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Stress Analysis for Reactor Coolant Pump Nozzle of Nuclear Reactor Pressure Vessel

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ABSTRACT

Integrated reactor structural design makes the pressure vessel itself and loads more complicated, so stress concentration makes strength failure easier at reactor coolant pump nozzle. The general purpose finite element program ANSYS/ WORKBENCH was used for 3D stress and fatigue analysis and the results of the evaluation are based on RCC-M criteria. The integrated reactor structural design is evaluated to demonstrate with applicable criteria and ANSYS/WORKBENCH has better operability than ANSYS APDL on stress analysis of reactor pressure vessel.

Keywords: Numerical Simulation; Reactor Pressure Vessel; Stress Analysis

1. Introduction

Integrated reactor is new generation pressurized water reactor developed by China [1]. Reactor structure is highly integrated, for example, once through steam generator placed in a pressure vessel; reactor coolant pump is placed on the pressure vessel nozzles; pressure vessel fixed and supported the main pump, control rod drive mechanism and the top of the heap structure. This structural design can simplify a loop system and eliminate LBLOCA, but makes the pressure vessel itself and loads more complicated. So the stress analysis is necessary to ensure the effectiveness and safety of the design and the integrity of the reactor pressure vessel.

Most domestic researchers [2-5] using traditional ANSYS APDL for stress analysis and evaluation of reactor pressure vessel calculation. With the development of computing software, ANSYS, Inc. has developed ANSYS/WORKBENCH software and pre-processing, calculation and post-processing become more convenient [6]. ANSYS/WORKBENCH is used in this paper.

2. Calculation Model

According to the structure features of the reactor pressure vessel, the reactor pressure vessel cylinder and outlet nozzle is → are simplified:

1) According to RCC-M, surfacing layer is not exposed to any structural strength in criteria O, criteria C and criteria D. So surfacing layer is ignored in numerical model.

2) Bolt holes on reactor coolant pump nozzle and the effect of in-line casing and annular flow distribution plate are ignored.

3) To reduce edge effects influence on the reactor coolant pump nozzle, pressure vessel cylinder must be long enough in calculation model. According to RCC-M, the length in pressure vessel cylinder axial direction from the center line of the reactor coolant pump nozzle is at a length of $2.5\sqrt{Rt}$ at least, where $R = (R_1 + R_2)/2$. R_1 and R_2 are the inside and outside radius of the pressure vessel cylinder, and t is the thickness of the pressure vessel cylinder.

Three-dimensional finite element model of pressure vessel cylinder and outlet nozzle is built by ANSYS/ WORKBENCH program as shown in the **Figure 1**. 1/4 model of pressure vessel cylinder and complete model of pressure vessel nozzle are built by hexahedral meshes with the size of 40 mm.

Reactor pressure vessel design temperature is 343˚C. Pressure vessels and outlet nozzle materials are 16MND5 forgings. According to RCC-M Parameter Manual, 16 MND5 material parameters at 350˚C are shown in **Table 1**.

3. Evaluation Conditions, Loads and Boundary Conditions

According to RCC-M, stress strength must conform to criteria O in the first operating condition when pressure vessel nozzle is analyzed. Self-weight, internal pressure and earthquake load are considered and each load is composed of six components. Force and moment are

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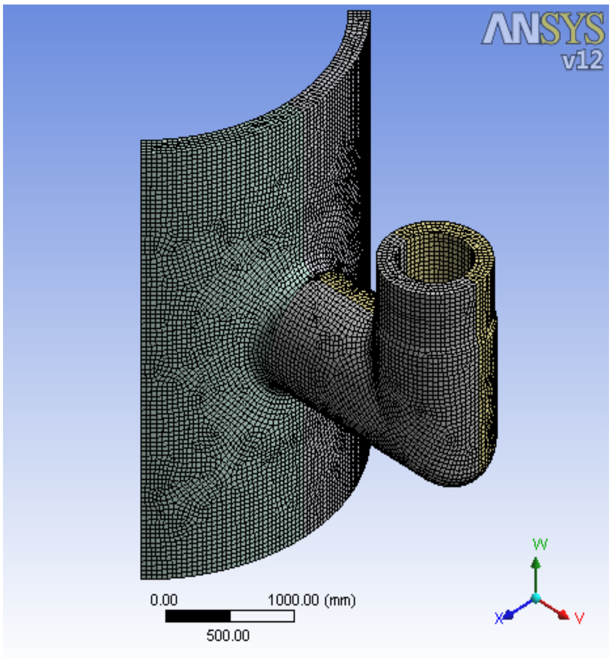

Figure 1. Reactor pressure vessel simulation mode.

Table 1. Material parameters of 16MND5.

ρ $kg \cdot m^{-3}$	E GPa	k $W \cdot m^{-1} \cdot K^{-1}$	α $^{\circ}C^{-1}$	S_m MPa	S_y MPa	S_u MPa
7800	180	38.7	1.34×10^{-5}	184	345	552

transmitted to the cylinder and nozzle ends through extension of pressure vessel cylinder.

Fixed boundary condition A is set in the bottom of the vessel; symmetry boundary condition B is set on the section of symmetrical structure of the reactor pressure vessel; hydrostatic pressure C and F are set on the upper section of reactor pressure vessel and reactor coolant pump nozzle; the mechanical loads D and E caused by self-weight and earthquake load are set on the upper section of the reactor coolant pump nozzle; the internal pressure G is set on the inner surface of all parts as shown in the **Figure 2**.

4. Results and Evaluation

The calculated stress intensity contours shown in **Figure 3**. The maximum stress is in the junction of the cylinder nozzle. According to RCC-M, stress is divided into primary membrane stress, secondary membrane stress and bending stress to be evaluated.

A typical evaluation section usually is the structural discontinuous section where stress intensity is high due to mechanical loads. Stress is analyzed by stress linearization in ANSYS/WORKBENCH. Firstly, the high stress intensity area is searched on the stress intensity contours,

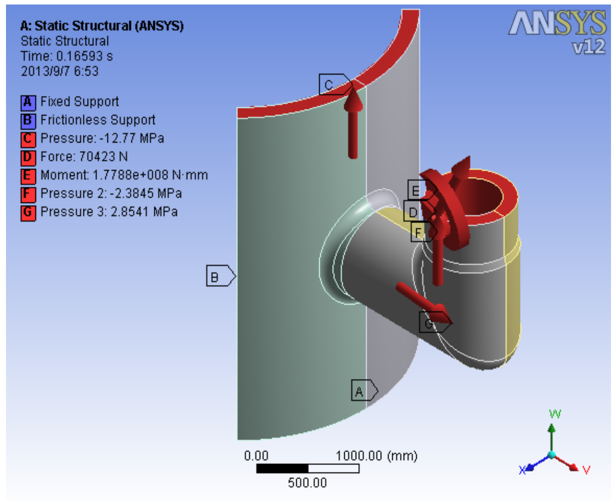

Figure 2. Loads and boundary conditions.

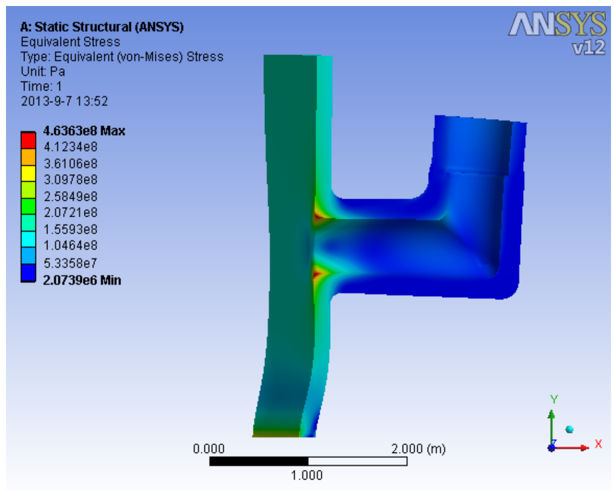

Figure 3. Stress intensity contours.

and then the two nodes which can run through the thickness of pressure vessel cylinder and nozzle are selected in the structure discontinuous area. Result data can be mapped to the path formed by connecting two nodes, and then the numerical calculation results can be analyzed by the selected path. Based on the above principles, twelve paths are set in the structure continuous areas, and stress concentration areas and structural discontinuous areas are shown in **Figure 4**.

Table 2 shows the results of stress analysis on evaluation section. The bending stress of the whole discontinuous area on the path 2, 3, 5, 8, 10 and 11 are secondary stress, and they are not evaluated in criteria O.

According to RCC-M, primary stress must conform to criteria O in the first operating condition. The criteria O requires that $P_m \le S_m$, $P_L \le 1.5S_m$, and P_m $(P_L) + P_b \le 1.5S_m$. P_m is general primary membrane stress, P_L is primary local membrane stress, Pb is primary bending stress

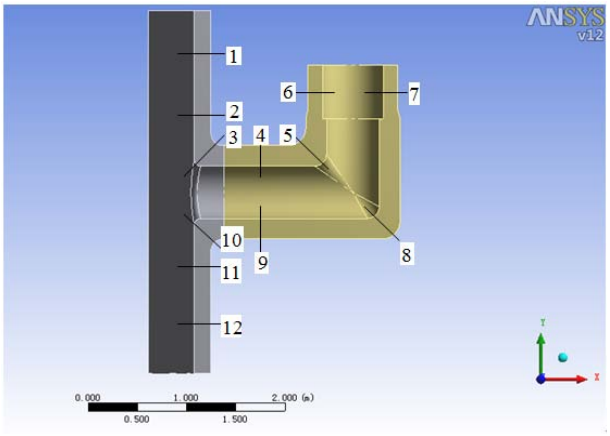

Figure 4. Evaluation section and paths.

Table 2. Stress linearization results.

Path	P_m	P_L	$P_m + P_b$
1	149.5	-	167.0
2	-	168.5	*
3	-	199.5	*
4	34.3	-	47.6
5	-	33.3	*
6	40.3	-	49.8
7	38.6	-	49.5
8	-	8.1	*
9	20.7	-	38.3
10	-	199.7	*
11	-	167.2	*
12	127.4	-	137.3

and Sm is Allowable Stress.

Path 1, 4, 6, 7, 9 and 12 are in the structure continuous areas. The membrane stress there is general primary membrane stress and the maximum "P_m(149.5 MPa)" is lower than "S_m(184 MPa)". The bending stress there is primary bending stress and the maximum "$P_m + P_b$ (167.0 MPa)" is lower than "1.5S_m (276 MPa)".

Path 2, 3, 5, 8, 10 and 11 are in the structural discontinuous areas. The membrane stress there is primary local membrane stress and the maximum "P_L(199.7 MPa)" is lower than "1.5S_m (276 MPa)". The bending stress there is secondary stress and it is not evaluated in criteria O.

As can be seen from the above, the structure designed can satisfy the intensity requirement in the criteria O of RCC-M.

6. Conclusions

1) The stress of reactor coolant pump nozzle of nuclear reactor pressure vessel is analyzed and evaluated by ANSYS/WORKBENCH. The results show that the structure designed can satisfy the intensity requirement in RCC-M.

2) ANSYS/WORKBENCH is more convenient than the traditional ANSYS APDL, which can be widely used in the geometry modeling, loading and post processing.

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