APR 1400 Spacer Grid Structural Modeling and Assessment of Deformation Behavior

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1. Introduction

The spacer grid is a key component of the nuclear fuel assembly as it offers support to the nuclear fuel rods during normal operation, anticipated operational occurrence, AOO as well as seismic occurrences [1]. The nuclear fuel spacer grids provide lateral support to the burnable absorber and the fuel rods to ensure that the axial forces do not cause the rods to bow or slide as a result of coolant flow drag or from any dynamic forces and that the grid to clad contact point the wear is within acceptable limits. They maintain structural integrity under different loading conditions imposed by shipping and handling, postulated seismic, and loss of coolant, LOCA events [2]. In an abnormal operating environment, the spacer grid must have sufficient strength and supply the path for the reactor cooling water flow. The fuel system is designed to satisfy the General design criteria, GDC specified in GDC 10, 27, and 35 of 10 CFR Part 50 Appendix A. This study was done to investigate the APR 1400 fuel assembly nuclear fuel spacer grid deformation due to the fuel rod weight. The results can be used to determine the minimum gap between the lower end-fitting and the lower cap of the fuel rod.

2. Methods and results

The gap between the lower end-fitting top surface and the lower cap of the fuel rod is an important assembly parameter. If it is too narrow, due to vibration, chattering may occur and failure of fuel rod may results. Too big a gap makes the total height of the fuel assembly unnecessarily long and may affect the seismic response of the fuel assembly.

2.1. Modeling

The APR 1400 is made up of one upper Inconel spacer grid, nine mid Zirconium alloy spacer grids, one Inconel bottom spacer grid, and one debris filtering spacer grid. The guide tubes and the fuel rod clad are made of Zirconium alloy material.

Some assumptions are made during the modeling of the spacer grid. The spacer grid is considered without considering the contacts with the fuel assembly to avoid complexity. For purposes of analysis, the contour dimples and springs are assumed to be absent in the spacer grid.

Parameters from APR 1400 SSAR are tabulated in table 1 for the material properties. The mid grid is made of Zirconium alloy and the material properties are listed in table 2. The equivalent density is to match the mass of the spacer grid. [6] The loading conditions for the analysis are listed in table 3.

Table 1 Material specification for APR 1400 Plus 7 fuel Assembly

Component	**Material**	**Remarks**
• Reconstructible top nozzle • Debris filtering bottom nozzle	Stainless steel 304	Material properties specified from ASME BPVC sect II, part D
• Protective grid • Top/bottom grid	Inconel 718	Weight, 0.38kg Weight, 0.65kg
• Guide thimble • Instrument tube • Mid grids	Zirconium alloy	
• Fuel rods	UO_2	

Table 2 Material properties of Zirconium alloy

Material property	**Value**
Density	13835.6 kg/m³
Young's Modulus	9.8e+10 Pa
Poisson's ratio	0.296
Bulk Modulus	1.2731e+11 Pa
Shear Modulus	3.6241e+10 Pa

Table 3 Design loading conditions

Loading condition	**Value (Kg)**
Fuel rod weight in each fuel assembly	611.24
Flow drag of the fuel assembly	1195.5

3D solid model of the mid-grid was generated using the CATIA design software (square grid model). For ease of mesh generation and analysis, the vanes, springs, and contour dimples were not included in the model.

A quarter model was created and analyzed and the results compared with the full 3D model. The quarter model is illustrated in figure 1 below.

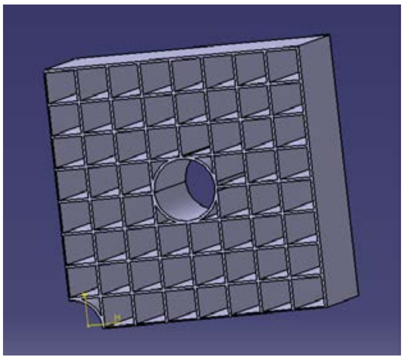

Figure 1 Quarter 3D model of the mid grid

The quarter model was transferred to ANSYS software for analysis. Material assignment was done and Zirconium alloy selected.

2.2. Mesh

Sufficient numbers of nodes and elements were generated in the three-dimensional model and is expected to give reliable results.

Mapped mesh presented in figure 2 and applied in the 3D model using the linear element order and 10 mm element size.

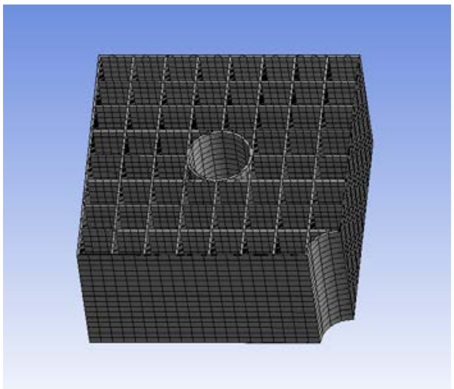

Figure 2 Quarter mid grid model mesh

The total number of generated nodes and elements are summarized in table 3.

Table 4 Number of elements and Nodes

Item	**Description**
Node	19908
Element	11679

2.3. Boundary conditions and load application

Axisymmetric condition is applied to obtain the quarter model.

A fixed support was applied to the in-core instrumentation and guide tube flanges as illustrated in figure 3 below.

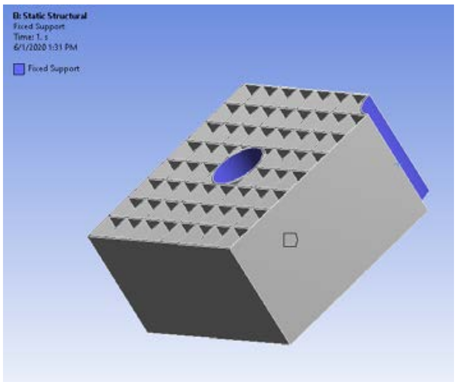

Figure 3 Setting up a fixed support boundary condition

To get displacement two loading scenarios were evaluated as shown in table 5.

Table 5 Force loading conditions

Case	**Loading condition**
Case 1	Fuel rod weight force loading
Case 2	Fuel rod weight with flow drag loading

2.3.1 Case 1, Force Boundary condition loading without hydraulic force

A force of about 1500 Newton is applied in the Z-direction. This was set up on the grid as shown in figure 4.

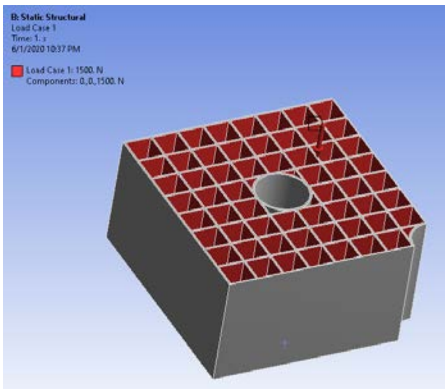

Figure 4 Setting up the force boundary condition

2.3.2 Case 2, Force Boundary condition loading with hydraulic force

For this loading condition, the fuel assembly hydraulic load is included. This hydraulic load is based on the design maximum primary coolant flow and the coolant temperature of 260 ^{o} C. Fuel assembly uplift load is 1195.5 Kg. [1] A force of about 1400 Newton is applied in the upward Z-direction. This was set up on the grid as shown in figure 5.

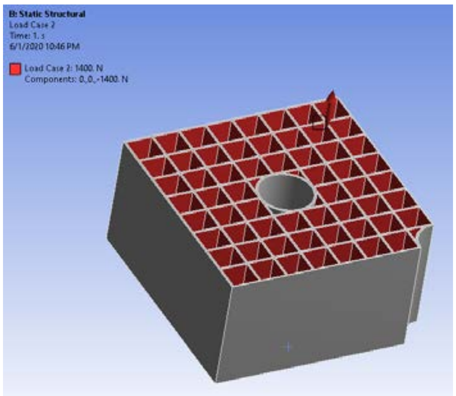

Figure 5 Force boundary condition with Hydraulic force

2.4. Results

Applying the fixed support and the force boundary conditions, the analysis was run to get the deformation and displacement in each of the directions. The total deformation solution was obtained as illustrated in figures 6 and 8. The equivalent stress obtained was illustrated in figures 7 and 9,

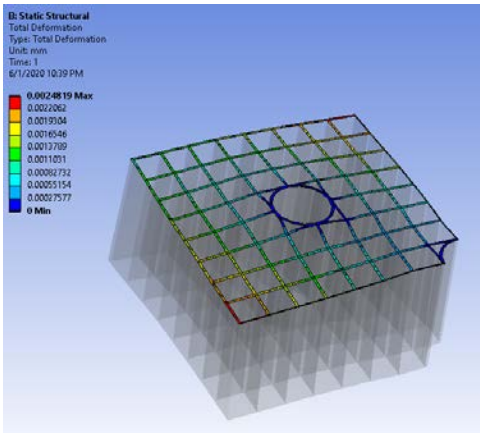

Figure 6 Total deformation case 1

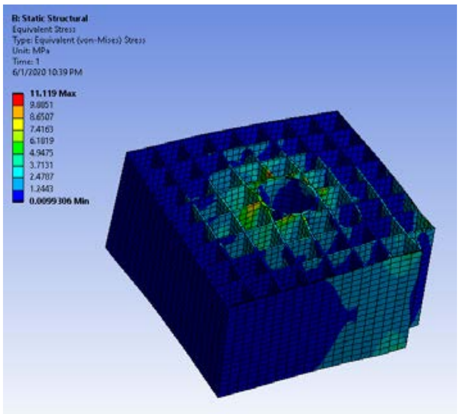

Figure 7 Equivalent stress (Von-Mises) case 1

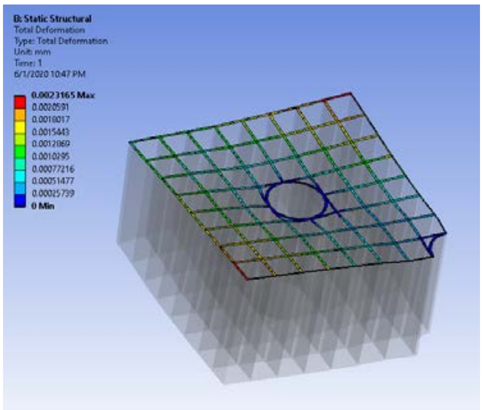

Figure 8 Total deformation case 2

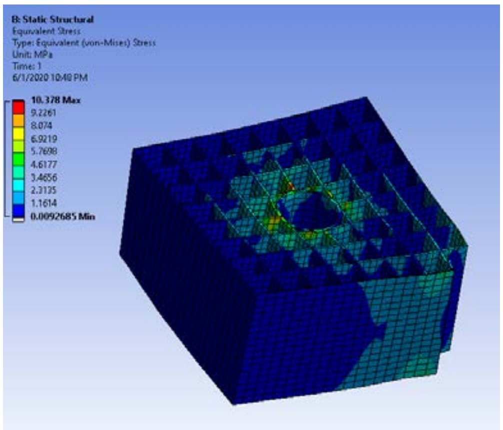

Figure 9 Equivalent stress case 2

Table 6.Summary of analysis results

Maximum deformation (mm)		**Equivalent Von-Mises stress (MPa)**
Case 1	-0.00248	11.119
Case 2	0.00232	10.378

Above results showed that the magnitude of maximum deformation is less than 0.0025mm with assumptions of solid geometry of Spacer Grid fabrication. Also it was assumed that there is no slippage of fuel rod and Spacer Grid.

In addition to above analysis, additional analysis for obtaining force-deflection curves were carried out as bases for simplified modeling of Spacer Grid.

According to varying input load in terms of vertical force and the corresponding y-deformations were obtained. The graphical representation of the total deformation against the applied force component was illustrated graphically in figures 10 and 11 for the different loading conditions.

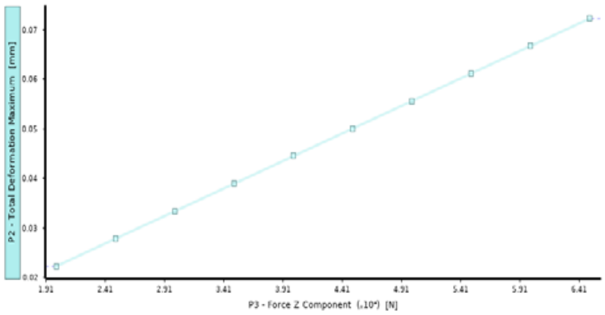

Figure 10 Graph of total deformation case 1

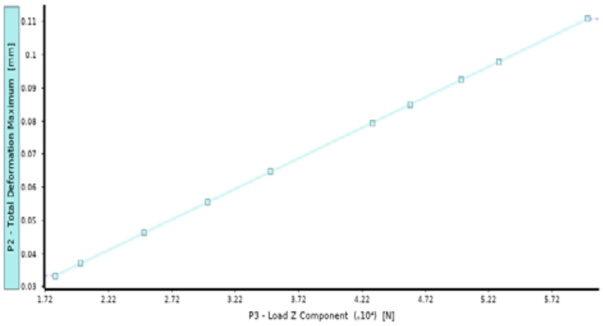

Figure 11 Graph of total deformation case 2

3. Conclusion

Design and analysis techniques using ANSYS Spaceclaim, mechanical, and CATIA were useful in this analysis. The mid spacer grid was evaluated to check the nuclear fuel spacer grid deformation due to the fuel rod weight when applying different force loadings.

The results from the static structural analysis were represented and a graphical representation of the results shown. The slope of the graph represents the deformation of the Spacer grid under different loading conditions. The first load condition considered the weight of the fuel rod assembly before the operation of the reactor. The maximum deformation for the fuel rod weight loading was 0.00248 mm and maximum equivalent stress is 11.119 MPa. The second load condition considered the design steady-state hydraulic load of the fuel assembly design maximum primary coolant flow and coolant temperature of 260 ^{o} C. The maximum deformation for the weight and hydraulic loading was 0.00232 mm and maximum equivalent stress is 10.378 MPa From the results maximum deformation will occur closest to the guide tube position. The proportional limit, as well as the elastic limit, is not exceeded and therefore that illustrates that the mid grid is relatively stable. From the analysis the concern of Spacer Grid deformation is very small and the issues of Spacer Grid deformation can be ignored with a caution where the analysis assumed full solid model and considered only vertical deformation. The force deformation curve is useful for future analysis to evaluate the equivalent Young's Modulus of the Spacer grid.

For more accurate and detailed analysis, detailed properties of the Zirconium alloy material are required to perform future analysis.

Acknowledgement

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