Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Sensitivity analyses of RPV integrity under an IVR-ERVC condition

Tae Hyun Kim*, Seung Hyun Kim* and Yoon-Suk Chang*
* *Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Kyunggi, 446-701, Korea*
**Corresponding author: yschang@khu.ac.kr*

1. Introduction

IVR (In-Vessel Retention) through ERVC (External Reactor Vessel Cooling) is one of effective management options against severe accident situations in a nuclear power plant. Accordingly, lots of researches for thermal-hydraulic and structural integrity have been performed to evaluate the IVR-ERVC. However, there are still many uncertainties in heat transfer and structural integrity assessment methods as well as severe accident phenomena. In this paper, verification of a preceding study[1] and further analysis were carried out to resolve some of uncertainties in the structural integrity assessment method.

2. Numerical analysis

2.1 Analysis model

Fig. 1 shows the CAD and FE (Finite Element) models of RPV (Reactor Pressure Vessel), which mesh consists of 173,870 nodes and 34,433 elements. Element types were selected as DC3D20 for heat transfer analysis and C3D20R for stress analysis in general-purpose commercial program element library[2].

(a) CAD model (b) FE model

Fig. 1. A quarter-3D models of RPV

2.2 Step procedures

Validity of stress and displacement calculation options was examined through a preliminary analysis. Especially, results obtained from both linear perturbation step procedure adopted in the preceding study[1] and static general step procedure adopted in the current study were compared.

Table I shows significantly different analysis results according to the step procedures. The maximum von Mises stresses obtained from the linear perturbation step procedure was higher than those obtained from the static general step procedure.

Table I: Comparison of maximum von Mises stresses

Step procedure	Max. von Mises stress	
	Current study (MPa)	Preceding study[1] (MPa)
Linear perturbation step	4,409	4,135
Static general step	600	523*

*: Re-analysis of the preceding study by the authors.

Maximum displacements according to the step procedures were also compared. As summarized in Table II, there were a little difference in the displacement between two step procedures.

Table II: Comparison of maximum displacements

Step procedure	Max. displacement	
	Current study (mm)	Preceding study[1] (mm)
Linear perturbation step	217.1	191.1
Static general step	211.9	184.1*

*: Re-analysis of the preceding study by the authors.

It has been known that the linear perturbation step procedure is effective for buckling analyses and a research considered largely deformed shape of RPV from thermal loading as in category of the buckling analysis. However, from the preliminary analysis by the authors, the effect of bucking was not significant so that the static general step procedure was adopted as the proper one in the current study. In addition, as shown in the above tables, the stresses obtained from the current study were somewhat higher than those of the preceding study although the difference was not much, of which reason was thought that the mesh of the present model was finer than the mesh of the preceding model.

2.3 Analysis method

Regarding the heat transfer analysis, heat flux was simplified by considering entire molten debris. As shown in Fig. 2, the surface heat flux was used to apply thermal loading to lower head of the RPV[3]. Also, the radiation heat transfer was applied to the top of metal layer. Here, emissivity value of metal layer and Stefan-

Boltzmann constant were set to 0.45 and 5.668×10^{-8} W/m^2-℃^{4}, respectively. Furthermore, the heat convection coefficient was decided to 300W/m^2-℃ in the case of water and 100W/m^2-℃ in the case of air[4].

With regard to the thermal stress analysis, the aforementioned static general step procedure was used. The annealing temperature option was also applied to set a stress data in molten region of the RPV as zero. For boundary conditions, upper face of the model was fixed to z-directions and side faces were only fixed to theta directions.

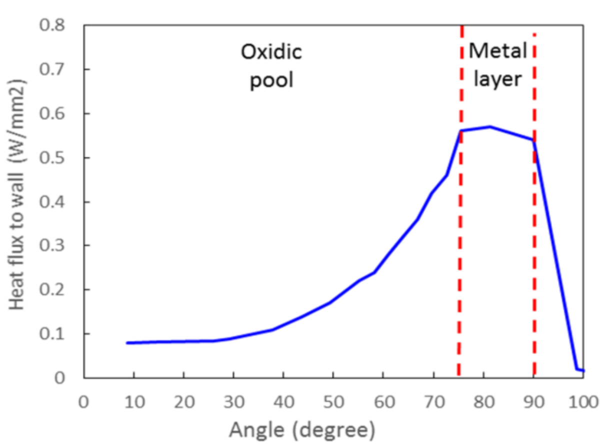


Fig. 2. Heat flux applied to RPV wall

3. Analysis results

3.1 Heat transfer analysis

As described previously, the surface heat flux method was used instead of the surface film condition method for more practical simulation of heat transfer behaviors. Fig. 3 depicts a typical temperature distribution at saturation condition. Since the heat flux was concentrated in the metal layer due to focusing effect, points A, B, C and D in metal layer zone through the thickness direction were selected to compare stress histories as well as temperature histories.

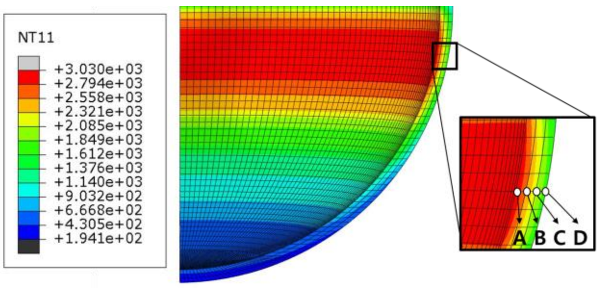


Fig. 3. A typical temperature distribution of RPV

3.2 Thermal stress analysis

Fig. 4 shows the change of von Mises stresses at four points, in which the maximum stress occurred at point A. Points B and D revealed almost the same maximum stresses while the stresses at point B were a little higher and rapidly stabilized to almost zero than those at point D. Fig. 5 depicts stress distributions according to time elapse. The maximum von Mises stress of 487 MPa occurred at 12sec of which location was near the metal layer.

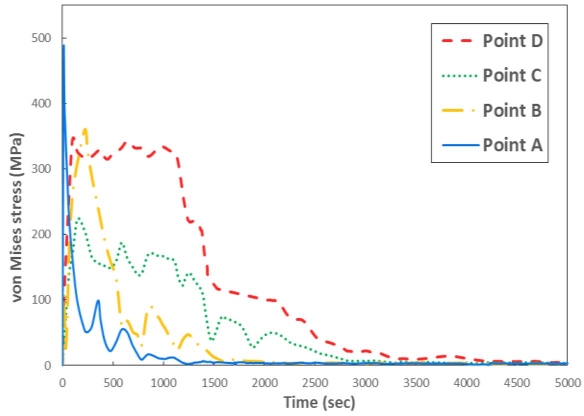
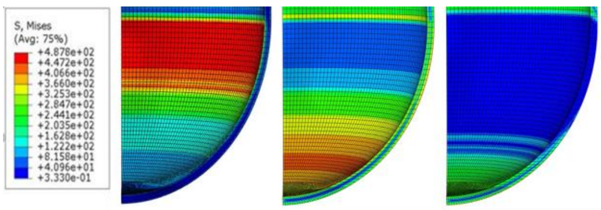


Fig. 4. Variation of von Mises stresses at 4 points



(a) 12 sec (b) 221 sec (c) 5,044 sec
Fig. 5. Variation of stress distributions of RPV

4. Conclusion

In this paper, sensitivity analyses to examine a RPV integrity were carried out. Temperature and stress distributions and histories according to different analysis step procedures and heat transfer methods were compared. Since the maximum stress appeared in the metal layer due to higher thermal flux, corresponding creep rupture analysis is necessary for detailed structural integrity assessment of the RPV under IVR-ERVC condition.

REFERENCES

[1] S.H. Kim and Y.S. Chang, Structural assessment of reactor pressure vessel under core melting conditions, Proceedings of the ASME 2013 pressure vessels & piping division, 2013.

[2] ABAQUS User's Manual, Ver.6-10.1, 2010, Dassault Systems.

[3] D. Tarabelli, G. Ratel, R. Pelisson, G. Guillard, M. Barnak, P. Matejovic, ASTEC application to in-vessel corium retention, Nuclear Engineering and Design Vol. 239, pp. 1345-1353, 2009.

[4] J.S. Kim, Y.S. Chang and T.E Jin, Damage analysis for reactor pressure vessel with external reactor, Proceedings of KSME conference, pp. 996-1001, 1997.

[5] J.S. Kim and T.E. Jin, Structural integrity assessment of the reactor pressure vessel cooling condition, Nuclear Engineering and Design, Vol. 191, pp. 117~133, 1999.