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A Study on Dynamic Impact Analysis of Simplified Spacer Grid Designed for 24-Finger and 28-Finger Control Rods

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1. Introduction

The innovative small modular reactor (i-SMR) nuclear fuel assembly has set an enhanced seismic performance target of 0.5g. Design factors that can improve the seismic performance of the fuel assembly are the number of guide tubes or spacer grids, as well as the joints and connections that make up the fuel skeleton. Among these, the spacer grid makes a significant contribution, so designing for the structurally enhanced spacer grid is crucial.

Also, another important requirement in i-SMR nuclear fuel design is flexible operation and the ability to operate without boron. Considering the above requirement, improved control rod worth is necessary to meet the core's subcriticality limitation. Accordingly, the number of control rod fingers has been increased from 24 to 28. To accommodate the 28 control rod fingers, four guide tubes need to be added to the existing 17x17 array fuel assembly, resulting in the exclusion of four fuel rods, as shown in Fig. 1.

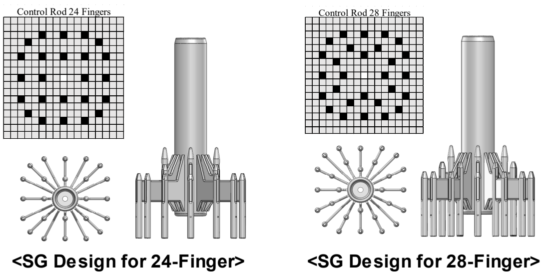


Fig. 1. Design of the spacer grid (SG) according to fingers

In nuclear fuel, the spacer grid has mechanical functions to support and protect the fuel rod by absorbing the impact force, and it also has a thermal hydraulic function to enhance the coolant heat transfer capability. However, when the nuclear fuel is subjected to an unwanted excessive load caused by earthquake during operating, it could lead to fuel failure such as spacer grid buckling and cladding tube deformation. For this reason, in order to ensure mechanical integrity of the fuel, spacer grid design is required to withstand the impact load and maintain high strength throughout the lifetime of operation.

The focus of this paper is to verify improved seismic performance and mechanical integrity when applying a 28-finger type spacer grid. Thus, in this study, two cases of analysis results that are 24-finger and 28-finger type spacer grids are compared and discussed.

2. Grid Impact Analysis

2.1 Dynamic Impact of the Spacer Grid

When a collision occurs between fuel assemblies due to an earthquake, this can be simply interpreted by assuming a dynamic impact between the spacer grids in one-span section. At this moment, the weight of the assembly corresponding to one-span is loaded on the spacer grid and collides with the adjacent spacer grid. Fig. 2 explains this.

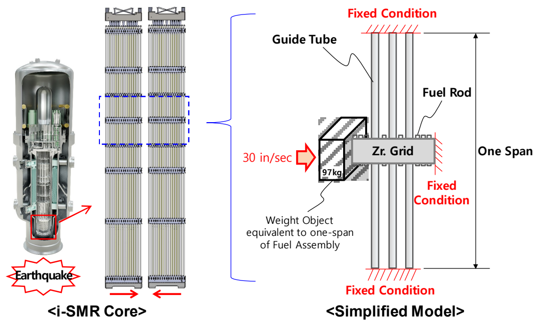


Fig. 2. Impact of spacer grid for one-span fuel assembly

2.2 Set-up for Analysis of Simplified Spacer Grid

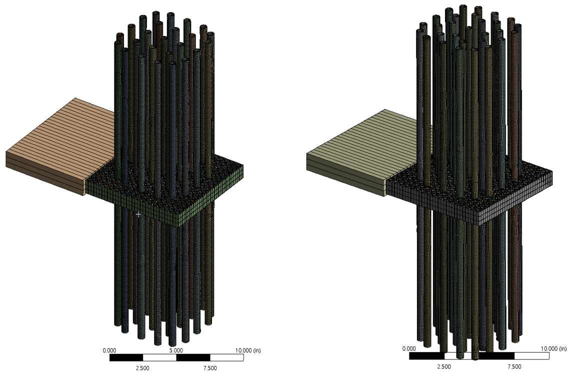
This study was conducted to perform a comparative analysis of the dynamic impact characteristics of the spacer grids when the structure of the 24-finger and 28-finger guide tube was applied, respectively. For this purpose, the analysis was simplified by leaving out the spring/dimple, slot, vane and other detail shape of the grid since those influences were considered minimal.

For the analysis, a commercial FEM software, ANSYS was used [1], and zirconium nonlinear properties were applied as the material. The analysis settings are briefly summarized below. And, the conditions of major parameters for the models are compared in Table I and meshed models are showed in Fig. 3.

- Set-up for Analysis
  - Type: Explicit Dynamics, Geometry: Shell
  - Impact Duration: 0.003 sec, Impact Speed: 30 in/sec
  - Weight of Impact Object: 97.3 kg

Table I: Comparison of major parameters for the model

Items	SG for 24-Finger	SG for 28-Finger
Rod Array	17x17	←
Fuel Tube [EA]	264	260
Guide Tube [EA]	24	28
Grid Material	Zir. Alloy	←
Detail Shape (Spring/Dimple, Slot, Vane)	X	X

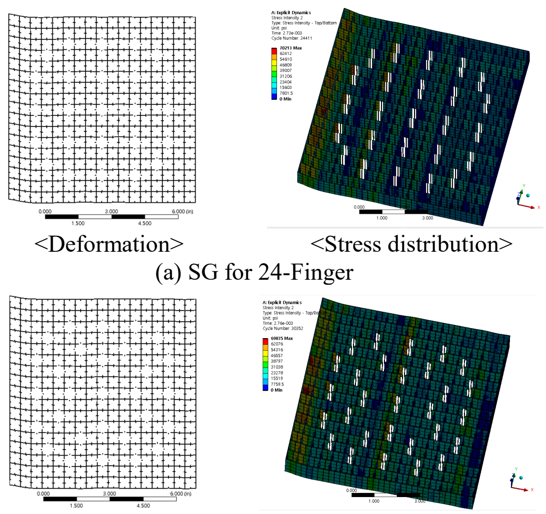


(a) Model for 24-Finger (b) Model for 28-Finger

Fig. 3. Analysis models for one-span generated with mesh

2.3 Analysis Results

In the dynamic analysis, the impact object was simulated for the weight of one-span that impacts the adjacent spacer grid of fuel assembly. The impact velocity was empirically set as the speed at which the spacer grid buckles sufficiently. The images from analysis were produced and compared for deformation at max values and stress distribution, respectively, as shown in Fig. 4.



<Deformation> <Stress distribution>

(a) SG for 24-Finger

<Deformation> <Stress distribution>

(b) SG for 28-Finger

Fig. 4. The results of impact analysis

2.4 Evaluation

The results were presented as relative comparison as shown in Table II and Fig. 5. As indicated in the results, the 28-finger type spacer grid shows better performance in terms of a mechanical design perspective in load, deformation, and stress compared to that of 24-finger.

Table II: Comparison of the analysis results (normalized)

Results	SG for 24-Finger	SG for 28-Finger
Load	1.0	0.89
Deformation (X-dir.)	1.0	0.97
Stress	1.0	0.99

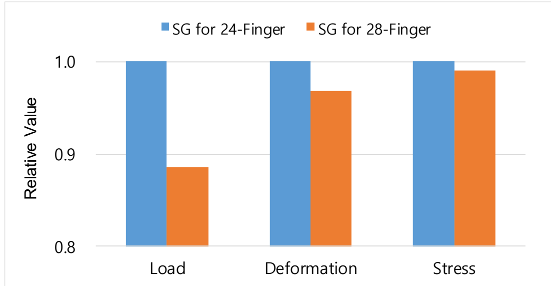


Fig. 5. Comparison of the analysis results (normalized)

From the above comparison, the improvement in deformation and stress of the 28-finger type spacer grid is not high, while the generated load (contact force) shows a reduced value of about 11%. A lower load generated when the impact speed is the same can be said to be advantageous in terms of structural integrity, and it means that there is a margin before the spacer grid buckles.

From a structural perspective, the array of the 28-finger guide tubes is somewhat less regularly arranged compared to that of 24-finger (refer to Fig. 1). Also, as described above, there are four more guide tubes that act as fuel skeleton. Therefore, it is concluded that 28-finger spacer grid would have further strengthened against the impact resistance.

3. Conclusions

The spacer grid of the i-SMR nuclear fuel was designed to allow the insertion of 28 fingers of control rod. The i-SMR nuclear fuel has requirements of improving seismic performance, flexible operation, and boron-free operation, and such requirements must be guaranteed throughout whole fuel lifespan. Therefore, it is necessary to verify the performance prediction of 28-finger type spacer grid. To achieve this, simplified spacer grid models of both the 24-finger and 28-finger types were defined, and the structural integrity of 28-finger spacer grid was analyzed and confirmed through dynamic impact analysis.

As part of future plan, impact analysis will be conducted continuously by reflecting detail geometry of the spacer grid as much as possible to produce more accurate results.

ACKNOWLEDGEMENTS

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REFERENCES

[1] ANSYS Workbench User's Manual