*Transactions of the Korean Nuclear Society Spring Meeting*
*Jeju, Korea, May 22-23, 2025*

# Prediction of Unmeasured Floor Response Spectrum Using Seismic Monitoring System

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***Keywords :** seismic monitoring system, multi-layer perceptron(ML), floor response spectrum

## 1. Introduction

Nuclear power plants as well as infrastructures are operating monitoring system to conduct heath assessments on ambient vibration or by external forces. While infrastructure is undergoing various research such as sensor deployment or data fusion, nuclear power plants are sensitive to disasters such as earthquakes but are only operating a minimal monitoring system. In other words, nuclear power plants operate limited monitoring systems having complex structural form. In this case, when machine learning technology is applied, the responses of the structure can be predicted more effectively than before. Conventionally, seismic responses at OBE level or SSE level were identified through seismic monitoring systems.

Therefore, in this study, prediction of unmeasured floor response spectrum using seismic monitoring system and machine learning was conducted and the results are presented. In the future, the developed technology will be applied to auxiliary building to conduct seismic fragility analysis of specific equipment.

## 2. Methods and Results

In this section, details on the development of a predictive model for the response spectrum of unmeasured floor are specified. Firstly, because of the limitations in utilizing real-measured data, we conducted research based on numerical analysis. Additionally, the currently operating seismic monitoring system and the locations where unmeasured floor are explained.

### *2.1 Target Structure*

The target structure is modeled using ABAQUS for the APR 1400 containment building [1] and performed a floor response spectrum prediction. Fig. 1 shows the cross-section of the target structure, with the red boxes representing the current seismic monitoring system and the blue box representing the reactor coolant system (RCS). The reason RCS floor response spectrum was predicted was that only the RCS is implemented as a beam-stick in the established analysis model, and therefore it was selected as the target floor. When evaluating the dynamic analysis of the target structure, the main natural frequencies and mode shapes shown in Fig. 2 were confirmed.

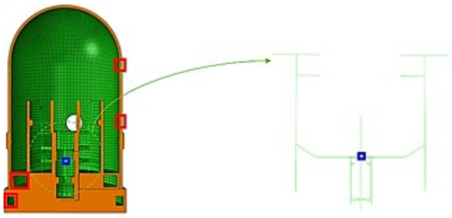

Fig. 1. Seismic monitoring system and unmeasured location.

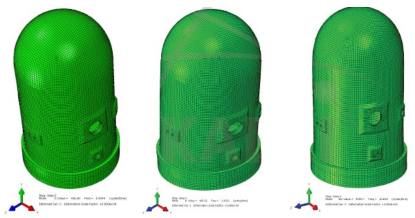

Fig. 2. Main frequencies and Mode shapes of containment [1]

### *2.2 Training Data Set: NGA-West2 DB*

As mentioned earlier, due to the limitations and limited data from measured data on a nuclear power plant site, prediction of unmeasured floor response is performed based on numerical analysis. The NGA-West2 has various ground motion databases operated by the Pacific Earthquake Engineering Research Center (PEER).

In this study, recorded earthquakes were classified according to the Peak Acceleration to Velocity ratio (A/V ratio) among various measured earthquakes [2]. The A/V ratio is an element that can be used to grasp the duration of strong motion and frequency characteristics of seismic motion and can be divided into three stages (high, inter-mediate, and low). Furthermore, peak ground acceleration (PGA) in one of horizontal directions of the raw data has to exceed 0.1g. finally, utilizing the selected recorded earthquakes, several times of analysis were performed considering the PGA level for 0.3g which is the safe shutdown earthquake (SSE) level for APR 1400.

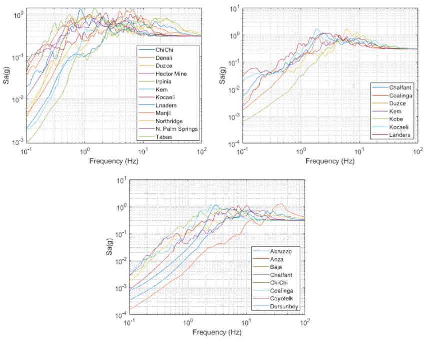

Fig. 3. Response Spectrum of classified earthquakes

### *2.3 Multi-Layer Perceptron (MLP) based Prediction Model*

As previously mentioned, target structure including the seismic monitoring system and unmeasured floor was described briefly. Additionally, training data were established using the NGA-West2 DB, which is used to build a response prediction model for the unmeasured floor. Among various machine learning models, the multi-layer perceptron (MLP) model was utilized in this study. The MLP is a type of artificial neural network (ANN), consisting of input, hidden, and output layers, and has demonstrated excellent performance in learning complex patterns in non-linear data.

The MLP-based floor response spectrum prediction model developed in this study consists of two hidden layers. The overall structure of the model is illustrated below. Initially, at the input layer, response spectrum values from each seismic monitoring system are set. The input data are arranged as vectors (4*115). Here, '4' represents the number of data sets for each seismic monitoring system, and '115' signifies the number of data points in the frequency domain representing the response spectra. By entering these directional response data from the seismic monitoring systems as vector inputs, the model learns to identify the response characteristics. Accordingly, at the output layer, the predicted response spectrum values in unmeasured floor are estimated. The output data are represented as scalars (1*115), ensuring that they correspond to the same frequency domain for the response spectra.

In the model, the variability in directional characteristics were not considered. This approach focuses on simplifying the model structure and enhancing efficiency by processing individual directional response data separately.

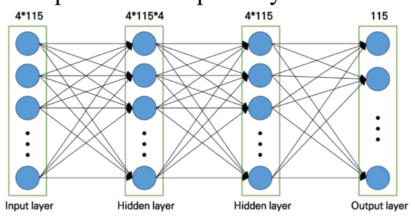

Fig. 4. Configuration of MLP-based Floor Response Prediction Model.

### *2.4 Prediction Results*

To predict the floor response spectrum at unmeasured location, a total of 77 learning datasets were secured. Among these, 30% were used as validation data. The following figures show the results obtained from predicting responses based on the developed model.

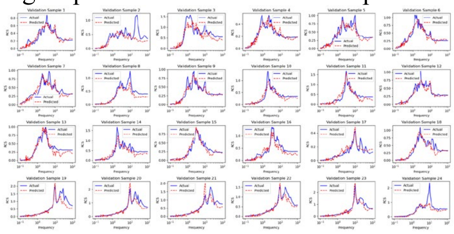
Fig. 5. Results of Validation dataset.

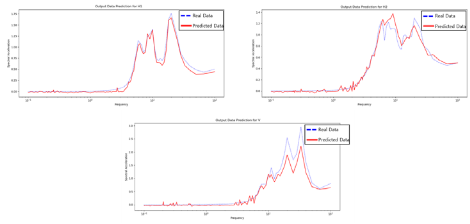
Fig. 6. Comparison between predicted response spectrum and numerical analysis

## 3. Conclusions

In this study, a model to predict the response spectrum of unmeasured floor by utilizing seismic monitoring system installed in the containment building of a nuclear power plant. The MLP model was used to predict the response of the structure effectively and accurately in a large and complex structures such as a nuclear power plant. In the future, the developed model will be applied to auxiliary buildings to predict the floor response of the main equipment and perform a seismic fragility analysis.

## Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grand funded by the Korea government (MSIT) (RS-2022-00144425).

## REFERENCES

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[2] W. K. Tso, T. J. Zhu, and A. C. Heidebrecht, Engineering Implication of Ground Motion A/V ratio, Soil Dynamics and Earthquake Engineering, 11(3), 133-144.