A Comparative Study on the Effect of Heat Transfer BC between Debris and Lower Head of Reactor Vessel in Severe Accident

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1. Introduction

The objective of this paper is comparative study on the effect of thermal boundary condition in contact area between debris and lower head of nuclear reactor in severe core melting accident. It is focused on the structural integrity of lower head and ICI (In-Core Instrumentation) nozzle under pressure and thermal loadings in severe accident scenario.

The core debris in severe core melting accident may be relocated to and accumulated in the reactor pressure vessel lower head. In case of insufficient cooling, the excessive heat would drive the overheating and melting of lower head, and hence govern the vessel failure mode and timing.

2. BC and Analysis

2.1 Thermal Boundary Condition

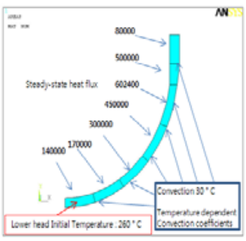
The recent idea in the management of severe accident is that the relocation of molten could be arrested at the inside of lower head by external flooding at the outside of lower head.

The boiling heat transfer was applied in the outside of lower head to the cavity water. It was suggested three kinds of thermal boundary conditions in contact area between debris and inside of lower head as shown in Fig. 1.

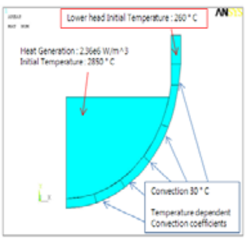
(1) applying the heat flux by natural convection of the debris pool.

(2) applying the perfect contact by assuming one body.

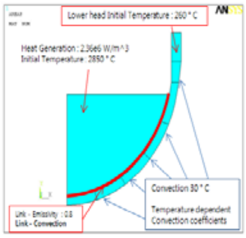
(3) applying the thermal resistance by assuming gap between solidified debris and lower head.



a) Heat flux model



b) Integral model



c) Heat resistance model

Fig. 1 Input thermal load on the surface of lower head

2.2 Mechanical Loading

The operating pressure was applied as 1.72 MPa (250psi) that was reduced after the accident. Also the pressure due to debris pool was applied in shown as Fig.2.

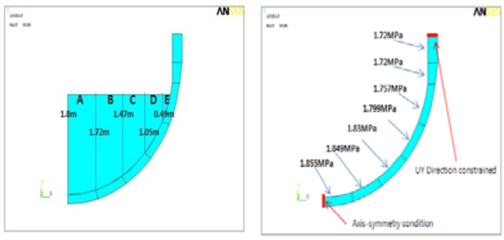


Fig. 2 Pressure load due to debris pool

2.3 FE model

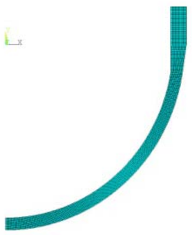
The steady state and transient heat transfer analysis were carried out to calculate the temperature of lower head applied boundary conditions. The elastic-plastic FE analysis was carried out to find the integrity of the lower head due to thermal and pressure loading. The material of the lower head is SA508 grade 3 class 1 steel. The stress-strain curve of SA508 is obtained in ASME B & PV code Sec. VIII, Div. 2.
Fig. 3 shows the finite element mesh structure of three models.

2.4 Failure Criteria

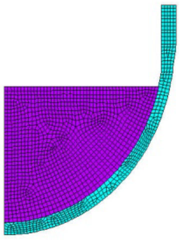
Failure criteria used by Bohl and Butler[2] and Berman et al.[3] were phenomenologically based on the continuum mechanics. Each criterion based on failure on equivalent plastic strain which is defined in terms of the principal plastic strains by the following equation.

$$\overline{\varepsilon_p} = \frac{\sqrt{2}}{3}\left[(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2\right]$$

According to Bohl and Butler, failure tends to occur at 12% of equivalent plastic strain.



(a)Heat flux model



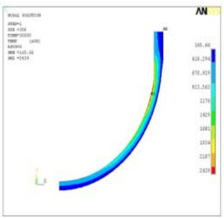
(b)Integral and heat resistance model

Fig. 3 Finite element meshes

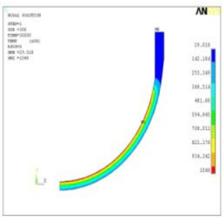
3. Results and Discussions

Fig. 4 shows the temperature distribution. The temperature in heat flux condition is much higher than other cases. Due to the exceeding of melting temperature, the head was melted. Fig. 5 shows the comparison of heat flux, it was shown that the heat flux in heat flux model BC is very higher than other cases.

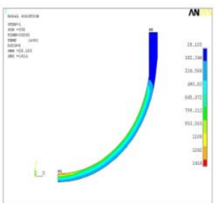
Fig. 6 shows the structural strain at 3000 sec. The calculated strains are not exceeded the allowable in shown as Table 1.



a) Heat flux model

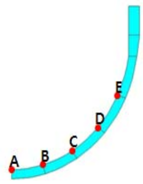


b) Integral model

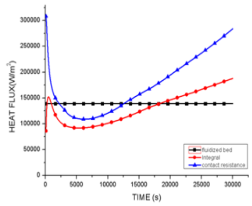


c) Heat resistance model

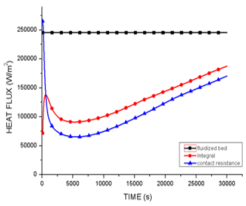
Fig. 4 Contours of temperature at 30000 sec



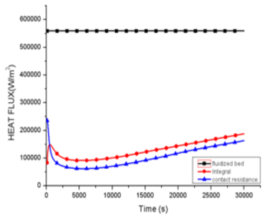
(a)Location ID



(b)Location A

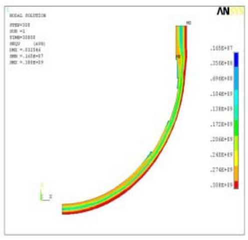


(C)Location C

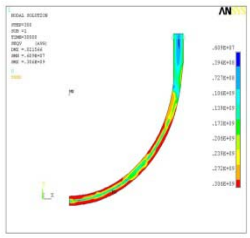


(D)Location E

Fig. 5 Comparsion of heat flux



(a)Heat flux model



(b)Heat resistance model

Fig. 6 Comparison of strain at 30000 sec

Table 1 Summary maximum strain

Model	Equivalent strain (%)	
	Calculated	Allowable
Heat flux	2.76	11
Integral	1.68	
Heat resistance	2.28	

4. Conclusions

The thermal and structural analyses are carried out to find the effect of boundary condition between debris and lower head in severe accident of reactor. It was found that the head temperature at the contact area heat up to melting temperature and the head causes damage. The standard of safety evaluation for structures in high temperature condition is using the strain. The strain value of result for structure is not exceeded allowable strain.

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