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Comparison of Stiffness According to Shape of Spacer Grid

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1. Introduction

Recently air pollution caused by greenhouse gases and fine dust generated by using fossil fuel has become important issue. On the other hand, nuclear energy is eco-friendly because it does not emit harmful substances. However, for the safe nuclear energy, it requires high level of the design and integrity evaluation because radioactive materials are used and generated during the fission reaction process. Therefore, the nuclear fuel itself is also designed with various design requirements for the safe operation of the reactor.

Enriched uranium dioxide (UO_2) is mainly used as nuclear fuel in Korea nuclear power plants. The fuel would be formed as pellet shape and assembled in fuel rods. The shape of the fuel rod can be found in Fig. 1. The cladding tube is placed surrounding the nuclear fuel pellets and miscellaneous apparatus like spring, etc. The fuel rods and supporting structures are assembled in fuel assemblies to be loaded into the reactor. The shape of fuel assemblies is depicted in right of the Fig. 2. Because it is important to secure safety of the assemblies while fuel loading and operating of the reactor, the rods are supported and protected by several spacer grids to avoid shock and vibrations during operation by flow of the coolant around the fuel assemblies and other external loading conditions like earthquake. A typical shape of the spacer grid is depicted in Fig. 2.

There are three types of spacer grids; top, middle, and bottom grid, depending on the location at the fuel assembly. A top and a bottom spacer grids made of Inconel 615, and 7~11 for the middle spacer grids made of zirconium alloy are used in a fuel assembly [1]. Therefore, the middle spacer grid is selected as analysis target. The mechanical performance and stiffness of the middle spacer grid ought to be enough to stably support the fuel rods. In this study, static buckling analysis for the middle spacer grid is performed and stiffness of spacer grid is evaluated with changing model size.

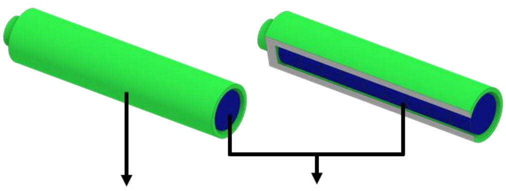

Fig. 1. Schematics of the fuel rod

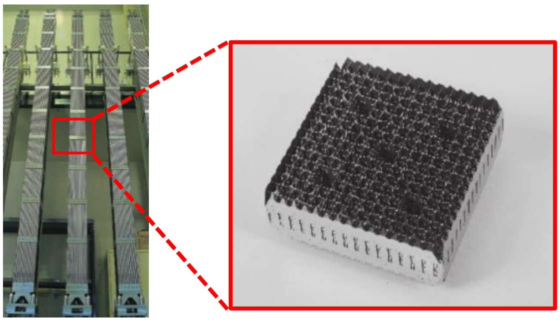

Fig. 2. Fuel assemblies and a middle spacer grid [3]

2. Buckling Analysis

2.1 Analysis Model

The middle spacer grid is considered in this study because it is the most spacer grid among the grids in fuel assembly and the middle spacer grid with springs and dimples to hold and constrain fuel rods movements [2].

The original geometry of the spacer grid is size of 17×17 or 16×16 [3] but the 1×1 and 3×3 spacer grids are considered in this study because of difficulties on convergence and huge computing time. Also, the stiffness variation of spacer grid according to its model size are analyzed. On the condition that nuclear fuel does not have effect on the stiffness of the fuel rod, the fuel rod was modeled as cladding tube without the internal fuel parts. As shown in Fig. 3 and Fig. 4, the analysis models are prepared with four cases (1×1 without fuel rod, 1×1 with fuel rod, 3×3 without fuel rod and 3×3 with fuel rod).

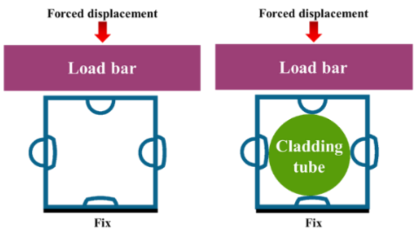

Fig. 3. 1×1 Spacer grid schematic

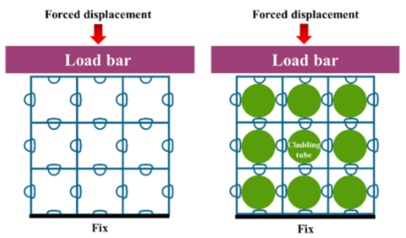

Fig. 4. 3×3 Spacer grid schematic

2.2 Material Properties

Material properties are applied as real state of the spacer grid and the fuel rod.

2.3 Analysis Condition

The boundary and loading conditions are introduced in Fig. 3 and Fig. 4. The models are fixed at the floor, and joints of the spacer grids are assumed as the bonded contact condition to consider spot welding at the joints, and the contact condition between the fuel rod and the spacer grid is applied as frictional condition with friction coefficient of 0.2. Then, the top load bar is assumed to be a rigid body without deformations. The load bar applied a forced displacement of 0.4 as loading condition. In the case of models with cladding tube, the forced displacement of the load bar is applied after the fuel rod is inserted. Finally, the four analyses are carried out by Ansys Workbench 18.2.

3. Analysis Results

3.1 Convergence Problem in Static analysis

In the static analysis, convergence of result can be achieved by satisfying the equilibrium equation in which the resultant force of all forces becomes zero [2]. However, if the load is suddenly changed by buckling, the convergence might become difficult. Therefore, when buckling occurs, analysis convergence becomes unstable and it can be solved by nonlinear stabilization method that cancels point at which the drastic force changes is the buckling point [4]. The Fig. 5 shows a graph of the buckling behavior and a peak point is to occur buckling. In equations (1) and (2), the instability problem can be solved by adding a damping coefficient c [4]. Where, P is the external force, I is the internal force, c is the damping factor, v is the nodal velocity, and M is the artificial mass matrix [4].

$$P - I - Fv = 0 \qquad (1)$$

$$F = cM \qquad (2)$$

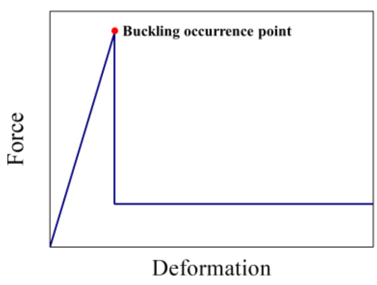

Fig. 5. Buckling behavior [4]

3.2 Spacer grid model without fuel tube

Firstly, the results of 1×1 model and 3×3 model without fuel rod are compared. The results of reaction force on displacement of loading bar are shown in Fig.6 and the force result is normalized by random number because of the security issue. The drastic changes of force for each cases can be observed and the points are assumed as buckling points. For the 1×1 model without fuel rod, the buckling point is 0.0020 inches in displacement. For the 3×3 model without fuel rod case, buckling point is at 0.0035 inches; 75% larger than that of the 1×1 model. Although the resultant reaction force of the 3×3 model is bigger than that of the 1×1 model, because the deformation of the 1×1 model is smaller, the stiffness of the 1×1 model is about 15% greater than that of the 3×3 model.

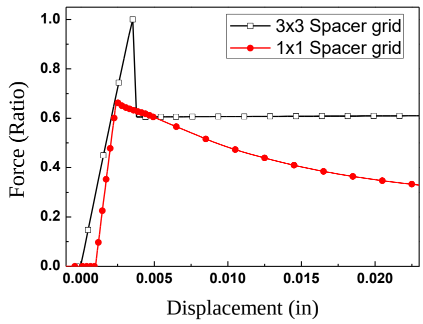

Fig. 6. Reaction force of spacer grid without fuel rod on loading bar displacement

3.3 Spacer grid model with fuel rod

The models with fuel rod are compared the1×1 model and the 3×3 model in the same manner as model without fuel rod. The results of the models with fuel rod are similar with that of model without fuel rod. The buckling of the 1×1 model is observed at a small deformation and the buckling force of the 1×1 model is smaller than that of the 3×3 model. However, because the deformation of the 1×1 model is small, the stiffness of the 1×1 model with fuel rod is about 23% bigger than that of the 3×3 model with fuel rod.

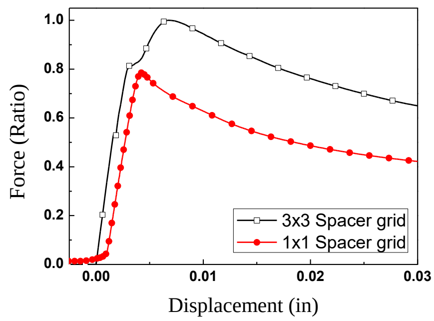

Fig. 7. Reaction force of spacer grid with fuel rod on loading bar displacement

The overall deformed shapes are depicted in Fig. 8 with true scale.

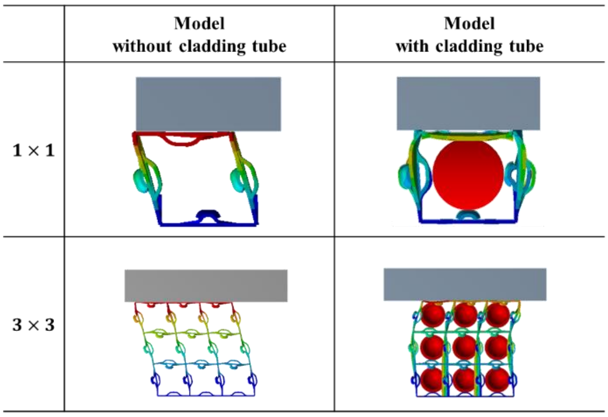

Fig. 8. Deformations of the spacer grids

4. Conclusion

In this study, stiffness sensitivity of spacer grids is examined with different size of the spacer grid models. The larger buckling forces are observed when the size of the spacer grid models increases, but the overall stiffness is reduced because the larger size of the spacer grid, the larger deformation of the spacer grid can occur. This phenomenon can be explained with decrease of the slenderness ratio. With increasing model size from 1×1, to 3×3, the length increases 3 times but cross-section area increases only 2 times. Therefore, the resistance to buckling is predicted to be decreased. Since the fuel rod increases the resistance to deformation of the spacer grid, the stiffness of the models with fuel rod are larger than that of the model without fuel rod.

As the size of the spacer grids increases, the overall stiffness of the spacer grids decreases, but it is confirmed that the spacer grids satisfy the self-limit criteria of KNF (KEPCO Nuclear Fuel).

In the future, the 6×6 model and the original model will be studied and the model size effect would be evaluated. The larger size of the model, the more computing time needed. Therefore, the possibility of using small models (1×1, 3×3, and 6×6) will be examined as replacement of original large model (16×16, and 17×17).

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