Improvement of PWR Fuel Spacer Grid Model based on Experimental Results

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1. Introduction

The fuel assembly comprises fuel rods, upper nozzles, lower nozzles, and spacer grids. To ensure safety in nuclear reactors, the spacing between fuel rods must be maintained uniformly while ensuring smooth coolant flow. Spacer grids play a crucial role in achieving this objective. Hence, spacer grids must maintain their shape even during emergency operations to keep the fuel rod configuration intact. They must also withstand external force like seismic loads while maintaining their form. Therefore, as a foundational investigation into understanding the reaction of spacer grid to external forces, an analysis of spacer grid deformation was conducted. With spacer grids typically composed of a 16x16 array, a full solid model requires substantial time and computational resources for analysis, a shell model was developed to reduce analysis time.

2. Methods and Results

To validate the shell model, experimental results were compared with the analysis of a 17x17 shell spacer grid model with clad. Experiments on the spacer grid can be found in the research conducted by Kore Nuclear Fuel Co. (KNF). They conducted studies on spacer grid deformation and mechanical integrity. Our study compared its findings with KNF's experiments. In their experiments, buckling occurred. Our analysis, based on finite element analysis, was compared until buckling occurred.

The analysis of the spacer grid was conducted for obtaining normal and shear stiffness parameters. For both normal load and shear load, fixed support was applied on the +x face, while displacement was applied on the -x face. In the case of normal load, displacement ranged from 0.2 to 10mm in the +x direction, whereas for shear load, displacement ranged from 0.5 to 20mm in the -z direction to observe deformation. From the input displacement and resulting reaction forces, we can obtain normal and shear stiffness.

2.1 Design of spacer grid

A 17x17 model was developed to get normal stiffness based on FEM analysis and the results are compared with experiments. The material property, i.e. elastic constant, was adjusted to match FEM result and experiment. The adjusted elastic constant is designated as equivalent elastic constant. This elastic constant is assumed same for 17x17 model of spacer grid, referencing the shape of the PLUS7 model as shown Fig. 1. Spacer grid plates were designed to interlock similar to actual spacer grids to achieve similarity with real spacer grids. To reduce analysis time, the pellets were modeled by beam elements as shown Fig. 2. As depicted in Fig. 1 and Fig 3, the design aimed to investigate force reactions through three models: spacer grid without clads, spacer grid with clad, and spacer grid with pellets.

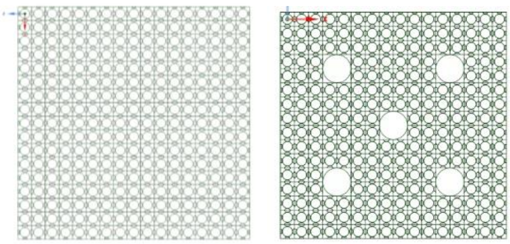

Fig. 1. 17x17 spacer grid with clad on the left, 16x16 spacer grid with clad on the right.

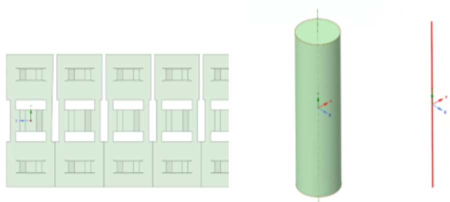

Fig. 2. Detail of spacer grid plate on the left, conversion of Pellets from Solid to Beam on the right.

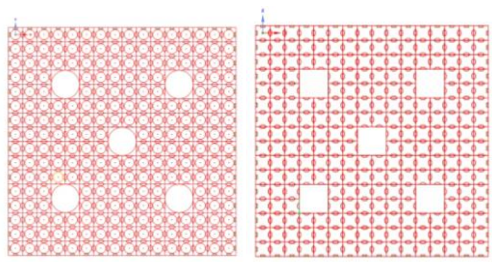

Fig. 3. Spacer grid with pellet on the left, spacer grid without clads on the right.

2.1 Material of Spacer grid and Pellet

The analysis involved the use of Zircaloy and UO2 pellets. To ensure consistency with experimental values obtained from the comparison with the 17x17 model, the values of Young's modulus of Zircaloy was adjusted according to temperatures.

Table I: Mechanical engineering data properties of Zircaloy

Temp (°C).	Young's modulus (GPa)	Adjusted Young's Modulus (GPa)
21	105.678	42.5
290	89.005	25.822
325	86.836	23.652

2.2 Results of Spacer grid

The analysis results obtained from the 17x17 shell model were significantly larger than the experimental values, by a factor of 2.48. By adjusting the Young's modulus, it was possible to obtain results consistent with the experimental data. In Fig. 4, a comparison is presented between experimental data and data obtained after adjusting Young's modulus using the 17x17 shell model.

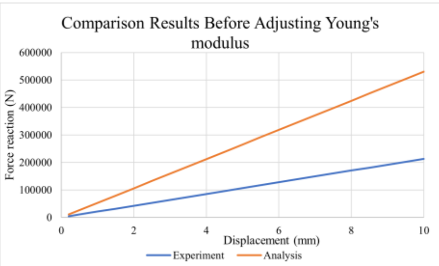

Fig. 4. Comparison Results Before Adjusting Young's Modulus

The difference of stiffness shown in Fig. 5 is related to the clad and pellet in the spacer grid model. It showed that the stiffness is smallest, indicated by yellow line, it increases as clad is added to the model. The largest value of stiffness is for model with clad and pellet. Fig.6 shows shear stiffness for the similar input displacement. It is noted that the reaction forces are much smaller for shear load cases. The stiffness ratio, determined by comparing the displacement values of equal magnitude in both normal and shear stiffness, is presented in Table II.

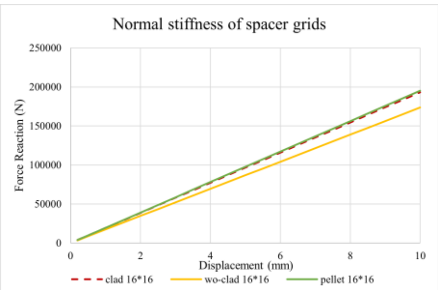

Fig. 5. Normal stiffness of spacer grids

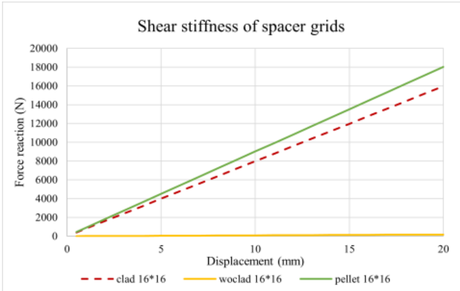

Fig. 6. Shear stiffness of spacer grids

Table II: Stiffness Ratio of Normal Stiffness and Shear Stiffness

Model	Without clad	With clad	With clad and pellet
Stiffness ratio	1989.27	24.21	21.66

3. Conclusions

Based on the experimental results, a equivalent Young's modulus was obtained and used for normal operating condition stiffnesses. We have successfully developed 3D shell model of 17x17 mid-spacer grid that utilized equivalent Young's modulus. From the analysis it was observed that shear stiffness was significantly smaller the normal stiffness. This result implies that nuclear fuel evaluation should include assessment of shear deformation and an improvement of spacer grid is desirable that has higher shear stiffness. For current spacer grid design the stiffness ratio of normal to shear is around 21.66.

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