Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Some insights on scale rack motion during the seismic excitation in simulated spent fuel pool accident

Kang-Hee Lee [a*], Heung-Seok Kang [a], Dong-Seok Oh [a], Kyung-Ho Yoon [a], Soo-Ho Kim [a], Cheong-Ryul Choi [b]
[a]*Nuclear Fuel Safety Research Division, KAERI,*
[b]*Elsoltec, Co.*
[*]*Corresponding author: leekh@kaeri.re.kr*

1. Introduction

Herein, the seismic accident simulation experiment using a model scale pool and storage racks were carried out to understand the fundamental physics on the fluid motion and submerged structure's dynamic behaviors in the spent fuel pool earthquake accident, which was based on equivalent similarity to real spent fuel pool. Especially, this short note will deliver brief introduction of the test and discuss some insights on measured scale rack's motion and its spectral features during the simulated seismic excitation. In addition, the frictional sliding motion of the model scale rack behaviors while seismic excitation and during the natural sloshed fluid motion in the pool. Scattered pattern of the rack from orbital trajectories of rack by earthquake in the pool, estimation impact force from the impact incident in the measured acceleration responses.

2. Methods and Results

The 1/8 scale model pool was fabricated in a rectangular open pool with 35 % higher height than the linear scale of the actual pool to avoid an unexpected overflow. All of the spent fuel masses were assumed to be attached to the model storage racks, reflecting the domestic situation where the national storage facilities are saturated. It also prevented random rattling noise in the response measurement from vibration of the nuclear fuel within each cell of racks. The seismic excitation to the model pool was determined by dimensional analysis so that the water motion and the response of the structure can be reproduced with the real pool in the real earthquake condition. The scaling correlations and methodology were validated through 2D fluid structure interaction model simulation.

Each test cases to simulate severe seismic accidents in Korean peninsula was based on following control parameters such as direction and magnitude of excitation, water level, waveform. The waveform of the seismic accident simulation was based on the standard earthquake input spectrum used in the seismic design of a nuclear power plant. The hydraulic shaker with 1 g maximum acceleration and 60 Hz maximum excitation frequency with 5 tons full loaded condition was used for the seismic accident simulation test of model spent fuel storage pool. The free surface water motion and model rack acceleration during the seismic base excitation were measured using a high speed camera and underwater accelerometers, respectively. Uni-axial accelerometers were mounted on the selected racks of interest in three perpendicular directions each. The reference input of the seismic accident simulation test was based on the US-NRC Reg Guide 1.6[1, 2]. A reference seismic acceleration input time history was created based on the Civil Engineering derivation guideline of the input time history. The reference acceleration input was appropriately scaled to represent safety shutdown earthquake(SSE) accident for the seismic design evaluation of the OPR1000 power plant.

The measurement data from underwater accelerometers mounted on the model scale racks provide various useful information such as the frictional sliding motion, the impact behavior with neighboring racks, the type of dynamic motion, motional trajectories along the time duration, and after-shock scattered patterns of racks by additional seismic events. Figure 1 shows typical measured three axis acceleration responses of the scale racks in the pool during the seismic excitation. Vertical responses of racks were measured in considerably large amplitude, compared to the horizontal ones that were directly excited by horizontal base motion. This can be indicated irregular flatness between the pool floor and feet of racks that needed further refinement in the complementary test trial. The random spikes in the measured acceleration response was caused by the random collision of the racks with the neighboring ones. Contrary to the randomly-distributed spectrum of the seismic excitation during the first 10-seconds in Figure 2, two distinct frequency components, which correspond to the fundamental sloshing frequencies of the rectangular pool in each side of direction, dominantly appeared in the spectrum of the residual response during the natural sloshing period. In addition, the 2D motional trajectory of the racks according to the initial position did not show any meaningful difference as shown in Figure 3, but they can indicate the range of motion of the rack trajectory, and if it crossed over the gap length of the racks, it might indicate that a shock to the neighboring rack can occur. Under the seismic base excitation, unique force acting on the moving racks relative to pool base is the friction force, except for relatively minor hydrodynamic force from fluid inertia. Since their kinetic energy decreased with the water depth, at the elevation of the rack, it was assumed that the fluid force was significantly small and negligible, compared to the frictional force. The kinematic friction coefficient in Figure 4 was obtained by subtracting the acceleration input of the shaking table from the measured acceleration of the rack and dividing it by the gravity. The resultant friction coefficient had a complicated waveform depending on the type of excitation and the corresponding rack motion, and also had a value in the range of about 0.2 to 0.8. Further study to the frictional behaviors of racks in air condition is needed for the complete description of the under-water frictional behaviors.

Finally, this study focused on the structural integrity evaluation of the submerged free-standing structures in the model scale pool under the event of a severe seismic accident. In particular, it measured the impact force acting on the storage rack while moving. Analytical studies related the storage racks movement in the pool, reflecting nonlinear and discontinuous characteristics such as fluid-structure interaction and frictional sliding behaviors, are also carried out through the close cooperation with industry partner so that the realistic prediction model can be developed.

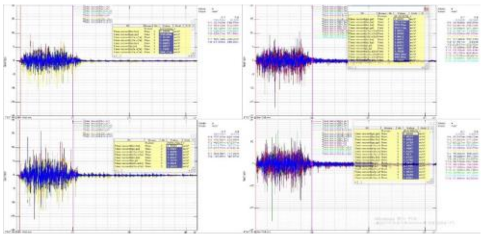

Fig. 1 Typical measured acceleration responses of the scale racks and infrequent impact events during the seismic base excitation of the scale pool.

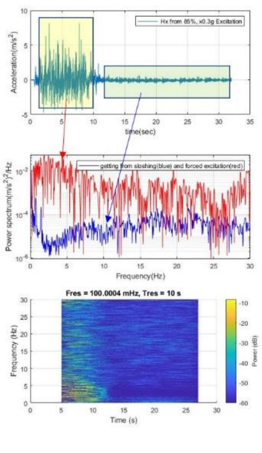

Fig. 2 Time-frequency spectrum for divided time sections of measured acceleration of the submerged model racks.

3. Conclusions

A 1/8 scale model spent fuel storage pool test was carried out in air and mostly under water filled with different water levels, to simulate severe seismic accidents in Korea. Various tests were performed using test parameters such as air/water, level of water, excitation direction, level of excitation, full and partial loading of the racks. Time history of acceleration responses of submerged racks in the pool were measured during the accidental seismic excitations of the pool base. The test results were consistent during the repeated test operations. This test was carried out to develop seismic safety evaluation technology for spent fuel pool and spent fuel using a scale model. In order to increase the usability of the results of this study, additional complementary experiments and analytical simulations should be conducted in the future.

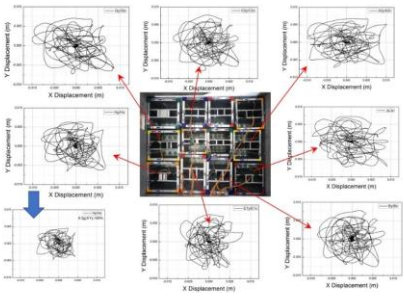

Fig. 3 Orbit trajectories of the submerged racks during the seismic excitations, according to the initial positions.

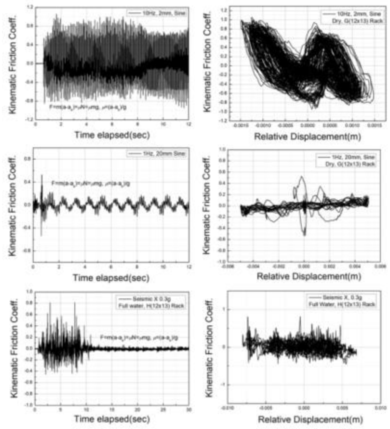

Fig. 4. Kinematic frictional coefficient of submerged model racks during the seismic base excitation.

Acknowledgements

This work was funded by the Industrial Technology Innovation Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy(MOTIE), Republic of Korea. (No. 20171510101920).

REFERENCES

[1] US NRC, A Regulatory Guide 1.60 "*Design Response Spectra for Seismic Design of Nuclear Power Plants*". in REG-Guide 1.6, Ground Response Spectrum. , US NRC, Editor.

[2] DeGrassi, G., *Review of the Technical Basis and Verification of Current Analysis Methods Used to Predict Seismic Response of Spent Fuel Storage Racks*, in NUREG/CR-5912, BNL-NUREG-52335, US-NRC, Editor(1992).