Structural Integrity Evaluation of Fuel Assembly Bottom Nozzle for OPR 1000

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1. Introduction

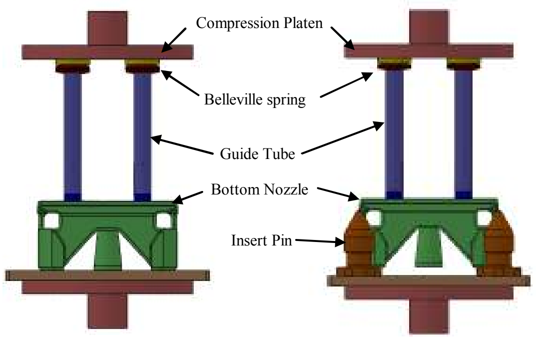
The bottom nozzle is made of stainless steel and consists of a flat plate with an array of holes and legs at each of the four corners. It sustains the fuel assembly loads and protects the fuel assembly during insertion and removal from the core and fuel storage racks.

In general, test and FEA(Finite Element Analysis) for bottom nozzle are performed to verify its structural integrity. The design load conditions considered in evaluation of the bottom nozzle are Condition I & II and Condition III & IV. The bottom nozzle is tested in the real condition of the worst load case, and analyzed using the conservative boundary conditions to confirm the structural integrity. This conservative analysis is good in point of design conservatism. However, this analysis method has a limit to optimize design and show true values of stresses.

In this study, FEA with test boundary conditions is presented. Also, the test results are compared with FEA results to verify the validity of the analysis.

2. Structural Test

The bottom nozzle was tested under 4g design shipping load and 10,000 lbs LOCA(Loss of Coolant Accident) design load which was assumed conservatively. The test was performed at room temperature in air condition utilizing the Instron Universal Testing Machine. The test arrangement is shown in Figure 1.

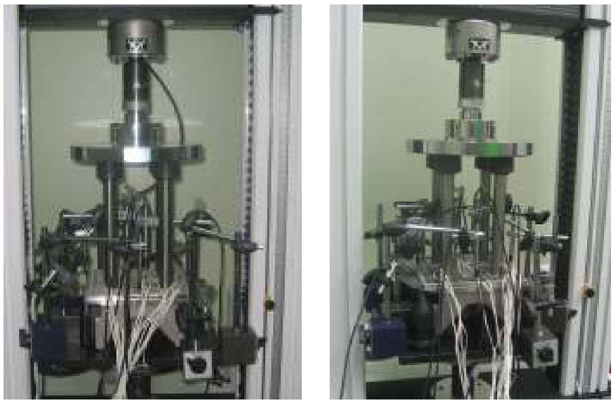


(a) Shipping condition (b) LOCA condition

Figure 1. Bottom Nozzle Test Arrangement

For Condition I & II loads, these loads are less than the 4g shipping load and no further test under these conditions is necessary. For Condition III & IV loads, the LOCA load is the worst case which induces an axial load of 10,000 lbs. The test load was applied axially through a set of Belleville springs which simulates the stiffness of the fuel assembly. The bottom nozzle for LOCA condition was placed on the lower core simulator with insert pins to simulate the in-core boundary conditions.

The LVDT and strain gages were mounted on the top surface of bottom nozzle to monitor the deflections and strains. The setup of test equipment is shown in Figure 2.



(a) Shipping condition (b) LOCA condition

Figure 2. Bottom Nozzle Test Setup

Before the test was performed, the strain gages and LVDT had been conditioned twice by loading and unloading the nozzle to 1,000 lbs. These were then balanced and zeroed.

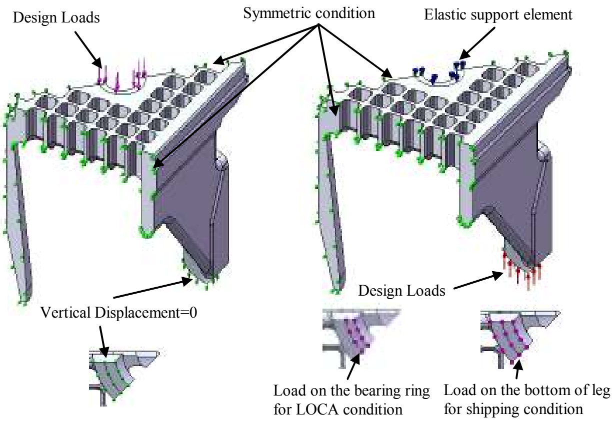
3. FEA and Comparison

3.1. FEA

The 3D solid model was generated using the SolidWorks 2009[1]. The model was then meshed and analyzed using the SolidWorks Simulation 2009[2]. Since geometry and applied load of the bottom nozzle are symmetric, only a 1/8 of bottom nozzle was modeled.

Figure 3 shows the previous boundary conditions for conservative analysis and the modified boundary condition for precise analysis. The symmetric boundary conditions were applied along symmetric cut sections. As shown in Figure 3(a), the design loads for shipping and LOCA conditions are uniformly applied to the contact area between the bottom nozzle and the guide tube. The bottom face of legs was vertically constrained.

Figure 3(b) shows that the axial restraint condition from the guide tube using the elastic support element given by the stiffness of Belleville springs. For the shipping condition, the 4g shipping load was equally shared by the 4 legs. Also, for the LOCA condition, the axial load of 10,000 lbs load was equally shared by the 4 legs. However since the legs of the bottom nozzle is not fully supported on the bearing rings of core pin, the load was applied at the contact area between the leg and the bearing ring of insert pin.



(a) Previous B.C (b) Modified B.C
Figure 3. Boundary Condition of FEA

3.2. Comparison with Test Results

The results of previous and modified FEA were compared with test results to verify the validity of the analysis. The stress intensity distributions of bottom nozzle and mounted strain gage and LVDT positions are shown in Figure 4.

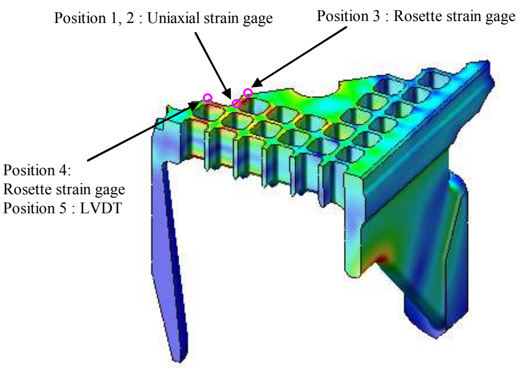


Figure 4. Stress Intensity Distribution and Positions of Strain Gage and LVDT

The comparison between the test and FEA can be assessed using the normalized values. Table 1 shows the normalized values of the maximum stress and deflection at each position. The normalized values of stress at position 1 and 2 are the ratio of the maximum uniaxial stresses, and the stress at position 3 and 4 are the ratio of the maximum principal stresses. The value at position 5 is the maximum deflection that was measured at the symmetric position of gage at position 4.

The average of normalized stresses shows the modified FEA is less than the previous FEA, which means the previous FEA is more conservative. The maximum deflection of the modified FEA is larger than the previous FEA. It means the previous FEA is more conservative. Finally, the modified FEA is less conservative and the results agree relatively well with the test results considering an error and uncertainty of measurement.

Table 1. Comparison of the Test and FEA

	Positions	Normalization(=FEA/Test)			
		Previous		Modified	
		Shipping	LOCA	Shipping	LOCA
Stress	1	0.96	1.06	0.96	1.04
	2	1.04	1.12	1.04	1.09
	3	1.03	1.06	1.01	0.99
	4	1.06	1.08	0.99	1.04
	Avg.	1.03	1.08	1.00	1.04
Def.	5	0.82	0.77	0.85	0.82

4. Conclusion

In this study, the bottom nozzle was tested in the real conditions to evaluate the structural integrity of bottom nozzle and then the FEA with modified and previous conditions were performed to calculate the more precise values of stress.

The previous FEA with conservative boundary conditions estimated larger stresses than the stress from the test. Although the previous FEA can be used for verifying the structural integrity, it could not apply to optimize design since it has too much stress margin. So, it needs to apply the real boundary conditions in order to estimate the true value of stress and develop the bottom nozzle for new fuel assembly design.

In conclusion, the FEA with modified boundary conditions has a good agreement with test results. Also since it is less conservative than the previous FEA, it could be used for optimum design of the new bottom nozzle.

ACKNOWLEDGEMENT

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REFERENCES

[1] SolidWorks Corporation, “SolidWorks Office (SolidWorks Essentials : Parts and Assembly)”, 2008.
[2] SolidWorks Corporation, “ SolidWorks Simulation 2009 User’s Guide”, 2008.