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Frequency-Based Finite Element Updating Method for Simulation-Based Digital Twin

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1. Introduction

There are various definitions for digital twin. One of the definitions is that digital twin means constructing a replica of real structure in a virtual space. In engineering perspective, it can be seen that digital twin means a mathematical model remarkably similar to actual structure. There are two kind of digital twin including data-based digital twin and simulation-based digital twin. Simulation-based digital twin uses physics such as Finite Element Method (FEM). To build a simulation-based digital twin, the numerical model using FEM has to represent the behavior of the actual structure. The behavior of initial numerical model may not match the actual behavior. The behavior of the numerical model is determined by parameters such as stiffness, mass and damping in seismic analysis. It is necessary to modify parameters through Finite Element Model Updating (FEMU) to increase the accuracy of numerical model. For accurate result, damping should be included as parameter. Also, the behavior of numerical model should match the actual behavior at all frequencies of interest, not just at some frequencies. For high accuracy and efficiency, frequency-based finite element updating method considering damping is proposed. In proposed method, data transformed from time domain to frequency domain is used for analysis. Parameters including damping are updated. In this study, through the seismic analysis of numerical example using Control Rod Drive Mechanism (CRDM), the accuracy and calculation time of the proposed method considering damping are verified.

2. Method

Previous time-based analysis method performs analysis using input data in time domain. And result data is only transformed to some frequencies. Calculation time of previous method is not efficient. Behavior is confirmed only at some frequencies not all frequencies of interest.

In proposed frequency-based finite element updating method, for efficient analysis, input data transformed to frequency domain is used. Accurate result data can be obtained in all frequency domain of interest. Through updating process considering damping, accuracy of result can be increased.

Input acceleration data is transformed from time domain to frequency domain by Fast Fourier Transform (FFT). FFT is an algorithm that can rapidly transform data from time domain to frequency domain. The analysis is performed by using the acceleration data in frequency domain. Stiffness, mass, and damping are set as parameters for updating. By updating the parameters considering damping, the accuracy of the numerical model can be improved. Result data obtained through analysis is in frequency domain. The result data using FFT is not appropriate for analyzing the structural response of the model. In order to analyze the response, Seismic Response Spectrum (SRS) is used. SRS is useful method to descriptive represent response. In order to use SRS, the result data should be in time domain. The result data is transformed from frequency domain to time domain using Inverse FFT (IFFT). Accurate result can be obtained using SRS in all frequency domain of interest by transforming the result data from time domain to frequency domain. In addition, total calculation time including updating time can be reduced by using the proposed method. Fig. 1 shows process of the proposed method considering damping.

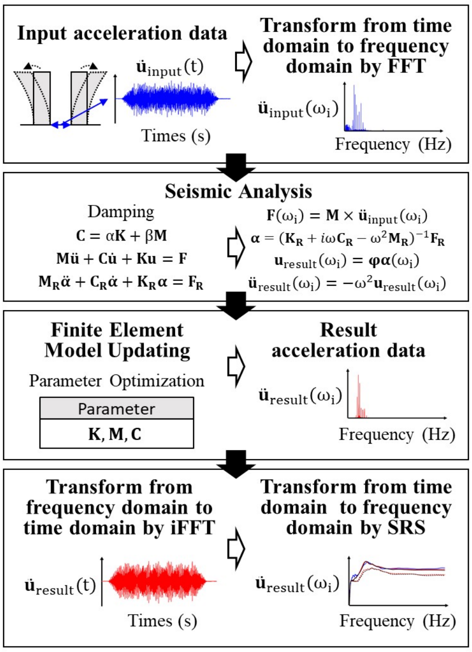


Fig. 1. Frequency-based finite element updating method with damping.

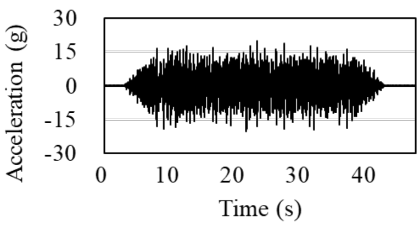
3. Results

The accuracy and efficiency of the proposed method are verified using numerical model of CRDM. CRDM is one of the components installed inside the reactor vessel. CRDM is used to control a power of the reactor by adjusting control rod. Result of numerical model is obtained by updating using proposed method. The result of proposed method is compared to that of previous method and experiment. Table I shows the element information of numerical model.

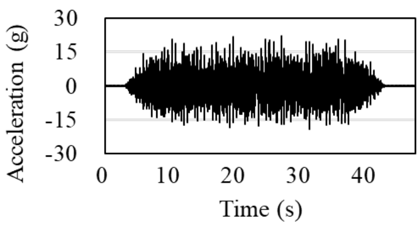
Table I: Element information of CRDM model

Element type	brick8
Number of elements	9584
Number of nodes	14013
Number of total DOF	42039

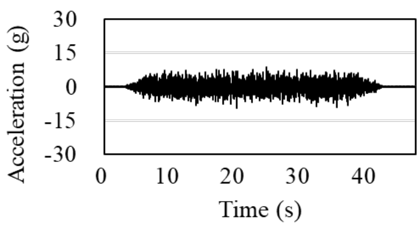
The Korea Atomic Energy Research Institute (KAERI) conducted an experiment using an actual CRDM prototype. Input acceleration data and result data are used for seismic analysis and updating of proposed method, respectively. In fig. 2, acceleration data in time domain for x, y and z axis are represented. The data is 47.5525 seconds with 76085 time steps.



(a)



(b)



(c)

Fig. 2. Input acceleration data in time domain (a) x, (b) y, (c) z axis.

For effective updating, the numerical model is divided into 11 areas. Parameters of each area are updated separately. To increase accuracy of updating, damping is set as parameter with stiffness and mass. To verify the influence of damping on accuracy of the result, the cases with and without damping are compared. In case without damping, results before and after updating are not accurate. In the other case, it is not accurate before updating, but after updating, it shows result close to the experiment. Therefore, it can be seen that accurate result can be obtained by considering damping as parameter for updating.

The accuracy of the result using proposed method is verified in all frequency domains of interest. In this seismic analysis, the frequency range of interest is up to 100 Hz. The result using proposed method is compared with that using previous method and experiment. Results using both methods are inaccurate before updating. But after updating, the results are closer to experiment. Through the proposed method, it can be seen that accurate result can be obtained in all frequency domain of interest.

By the proposed method, efficiency of calculation can be increased. The calculation time and number of iterations using both methods are compared. The calculation time per iteration using previous method and proposed method take 74.099s and 29.173s, respectively. Time for updating of previous method takes 18524.724s (5.15h) with 250 iterations. Time for updating of proposed method takes 2012.931s (0.56h) with 69 iterations. Proposed method requires less updating time than previous method. It can be observed that the proposed method is more effective than previous method.

4. Conclusions

The proposed frequency-based finite element updating method can provide accurate analysis not only in some frequencies but also in all frequency domains of interest. Using proposed method, analysis is performed using data transformed into frequency domain. For an accurate result, damping should be considered as a parameter in the updating process. High accuracy and efficiency of the proposed method are demonstrated in verification using numerical example of CRDM. It is seen that proposed method would be useful for constructing effective simulation-based digital twin. It is expected that proposed method can be used for design of reactor.

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