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Development of Safety Enhancement Technology for SSCs in Nuclear Power Plant considering Beyond Design Level Earthquake

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ABSTRACT

This paper introduces the research project that started in early 2022 name is 'IRONS-EQ'. The 'IRONS' means the integrated researches on nuclear safety and the 'EQ' means earthquake. The purpose of the IRONS-EQ is the development of safety enhancement technology for SSCs in Nuclear Power Plant considering beyond design level earthquake. The IRONS-EQ research project constructed as main three part. There are the ground motion generation, a real time seismic response technology and seismic risk assessment technology. In seismic hazard research to determine input seismicity, research to improve the reliability of seismic hazard assessment by applying artificial intelligence technology and development of methods to apply Monte Carlo methods are underway. For the safety assessment of nuclear power plants through real-time monitoring, technologies are being developed that can quickly evaluate the seismic response of nuclear power plant structures and devices and diagnose damage by applying machine learning methods. For quantitative safety assessment of nuclear power plants considering deterioration, technologies are being developed to improve probabilistic seismic safety assessment techniques and substantially improve the safety of nuclear power plants.

INTRODUCTION

The magnitude 5.8 earthquake in Gyeongju in 2016 struck fear into the hearts of South Koreans who had rarely experienced an earthquake. In particular, the manual shutdown of four reactors at a nearby nuclear power plant site due to the earthquake raised concerns about the safety of nuclear power plants from earthquakes, even though the measured seismicity at the plant was below the OBE level of 0.1g. In response, since 2017, a research project has been conducted to develop a method to more accurately assess the safety of domestic operating nuclear power plants. However, from 2022, we will begin to develop technologies that can improve the safety of operating nuclear power plants against earthquakes, not just evaluate their safety against earthquakes. The research projects are divided into seismic hazard assessment technology to accurately predict ground shaking caused by earthquakes, technology to quickly assess seismic safety by observing seismic activity in real time during earthquakes, and probabilistic safety assessment technology that can quantitatively assess the safety of nuclear power plants due to earthquakes.

For the seismic hazard analysis, we try to perform an 'Artificial Intelligent Technology' was applied. The AI based PSHA technology is developing for more accurate and efficient PSHA technology and try to develop the ground motion generation technology using big data that constructed based on previous occurred earthquake data in Korea. For the quick assessment of seismic safety during the development of real time seismic response technology, seismic response technology based on real time monitoring and deep learning and machine learning technology are now developing. For the developing a seismic risk assessment technology, seismic PSA software is under developing and seismic safety improvement and reinforcement technology are also developing. All overview of this research project are shown in the Figure 1.

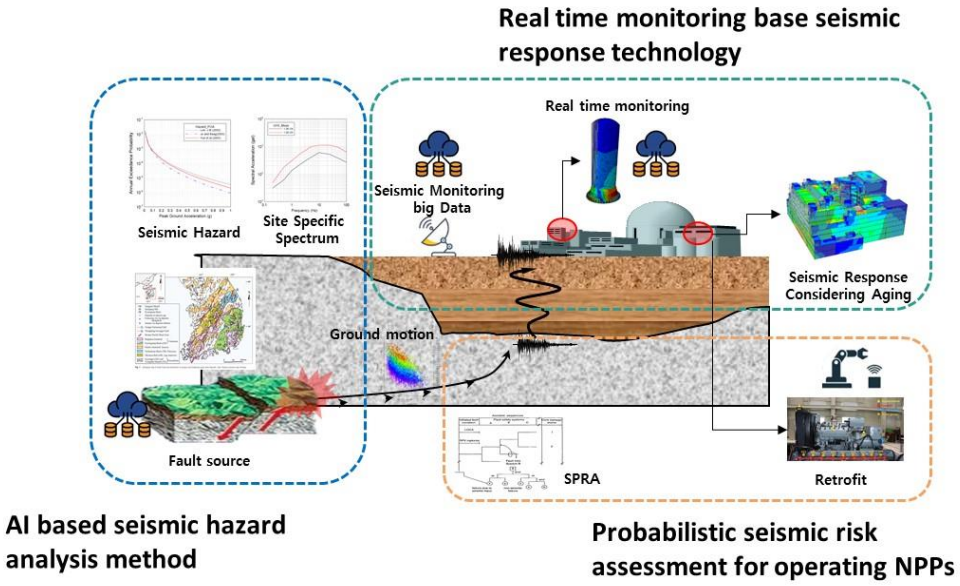


Figure 1. Overview of All researches Area for the development of Safety Enhancement technology for SSCs in NPP considering Beyond Design Level Earthquake

GROUND MOTION GENERATION TECHNOLOGY

PSHA Technology

Determining the seismic source model is one of the most important steps in the process of performing a PSHA. The seismic source model is usually determined by following the SSHAC procedures with the advice of a number of seismologic experts. However, this process produces different results depending on the opinion of each expert, which greatly affects the outcome of the seismic hazard. Therefore, this study attempts to apply artificial intelligence technology to the determination of the seismic source model. A clustering technique was applied to create a seismic source model for seismic hazard assessment, and seismic hazard assessment was performed based on this model and compared with the results of seismic hazard assessment using conventional methods. The completed method is currently under development, and the interim results are presented in the following figure.

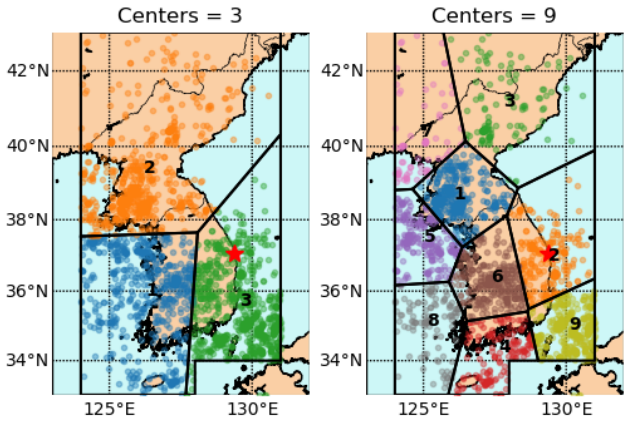


Figure 2. Area sources by Clustering

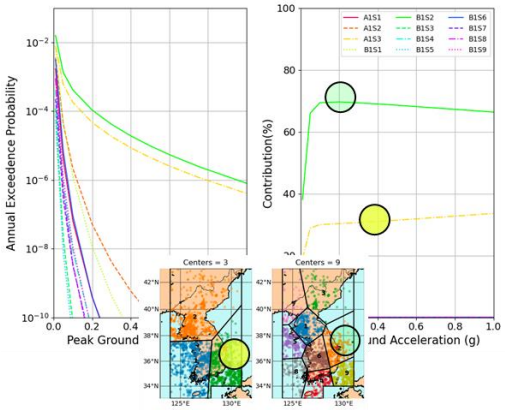
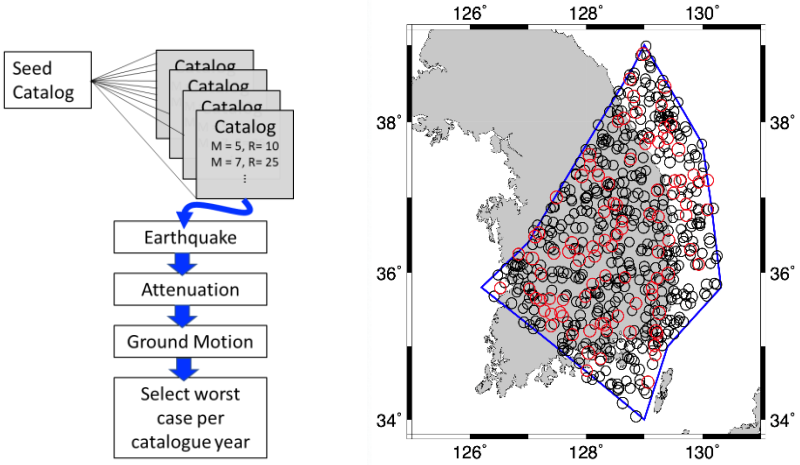


Figure 3. Source contribution from PSHA

Also, PSHA methodology using Monte Carlo Method in now developing. For the developing PSHA methodology, synthetic earthquake catalog using Monte Carlo Simulation is developing and PSHA using the generated earthquake catalog in now developing. The procedure of Monte Carlo Method for developing PSHA technology and the example generation of synthetic catalogue is shown in Figure 4.



(a) Procedure of MCM for developing PSHA (b) example generation of synthetic catalogue

Figure 4. Procedure of Monte Carlo Method for developing PSHA technology and the example generation of synthetic catalogue

Site Specific Ground Motion

Separately from PSHA, we are developing a technique for generating big data-based site input ground motion generation technology. For the big-data based seismic ground motion technology, the seismic data management platform and the Smart Seismic instrument are now developing (Figure 5).

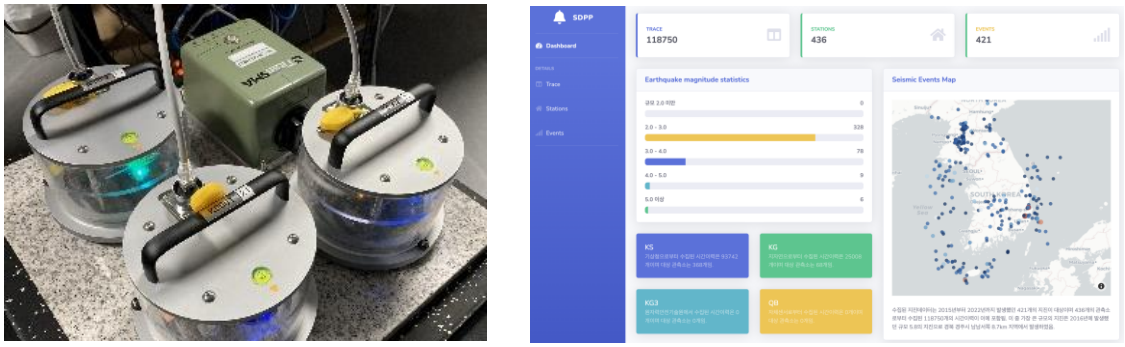


Figure 5. Developed Smart Sensor & Seismic Data Platform

Also, site response analysis considering ground motion incoherency is performing and probabilistic 2-D site response method is developing. The sample results for 2-D seismic response analysis is shown in Figure 6. And, site-specific input motion for seismic performance evaluation is performed for determine the selection method of seismic motion based on site-specific scenarios. One of the site specific input motion generation result is shown in Figure 7.

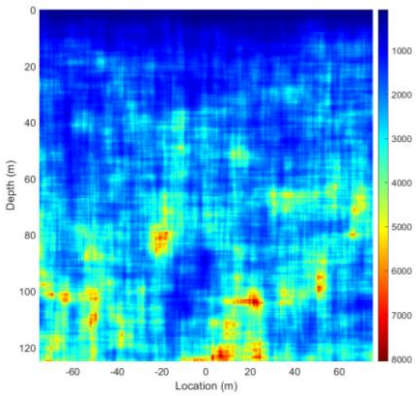


Figure 6. 2D Site Response Analysis

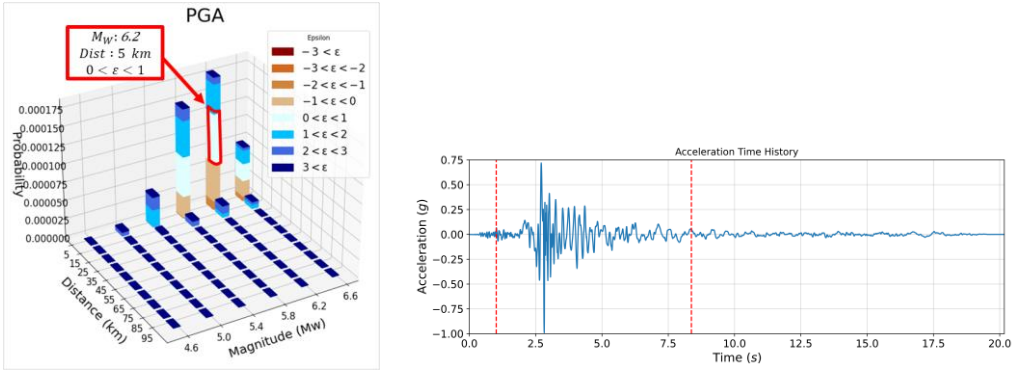


Figure 7. Development of Site-specific Input Ground Motion

REAL TIME MONITORING

Monitoring System for Fragility Assessment & Prediction

We are conducting research to optimize seismometer placement using the beam stick model. Developing techniques to optimize the placement of sensors for the application of real-time monitoring technology in nuclear power plants. The three-dimensional analytical model and the one-dimensional beam stick model used for development are shown in Figure 8. To facilitate the fragility assessment, we are developing a method to reduce the order of the three-dimensional model using the reduced order model(ROM) while maintaining the accuracy of the analysis, and the results of reducing the order using the real ROM method are shown in Figure 9 compared to the existing results.

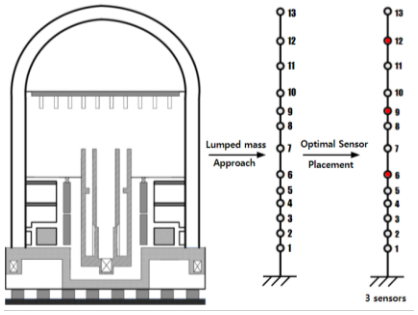


Figure 8. Seismometer placement (3-D Model vs. 1-D Model)

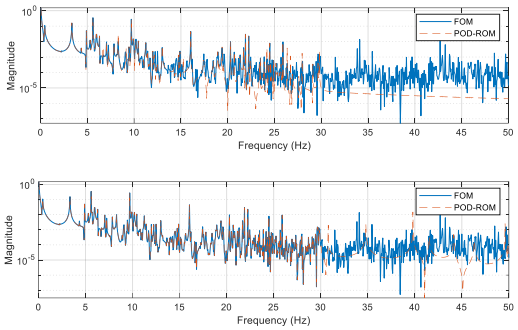


Figure 9. ROM-based Frequency response comparison

We are developing a method to detect and classify damage to structures caused by earthquakes using deep learning methods, and in particular, we are developing a technology to classify damage by applying CNN methods. The changing shape of the floor response of the nuclear power plant structure due to damage is shown in Fig. 10. In addition, since there is not enough seismometer installed in nuclear power plants, we are developing a machine learning method to predict the floor response spectrum (FRS) without seismometer. In other words, we are developing a technology to predict the FRS without seismometers using the Multi-layer perception method based on the seismic response system. The results of predicting the FRS where no seismometers are installed are shown in Figure 11.

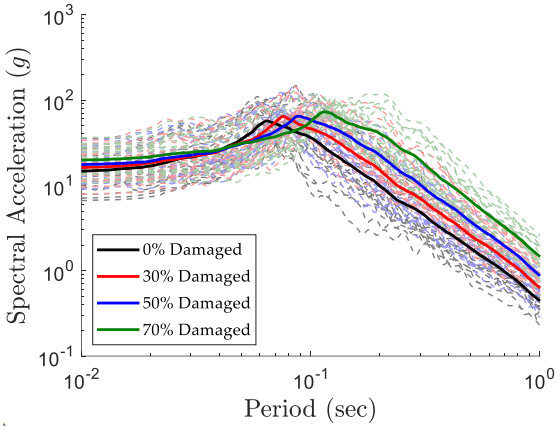


Figure 10. Response Spectrum according to the damage

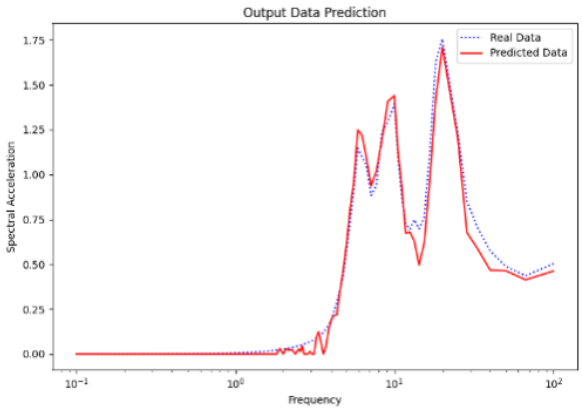


Figure 11. Prediction of Floor Response Spectrum based on Seismic Monitoring System

Deep Learning for Seismic Response

We are developing the deep learning & machine learning-based prediction model and after that, we are developing the database of earthquakes & responses of NPP structure/equipment based on the DL and ML analysis results. For the validation of deep learning-based prediction model through machine learning model is used. The architecture of NPP structure response prediction deep learning model is shown in Figure 12 and the results of floor response prediction model using ANN is shown if Figure 13.

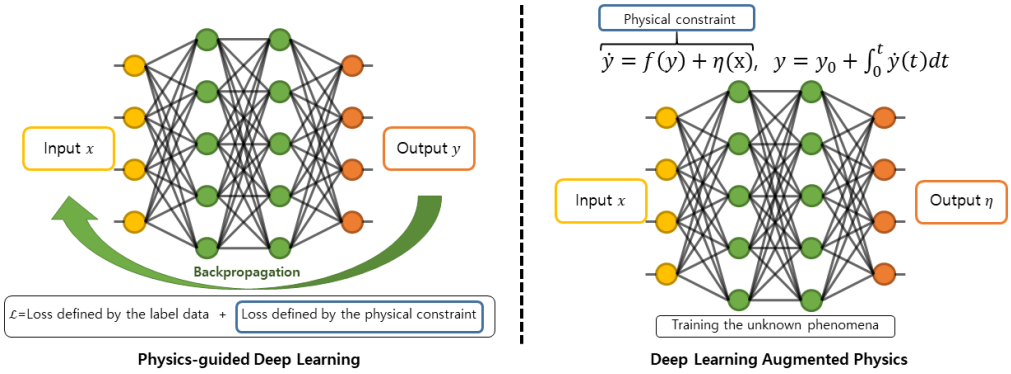


Figure 12. Architecture of NPP structure response prediction Deep Learning Model

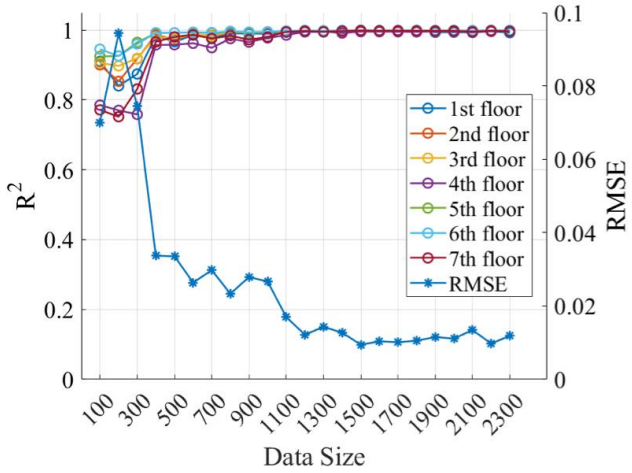


Figure 13. Results of Floor Response Prediction Model using ANN

DEVELOPMENT OF SEISMIC PSA METHODOLOGY

For the perform a seismic safety assessment for nuclear power plant, a probabilistic seismic safety analysis (SPSA) program is developing. The name of SPSA program is ARES (Advanced Risk Assessment Program Considering Earthquake Scenarios). The ARES can calculate a total CDF and sequence CDF for nuclear power plant using seismic hazard, seismic fragility, correlation of each equipment and structures in NPP and the probability of human error. The PSA model is used as fault tree format. The all overview of the AREA program is shown in Figure 14.

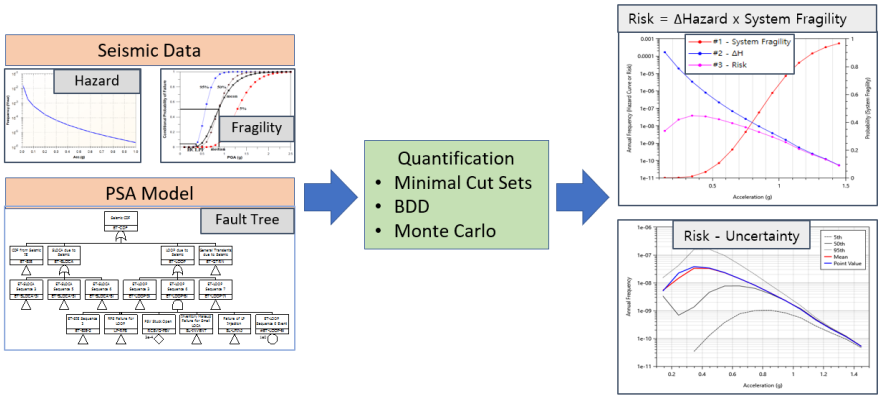


Figure 14. The overview of Probabilistic Seismic Safety Assessment Program (ARES)

CONCLUSION

A number of papers related to this project will be presented at the SMiRT27 conference. There are seismic hazards analysis, real time monitoring, seismic fragility assessment considering the aging related degradation of SSCs, machine learning technology for the estimate seismic response of structures and equipment and seismic PRA technologies. It is expected that the seismic safety of operating nuclear power plants will be improved by 2026, when this R&D program ends.

At the end of this research project, we expect to achieve the following outcomes.

- Advanced PSHA Software (KOHAZ)
- Seismic Ground Motion Big Data
- Smart Sensor
- Deep learning, Machine Learning Technology for determine seismic response of NPP structure and equipment
- Optimized Seismometer Placement
- Seismic Fragility Evaluation Technology considering aging related degradation (Structure, Equipment)
- Seismic Reinforcement Technology
- Improved SPRA Software (ARES)

REFERENCES

Jeong-Gon Ha, In-Kil Cho, Minkyu Kim (2023), A study on the procedure of determining seed motion for seismic analysis, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 18-19, 2023

Jin Koo Lee, JeongBeom Seo, Seong Jin Jeon (2023), Study on the use of CNN models for high-pass filter frequency in ground motion data generation for evaluating seismic fragilities, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 26-27, 2023

Minkyu Kim (2023), INTEGRATED RESEARCH ON NUCLEAR SAFETY, Technical Meeting on the Protection of Nuclear Installations Against External Hazards, 17th Plenary Meeting of EESS EBP, 19-22 September 2023

Yongmoon Hwang, Minkyu Kim (2023), Preliminary Study of Prediction of Response Spectrum in unmeasured floor through Multi-Layer Perceptron of seismic monitoring system, Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 26-27, 2023