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An Integrity Assessment for Reactor Lower Head under In-Vessel Vapor Explosion Loads

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1. Introduction

The purpose of this study is to assess the integrity of the ICI nozzle in lower head of reactor vessel (PWR) under in-vessel vapor explosion loads. The premixing and explosion calculations were performed using TRACER-II code. Transient analysis using ANSYS code was performed to calculate strains under explosion pressures imposed on the lower head inner wall. The calculated strain results and the established failure criteria were used in determining the failure probability of the lower head. Strain analyses show that the vapor explosion-induced lower head failure is not possible under the present framework of assessment.

2. Assessment of ICI nozzle

2.1 Integrity assessment process

The explosion calculations were performed using TRACER-Ⅱ code[1], then can obtain the transient pressure load. The structural analysis process is: using the calculated explosion pressure imposed on the lower head inner wall, strain and stress calculation were performed using ANSYS version 6.0, and then comparing the calculated value with the allowable failure criteria value to determine the failure probability of the lower head.

2.2 Failure criteria

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

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

According to Bohl and Butler, failure should occur at 12% equivalent plastic strain. Berman et al. on the other hand, placed this criterion at 18%.

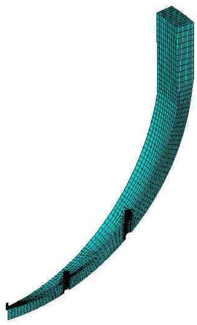
The failure criteria will have to be evaluated conservatively. For this purpose, the mechanistic ideas of ductile failure based on void nucleation, growth, and with particular reference to the work of Shockey et al.[4] were used. It was found that voids nucleate predominantly on included particles, and that the threshold strain of 11% is needed for nucleation.

2.3 Finite element modeling

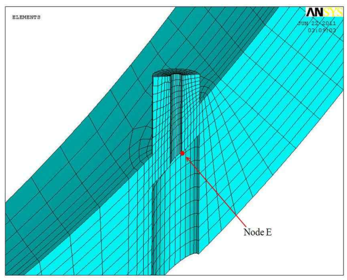
Fig. 1 shows three dimensional modeling that is 1/18 of lower head and included only three instrumental nozzle at bottom 0°, 20° and 40°. The material of the lower head is SA508 grade 3 class 1 steel, and assumed as a elastic behavior ignoring strain rate hardening effects. The stress-strain curve of SA508 is obtain in ASME B & PV code Sec. VIII, Div. 2. Table 1 shows the material properties at 260 °C.

Table 1 Mechanical properties of material at 260℃

Young's modulus (GPa)	177.2
Tangent modulus (GPa)	9.87
Yield strength (MPa)	184
Density (Kg/ m^3)	7830



(a)



(b)

Fig. 1 (a) FE model of lower head in 3D analysis (b) Zoomed view near ICI nozzle at 43° from bottom

2.3 Explosion pressure used in analysis modeling

For the explosion loads, transient dynamic analysis is performed. The initial pressure of 0.5MPa is applied during 1.0sec before explosion to be reached the steady state. Explosion pressure in case of bottom trigger is shown in Fig. 2.[6]

3. Results and discussions

Fig. 3 and Fig. 4 show the history of equivalent stress and strain with time. The stress and strain are steady after 1.019sec. The distributions of equivalent strain at 1.02 sec are shown in Fig. 5. It shows that the maximum equivalent stress and strain are 352.9 MPa and 0.199%, respectively.

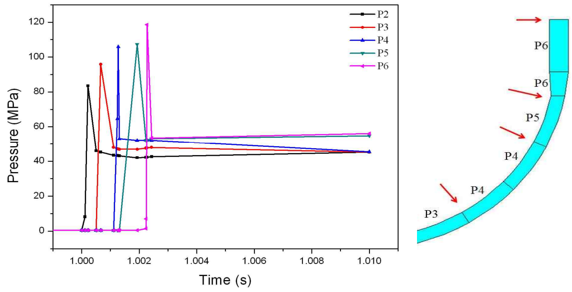


Fig. 2 Input pressure load on the surface of lower head

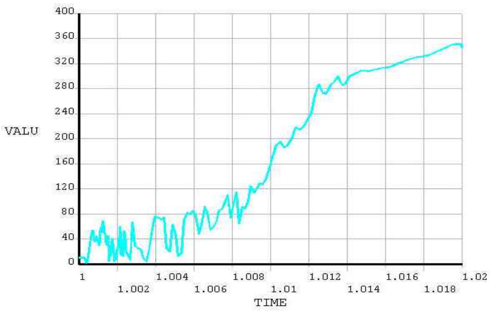


Fig. 3 Time history of equivalent stress a node E

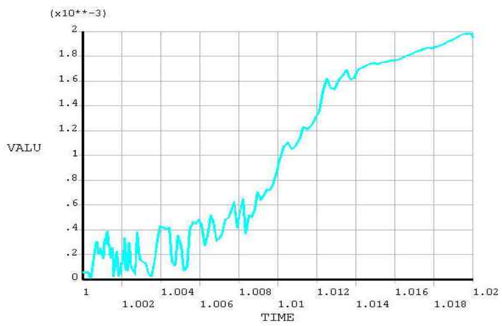


Fig. 4 Time history of equivalent stress a node E

4. Conclusions

In this paper, it's only considered the transient elastic linear work-hardening plastic and 3-dimensional solid model focused on ICI nozzle under transient explosion pressure load.

Summarizing the results of 3-dimensional dynamic analysis, the maximum equivalent strain was 0.199 % which is much less than 11% of the failure criteria. Thus the probability of head fragility does not exist.

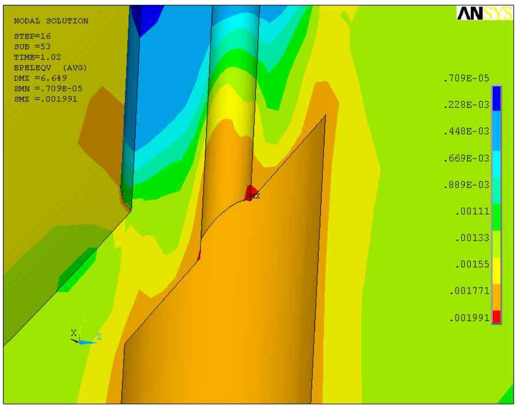


Fig. 5 Contour of equivalent strain at 1.02 sec

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