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Division III

IMPACT ANALYSIS OF A SPACER GRID ASSEMBLY OF DUAL COOLED FUEL FOR PRESSURIZED WATER REACTOR

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ABSTRACT

A spacer grid assembly is one of the most important structural components in a dual cooled fuel assembly. The dual cooled annular fuel assembly has 12x12 spacer grid assembly. To prevent the fracture of the fuel rods, the spacer grid should be designed to endure lateral impact loads due to lateral seismic accelerations, shipping and handling load. An impact tests was performed by applying the various conditions such as impact speed and direction. However, the spacer grid is very expensive due to the high cost of material and welding. Therefore, to evaluate structural integrity of 12x12 nuclear fuel assembly was performed by impact analysis using LS-DYNA. In this analysis, a range of the impact velocity was 121 mm/sec ~ 401 mm/sec. The impact velocity - force curve was derived from initial velocity and reaction force. The dynamic Characteristic of 12x12 spacer grid assembly was obtained from dynamic behavior of specific node and impact rigid plate.

INTRODUCTION

A pressurized water reactor is a major reactor type for power generation. KAERI launched a R&D program for dual cooled annular fuel technology. The dual cooled annular fuel has the cooling flow inside as well as outside the surface. The shape of the annular fuel decrease the fuel temperature and so provide a potential of high power density fuel. The dual cooled fuel is designed to be used on existing OPR-1000 reactor. The existing OPR-1000 consists of 16x16 spacer grid assembly with fuel rod and guide tube. An external diameter of the dual cooled annular fuel rod was 15.9 mm. The annular fuel rod's diameter was 1.67 times longer than the diameter of the existing fuel rod. For this reason, the dual cooled fuel assembly has 12x12 spacer grids. Figure 1 shows 12x12 spacer grid assembly of dual cooled fuel.

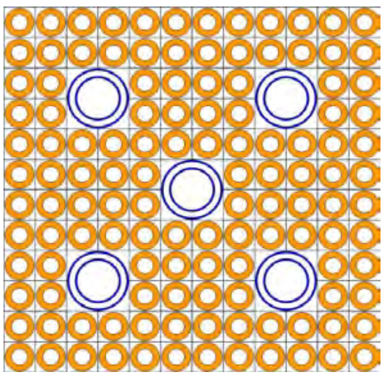
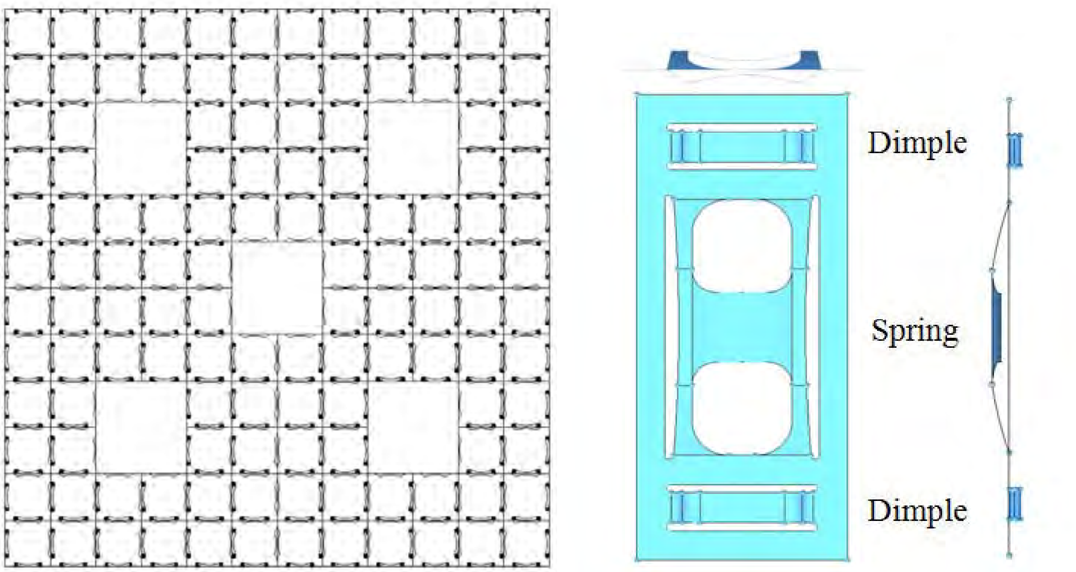


Figure 1. Configuration of 12x12 spacer grid assembly with rod and guide tube

Dual cooled fuel rod was supported by multiple spacer grid. The spacer grid in nuclear fuel assemblies provides both lateral and vertical support for fuel rods, and also provides flow channels between the fuel rods. Fracture of fuel rod cause serious injury. To prevent the fracture of the fuel rods, the spacer grid should be designed to endure lateral impact loads due to lateral seismic accelerations, shipping and handling load. An impact tests was performed by applying the various conditions such as impact speed and direction. However, the spacer grid is very expensive due to the high cost of material and welding. Therefore, to evaluate structural integrity of 12x12 nuclear fuel assembly was performed by impact analysis using LS-DYNA.

ANAYSIS MODEL



(a) 12x12 square array without rod and guide tube (b) Shape of H-grid

Figure 2. Geometric model of 12x12 spacer grid assembly

A geometric model of 12x12 spacer grid assembly was made using a commercial 3D CAD program. Figure 2 shows the geometric model of spacer grid assembly. The thickness of spacer grid was 0.46 mm. It is very thin compared with size of grid. Therefore, the spacer grid was modeled as a shell.

Table 1 shows the Mechanical properties of Zircaloy-4. Zirconium alloy has very low absorption cross-section of thermal neutrons, high hardness, ductility and corrosion resistance. For this reason, one of the main uses of zirconium alloys is in nuclear technology, as spacer grid and cladding of fuel rods in nuclear reactors. The material for spacer grid assembly of dual cooled fuel was Zircaloy-4.

Table 1: Mechanical properties of Zircaloy-4

Mechanical Properties		Strain	Stress (MPa)
Elastic modulus (GPa)	113.667	0.000	0.000
		0.003	379.470
Yield strength (MPa)	379.47	0.015	419.950
		0.040	472.670

Poisson's radio	0.296	0.068	505.578
		0.101	529.212
Density (kg/m^3)	6,550	0.212	579.014
		0.274	595.460

FE-MODELING

The finite element model is required in order to perform impact analysis. Shell elements should be used because it has a very thin compared to the size of the spacer grid. The upper welding used solid element. The spacer grid assembly has symmetry condition. Figure 3 shows symmetry of spacer grid assembly. The symmetry condition of a quarter of full model is used to make the FE-model of spacer grid assembly.

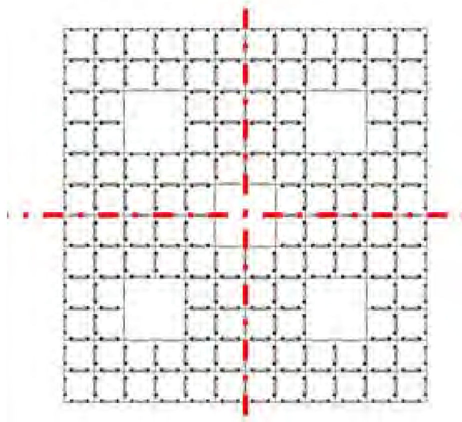


Figure 3. Symmetry of 12x12 spacer grid assembly

A H-grid is the smallest part in spacer grid assembly. It has one spring and two dimple. The fuel rods are supported at six points within each spacer grid cell by a combination of the springs and dimples. Figure 4 shows shape and progress on FE-modeling of H-grid. The H-grid has symmetry conditions. Therefore, a quarter of H-grid surface model was used for FE-model. The quarter of H-grid surface model should be sliced for mesh quality of FE-model. For the accuracy of the finite element analysis, FE-model should be modeled by considering the curvature of spring and dimples. Finite element model of H-grid is composed of 800-elements and 977-nodes.

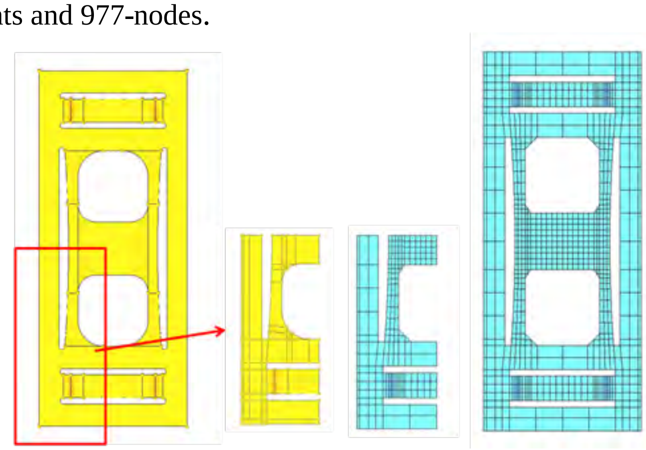


Figure 4. FE-modeling of H-grid

A strap of H-grid is shown in figure 5. The bilateral symmetry condition of H-gird was used to one strap that is composed of twelve H-grids. The strap of H-grid has top and bottom symmetrical structure. Figure 6 shows check points of strap for connection with each other. The check point A was cross-connection area that is connected row strap and column strap. The check point B was weld zone that is connected outer strap and inner strap. It is necessary to check gap size of point A and B when modeling strap.

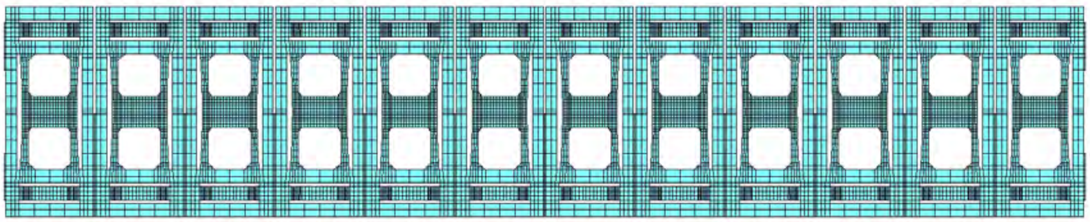


Figure 5. Shape of one strap with twelve H-grids

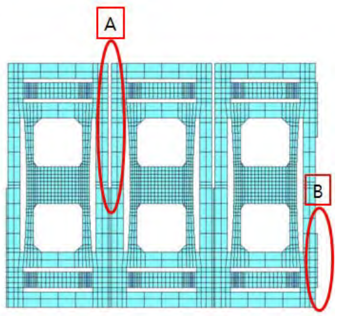


Figure 6. Check point for connection of strap

The spring and dimple of straps have pattern because spacer grid assembly has to maintain symmetry condition. The fuel rod was supported by two springs and four dimples. Figure 7 shows pattern of dimple and spring. It is necessary to check direction of spring and dimple when modeling spacer grid assembly with straps.

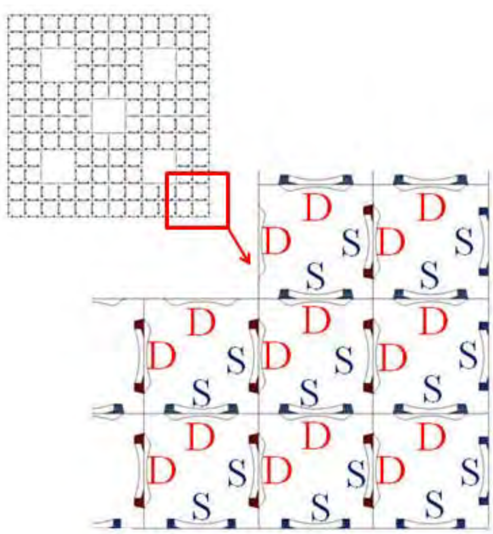
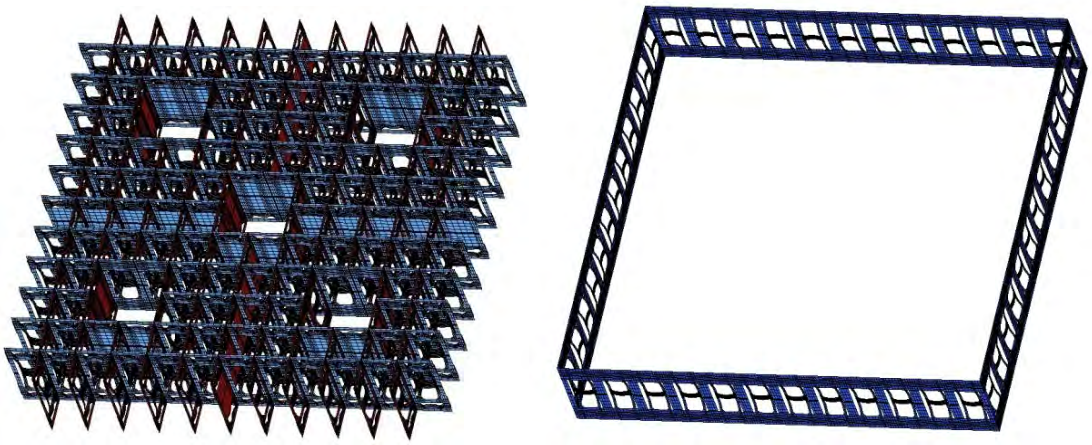


Figure 7. Position of dimple and spring



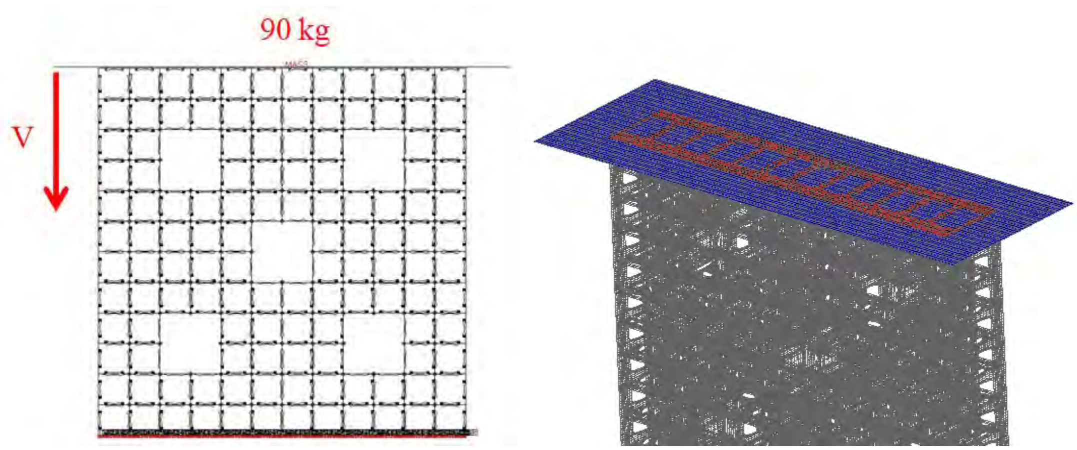
(a) Inner straps (b) Outer straps

Figure 8. FE-model of 12x12 spacer grid assembly

Figure 8 shows an FE model of the 12x12 spacer grid assembly. The Hyper-mesh was adopted in order to perform the post-process. Finite element model of inner straps assembly is composed of 182,692-elements and 220,050-nodes. The totals of 207,460 elements and 247,674 nodes points were applied to describe the FE model of spacer grid assembly.

BOUNDARY CODITIONS

A boundary condition for impact analysis is shown in Figure 9. In this analysis, a range of the impact velocity was 121 mm/sec ~ 401 mm/sec. Impact rigid plate has 90 kg. The interaction between impact rigid plate with spacer grid was Surface-to-Surface contact condition. Figure 9(b) shows contact surface between rigid plate with spacer grid assembly.



(a) Impact load (b) Contact

Figure 9. Boundary conditions of impact analysis

IMPACT ANAYSIS

The analysis were performed for the full spacer grid by an explicit finite element method using LS-DYNA program

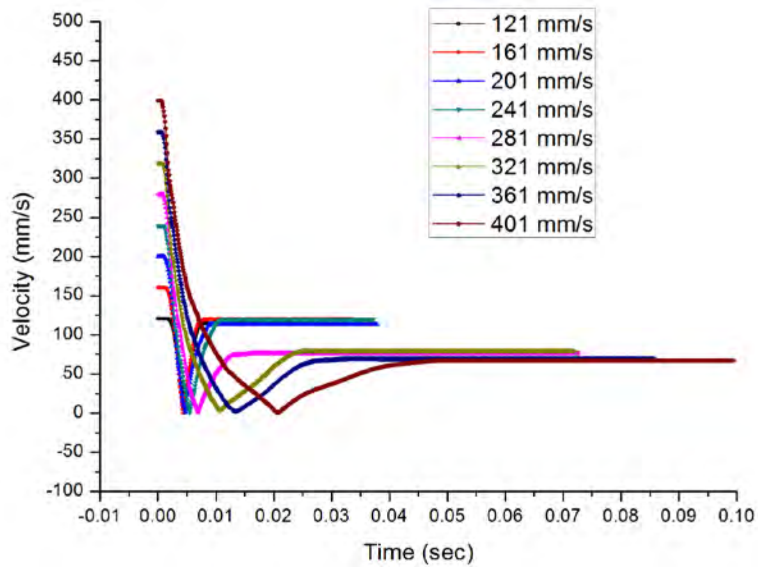


Figure 10. Time history of velocity of impact plate

Figure 10 shows time history of velocity of impact plate. The impact plate moves in the opposite direction by elastic restoring and reaction force of spacer grid assembly. The graph of velocity shows a tendency to converge at two velocities after the change of direction.

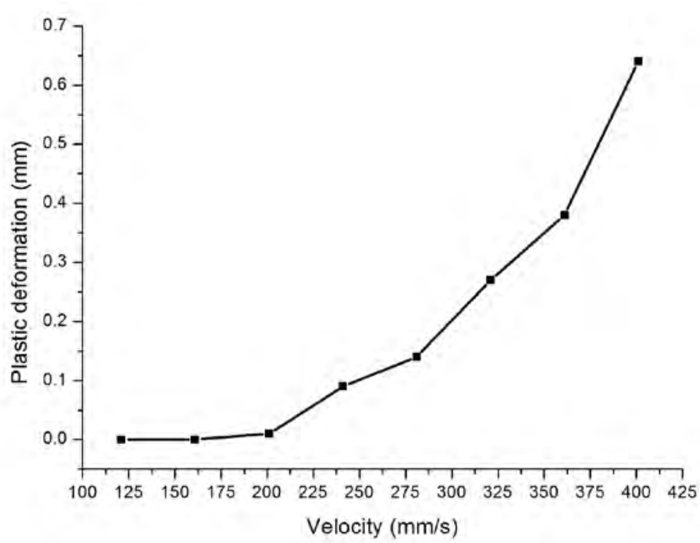


Figure 11. Plastic deformation of spacer grid assembly

As a results of impact analysis, the spacer grid assembly occur plastic deformation. Plastic deformation of spacer grid assembly after impact is shown in Figure 11. The plastic deformation was occurred at velocity of 201 mm/s and over. The graph of plastic deformation shows the tendency of increase with nonlinear. The rate of increase of graph was gradually increase.

Figure 12 shows graph of velocity vs maximum reaction force of spacer grid assembly. The range of reaction force was 5,903 N ~ 10,561 N. The graph of velocity vs reaction force shows the tendency of increase with linear.

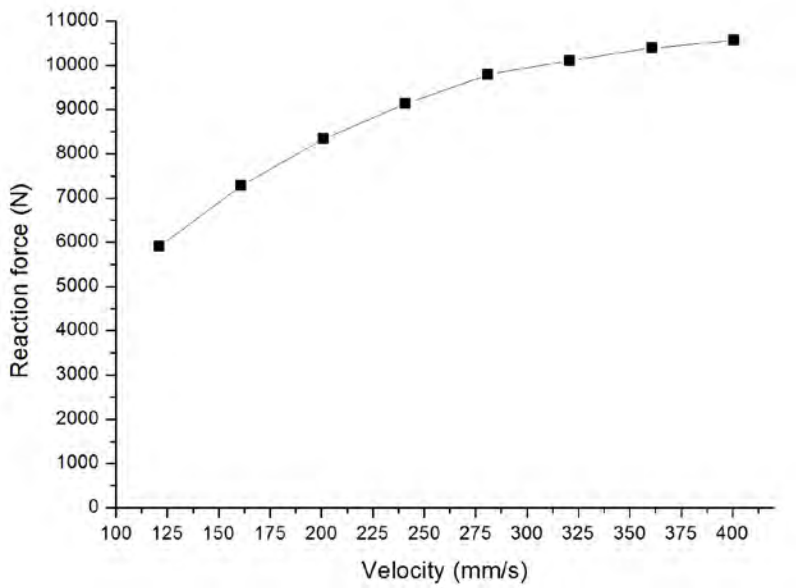


Figure 11. Graph of velocity vs reaction force of spacer grid assembly

CONCLUSION

The dynamic impact analysis was performed to evaluate the impact characteristics of the spacer grid assembly of dual cooled fuel for pressurized water reactor. The analysis was performed for the full spacer grid by an explicit finite element method using LS-DYNA program. The major conclusions from this study are as follows. The plastic deformation of spacer grid assembly was the tendency of increase with nonlinear. The range of reaction force was 5,903 N ~ 10,561 N. The graph of velocity vs reaction force shows the tendency of increase with linear.

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