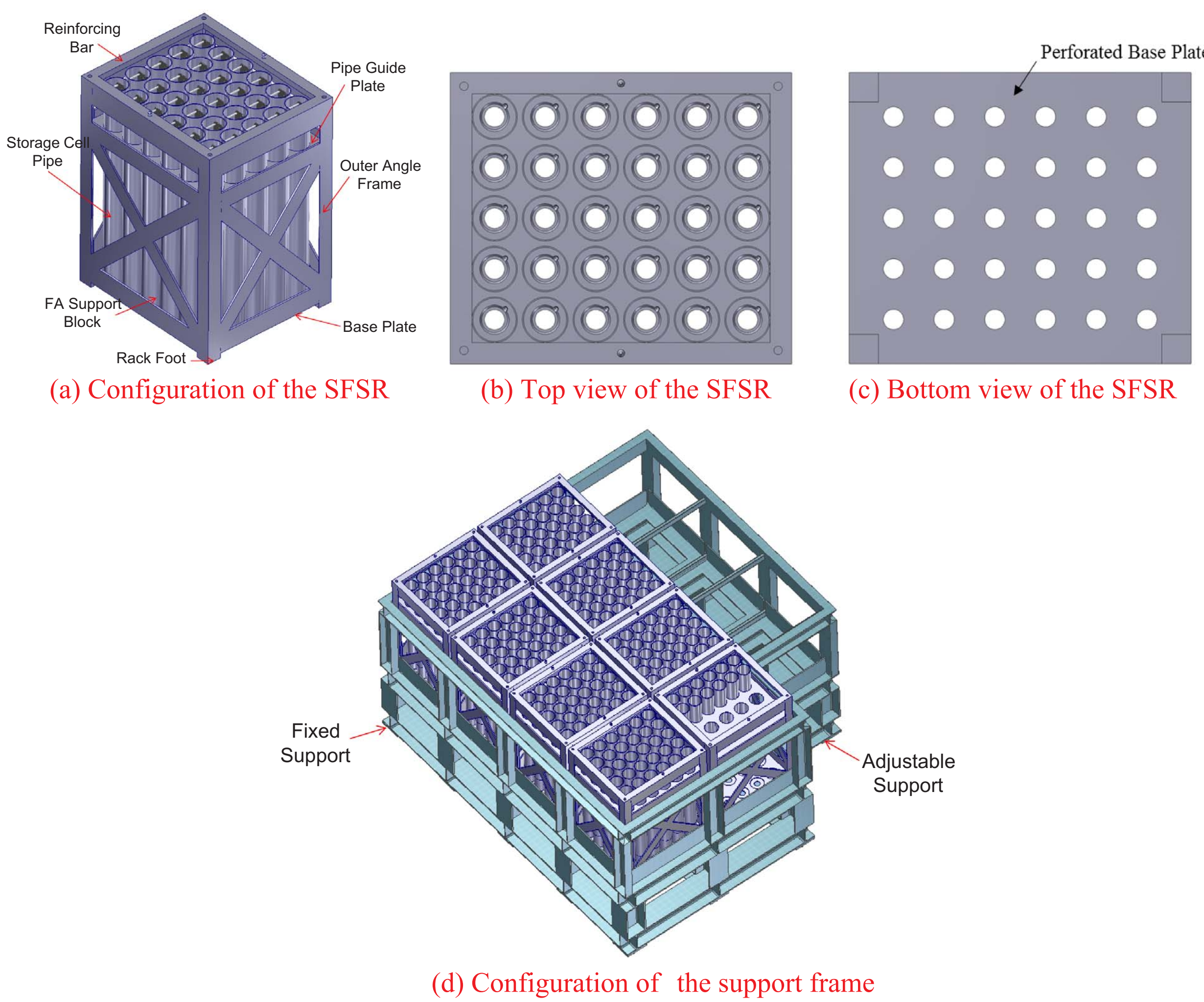

Fig. 2. Proposed spent fuel storage system.