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A Basic Study on the Ejection of ICI Nozzle under Severe Accidents

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1. Introduction

In condition of severe accidents in nuclear reactor, the lower head of reactor vessel and the inner side of ICI nozzle start melting. When melting, the weld between the lower head and the inner nozzle should be removed and the ICI nozzle would be ejected. Nozzle injection should be blocked because it affect to the environment if its melting core exposes outside. The purpose of this study is to carry out the thermos-mechanical analysis due to debris relocation under severe accidents and to predict the nozzle ejection calculated considering the contact between the nozzle and lower head, and the supports of pipe cables.

2. Methods

The analysis has proceeded with 2 following cases. At first, the heat transfer analysis was done with transient condition (Case 1).And the structural analysis of lower structure(Fig.1) was performed considering the nozzle ejection pressure and the displacement(Case 2). The structure was modeled by solid, beam and shell elements. We predicted process of ejection with not melted length of nozzle obtained by the Case 1 and the value of stress and displacement by the Case 2. ANSYS, structural analysis code, was used for finite element analysis.

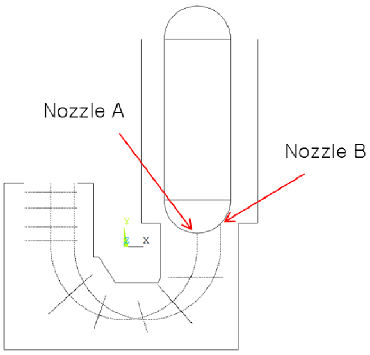

Fig.1. Structure of reactor vessel

2.1Criterionof Nozzle Failure

In general, nuclear reactor vessel is designed within standard elastic limit in case of loading condition. When it gets over the criteria, damage comes with it. In the analysis, Inconnel690 was considered nozzle material. Failure criterion of nozzle ejection (Fig. 2) is calculated as follows.

$$\tau_w = \frac{p_i \pi r_0^2}{2\pi r_0 L_w} = \frac{p_i r_0}{2L_w}, \sigma_e = \sqrt{3}\,\tau_w, \sigma_e \geq \sigma_u \quad (1)$$

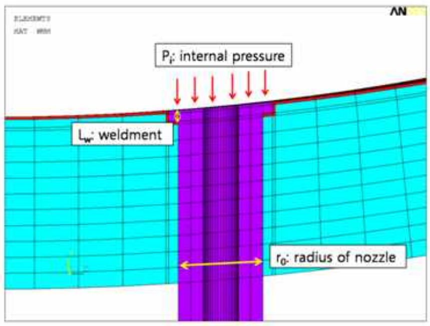

Fig.2. Modeling of ICI nozzle and weld

2.2 Thermal Boundary Conditions

In Case 1, heat flux(Fig. 3)[3]occurs as a result of fluid situation of inner structure and melting core. In the inside of lower head and nozzle, heat flux loading was applied. The convection heat transfer coefficients refer to reference[4] were applied on the outside of lower head as shown in Fig. 4. External convection value was calculated in consideration of the nucleate boiling so as to maintain the outer surface temperature of 100°C.

Fig. 5showsthe thermal boundary condition that it was used in the ANSYS code.

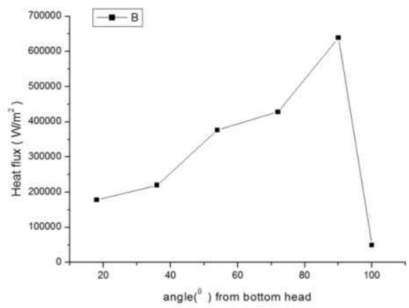

Fig.3.Heat flux on inside of lower head

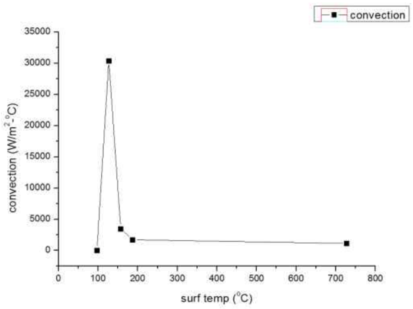

Fig.4.Heat transfer coefficient on outside of lower head

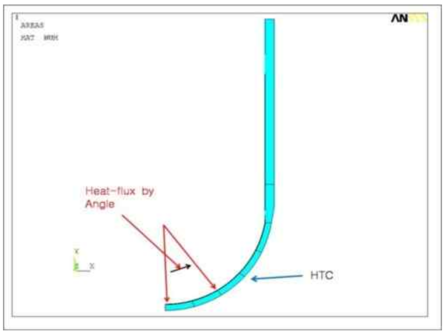

Fig.5.Thermal boundary condition

2.3 Analysis of Lower ICI Nozzle Structure

In Case 2, it is applied the data of nozzle displacement and the inside pressure(Fig. 6). Displacement value is from the result of the Case1. The analysis was performed with lower nozzles and its supports and cables. The nozzle cable and support was coupled by normal directions while the sliding direction was not fixed so that the nozzle be free to slide itself.

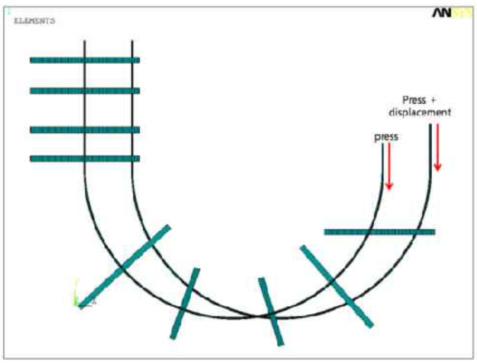

Fig. 6. Boundary condition of structure loading

3. Result of Analysis

3.1Result of Thermal Analysis in ICI Nozzle

The melting lasts until 25200 sec, and after that there was no more melting reaction maintaining the nozzle and thickness of lower head. After the melting reaction, we found the average remaining length of ICI nozzle is 120mm. Fig. 7 shows temperature distribution of lower head and nozzle after melting reaction. There are laid on grey color above the standard melting temperature 1450°c.

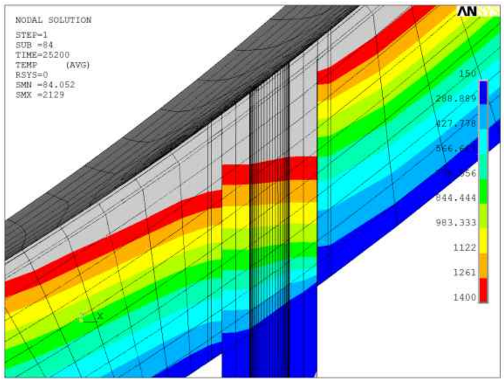

Fig. 7.Melting depth of nozzle and lower head

3.2Result of Structural Analysis in ICI Nozzle

The maximum displacement of nozzle cable was 8mm(Fig. 8). The vertical displacements in nozzles were 3.3mm to nozzle A and 2.3mm to nozzle B respectively (Fig. 9). It was concluded that ICI nozzles would not be ejected considering the cables and supports. The equivalent stress was 39.7MPa(Fig. 10) not exceeding allowable stress.

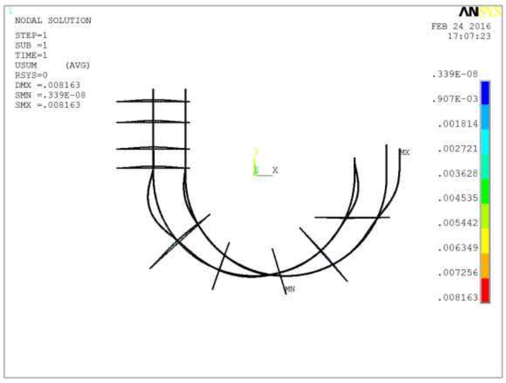

Fig. 8.Maximum displacement of nozzles

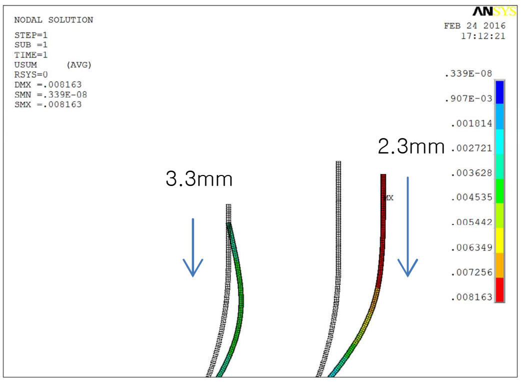

Fig. 9.Maximum displacements in weld region of nozzles

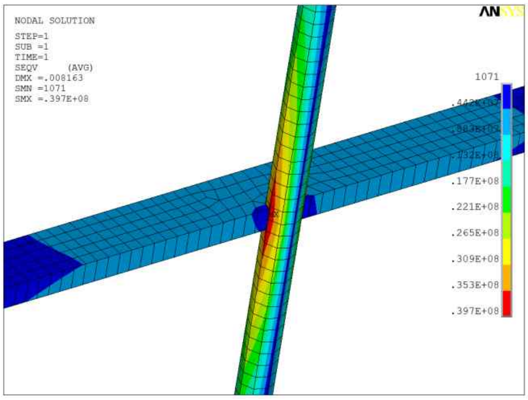

Fig. 10.Maximum equivalent stress in contact area between cable and support

4. Conclusion

As a result of analyzing process of severe accidents, there was melting reaction between nozzle and the lower head. In this situation, we might predict the non-uniform contact region of nozzle hole of lower head and nozzle outside, delaying ejection of nozzles. But after melting, the average remaining length of the nozzle was 120mmand the maximum vertical displacement of lower nozzle near the weld is 3.3mm so there would be no nozzle this model, because the cable supports restrains the vertical displacement of nozzle.

REFERENCE

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