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The effect of the fuel rod friction force to the fuel assembly lateral mechanical characteristics

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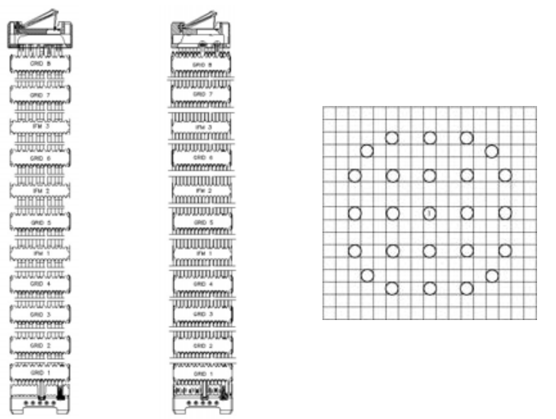
1. Introduction

The Fuel Assembly (FA) for light water reactor consists of hundreds of fuel rods, guide tubes, spacer grids, top/bottom nozzles. The guide tubes transmit vertical loads between the top and bottom nozzles, position the fuel rod support grids vertically, react the loads from the fuel rods that are applied to the grids, and provide some of the lateral load capability for the overall fuel assembly. The guide tubes are the structural members of the skeleton assembly. And the spacer grids maintain the fuel rod array by providing positive lateral restraint to the fuel rod but only frictional restraint in the axial direction. Figure 1 shows the outline of skeleton, FA and the location of guide tubes in the view of cross section. 17x17 FA has 24 guide tubes and one instrumentation tube. When the FA is in reactor, the lateral stiffness is one of very important factors from the view point of in-reactor integrity of fuel assembly such as guarantee of the coolable geometry, the control rod insertion etc.

The lateral stiffness of FA is mainly determined by skeleton lateral stiffness. And the fuel rods loaded in the spacer grids reinforce the FA lateral stiffness. Generally, fuel rods and spacer grids create the nonlinear friction force between fuel rod tube and grid spring/dimple against external lateral force of FA. Thus, it is necessary to study the contribution of the fuel rods friction force to the FA lateral stiffness. So, this paper is to show how much amount of the fuel rod-grid interaction contributes to the FA lateral stiffness based on the test results.



(a) Skelton (b) FA (c) location of guide tubes

Fig. 1. Typical 17x17 skeleton and fuel assembly

2. Mechanical Test Results

Several mechanical tests for the 17x17 single skeleton and FA had been performed in FAMeCT (Fuel Assembly Mechanical Characterization Tester) in KAERI (Korea Atomic Energy Research Institute). The facility has the capacity for conducting mechanical tests to measure mechanical characteristics such as bending, vibration, and impact etc. on a single fuel assembly in normal air conditions [1]. Figure 2 shows the test configuration. A shaker and load jack was connected with the center spacer grid for the lateral vibration and bending test, respectively.

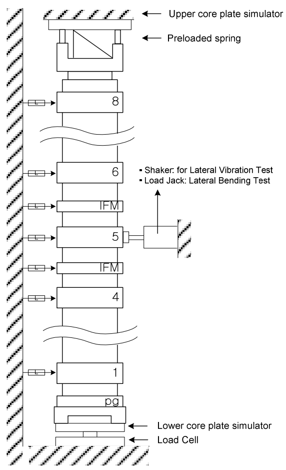


Fig. 2. Schematic diagram of lateral vibration & bending test

2.1 Lateral Vibration Test

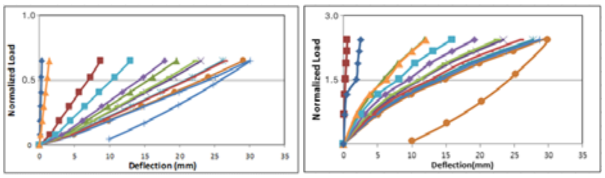
The objectives of the lateral vibration tests are to obtain the skeleton and FA dynamic characteristics such as natural frequencies, mode shapes and structural damping. During the forced vibration testing, a sinusoidal input force of a shaker was applied to the center spacer grid. The normalized natural frequencies of skeleton and FA are tabulated in Table I. These values are obtained from test results. Test results show that the natural frequencies of FA are approximately 50~60% of skeleton's. It is because that fuel rod-grid interaction makes a FA stiffer.

Table I: Normalized natural frequencies

	1st Mode	2nd Mode	3rd Mode
Skeleton	1.6	4.4	6.6
FA	1.0	2.3	3.6

2.2 Lateral Bending Test

The purpose of the lateral bending test is to determine the lateral load-deflection characteristics of an axially pre-loaded skeleton and FA. Through this test, the stiffness of the skeleton and FA can be obtained. The later loads were incrementally applied and removed at center spacer grid. Displacements and strain gage readings were taken at each displacement increment. The normalized lateral load versus deflection characteristics are displayed in Figure 3. The curve of skeleton is more linear than FA's. It is thought that the FA's nonlinear characteristic is mainly due to the fuel rod slippage. Figure 4 shows the normalized lateral stiffness of skeleton and FA. The stiffness can be calculated from load-deflection data in Figure 3. From the normalized stiffness evaluation results, it is found that the fuel rods are contributing to FA's lateral stiffness about 70%.



(a) Skelton (b) FA

Fig. 3. Normalized load-deflection characteristics

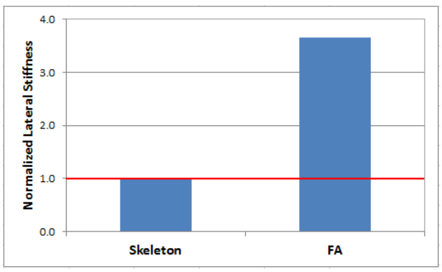


Fig. 4. Normalized lateral stiffness of skeleton and FA

3. Discussion

In chapter 2, we can find that the fuel rod slippage loads are contributing to the lateral mechanical characteristics of FA. The guide tubes in skeleton can be considered as fixed-fixed beams. Though the both ends of fuel rods are in free-free conditions, fuel rods can be roughly simplified fixed-fixed beams in a single span length. Generally the lateral stiffness of fixed-fixed beam is directly proportional to the flexural rigidity (*EI = young's modulus × Area moment of inertia*) of beam [2]. But the flexural rigidity of fuel rods cannot be easily calculated by numerical solution, because of the nonlinear behavior in the fuel rod-grid interaction. The resistance to the lateral force of the fuel rod-grid interaction is a function of the spring and dimple forces and the coefficient of friction, as equation (1).

$$F_L = F_N + 2\,F_F = F_N + 2\,(\mu \times F_N) \qquad (1)$$

where,

F_L: *Lateral load on a spacer grid*
F_N: *Spring/dimple normal force*
F_F: *Friction force on the spring & dimple (2 effective contact point)*
μ: *Coefficient of friction*

The exact test data of the lateral load on spacer grids and friction coefficient between fuel rod tube and springs/dimples of each grid are required prior to estimation of the contribution of fuel rods to the FA's lateral stiffness. Therefore, a full-size mechanical test, such as lateral bending test, is indispensable to study the FA's lateral integrity.

4. Conclusions

This paper quantitatively shows how much amount of the fuel rod-grid interaction contributes to the FA's mechanical characteristics, such as lateral vibration and stiffness, based on the test results. The 17x17 skeleton and FA test results can be summarized as follows:

(1) The fuel rod-grid interactions show a nonlinear behavior because of the slippage between fuel rod and grid spring/dimple.

(2) FA's natural frequencies are approximately 50~60 % of skeleton's. The fuel rod-grid interaction makes FA stiffer.

(3) The fuel rod-grid interaction contributes to the FA lateral stiffness, approximately 70%.

Acknowledgement

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