Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

A Study on the Development of Simplified Fuel Assembly SSE/LOCA Analysis Model using Optimization Technique

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1. Introduction

Under the Safe Shutdown Earthquake (SSE) and Loss of Coolant Accident (LOCA) events, the fuel assembly deflection and impact force between fuel assemblies are obtained by the dynamic transient analysis for the reactor core model.

The impact behavior between fuel assemblies shows non-linear characteristics, because fuel assembly shows non-linearly dynamic characteristics and its geometry is complicated. Furthermore, since a reactor core consists of a large number of fuel assemblies, the dynamic behavior of the core under the postulated events is very difficult to analyze. Therefore, it is necessary that fuel assembly model be simplified considering dynamic non-linear characteristics in core analysis.

In this study, a simplified fuel assembly finite element model for 17 Type RFA has been developed using optimization technique. To obtain the simplified model, the optimization algorithm of ANSYS was used, and the model was verified by comparison with fuel assembly mechanical test results.

2. Methods and Results

2.1 Definition of Optimization Problem

The optimization problem for simplified model of fuel assembly was defined as follow;

- Object function: Minimize $|\Omega_T - \Omega_C|$
  where Ω_T: Target Frequency (test results)
  Ω_C: Converged Frequency
- Subject to $\Delta f_i \leq \pm\varepsilon_i$
  where Δf_i: difference of each frequency at the i^{th} mode
  ε_i: Converged tolerance

2.2 Configuration of Simplified Model

In order to determine the configuration of simplified model which has equivalent dynamic characteristics with fuel assembly, the scoping analysis were performed.

First, fuel assembly was considered as uniform/non-uniform simple beam, and rotational springs in core support, and consistent/lumped mass for fuel rods as shown in Figure 1. The sub-problem approximation method in ANSYS was used for the optimization of model, and the design variables for beam stiffness (I) and the rigidities for each rotational spring were optimized.

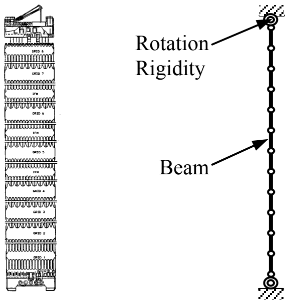


Fig. 1 Fuel Assembly and Simplified Model

The optimization iteration for the first simplified model was performed. However, the iteration was not converged, and the mode shapes of the best solution in iterations were shown to be different compared to test results.

It seems that the divergence and incorrect results of the first case model are caused by the non-linearity of fuel assembly. That is, the first case model could not simulate the interface between the grid spring/dimple and the fuel rod, non-symmetric of IFM attached in the upper region of fuel assembly, and non-linear gap characteristic between IFM dimple and fuel rod.

Next, in order to resolve this problem, the additional rotational springs between each grid and top and bottom ends of fuel assembly were considered in the first model as shown in Fig 2.

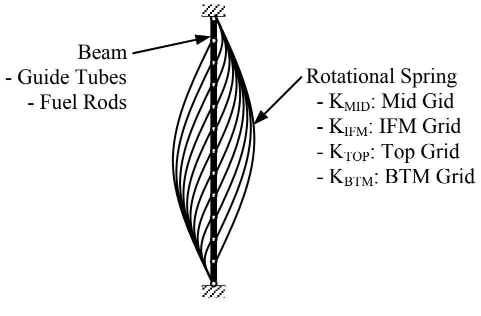
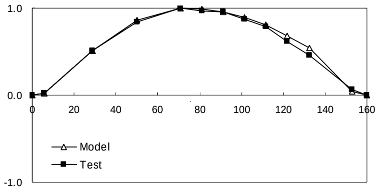


Fig. 2 Simplified Fuel Assembly Model

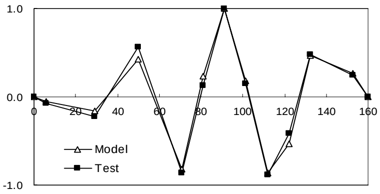
The optimization method of the second case model is the same as that of the first model, and the uniform beam was assumed, and the design variables for the beam and rotational spring stiffness were optimized. The optimized results for the second model are shown in Table 1 and Figure 3.

Table 1: Comparison of Natural Frequencies

Mode	Ω_C / Ω_T
1st	1.000
2nd	1.000
3rd	1.016
4th	1.040
5th	1.008
6th	1.043



(a) 1st Mode



(b) 6th Mode

Fig. 3 Comparison of Mode Shapes

2.4 Sensitivity Analysis

As shown in Figure 1, the fuel assembly structural geometry is complicated. The fuel rod mass and stiffness are distributed from top grid to bottom grid. Therefore, to consider the non-uniform condition of fuel assembly due to fuel rod, the sensitivity study was performed for cases of Table 2.

Table 2: Case for Sensitivity Analysis

Cases	Fuel rod mass distribution	Fuel rod stiffness
Case 1	Overall Length	Overall Length
Case 2	Grid 1~ 8	Overall Length
Case 3	Overall Length	Grid 1~8
Case 4	Grid 1~ 8	Grid 1~ 8

The optimization and modal analysis for the models were also performed. The results of natural frequency and mode shape for all cases are very similar with the results of Table 1 and Figure 3. Therefore, the model of case 1 was used as the typical simplified model.

2.5 Verification of Simplified Model

In order to verify the model, the simulations for static and pluck vibration test were performed. The results are shown in Figures 4 and 5.

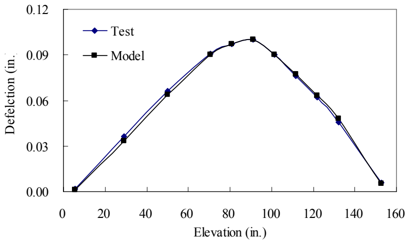
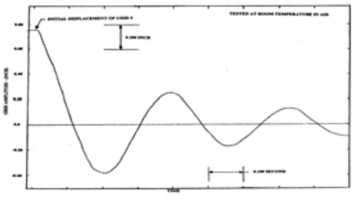
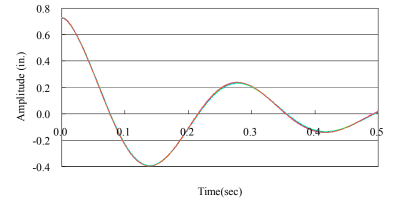


Fig. 4 Comparison of Static Analysis



(a) Test



(b) Model

Fig. 5 Comparison of Vibration Analysis

3. Conclusions

The simplified fuel assembly model for fuel assembly SSE and LOCA analysis has been developed using optimization technique, and the design variables to decide the fuel assembly model have been determined by sensitivity studies. The optimized simplified fuel assembly model shows a good coincident with fuel assembly mechanical test results.

Through this study, the possibility of using optimization technique can be confirmed to generate the fuel assembly model. Furthermore, this model and technique can be used to increase the efficiency and accuracy of fuel assembly SSE/LOCA analysis.

Acknowledgement

This study was carried out under the project “Development of the Major Design Codes for a Nuclear Power Plant” which was funded by the Ministry of Knowledge Economy.

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