Structural Evaluation of Reactor Support Structure for a PGSFR in a Steady State Condition

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1. Introduction

The Reactor Support (RS) structure is one of the most important structures in the Prototype Gen Ⅳ Sodium-cooled Fast Reactor(PGSFR)[1]. The RS provides various penetrations for an in-service inspection (ISI). In addition, it also supports the weight of the primary sodium and several main components such as Primary Heat Transport System (PHTS), Reactor Internal (RI), fuel assemblies and Reactor Enclosure System (RES) but except the Containment Vessel(CV).

In this study, the steady state analysis for the RS was performed and the structural integrity was assessed in accordance with ASME Section III, Division 5, Subsection HF[2].

2. Methods and Results

2.1 Analysis Condition

Figure 1 shows the current RS design in the PGSFR[3]. The skirt-type reactor support structure is supported on the concrete floor by the bolt joints integrated with the guard vessel top flange. The RS has an important role to support everything inside the reactor vessel and the reactor vessel. The RS is a thick forged circular plate with 100mm thickness and 10,746 mm in diameter.

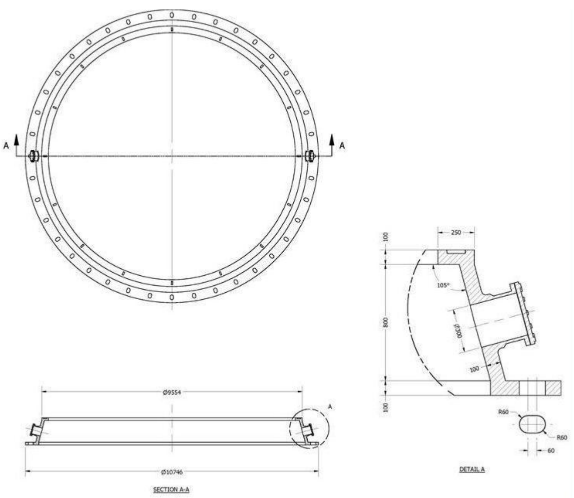

Fig. 1 Design configuration of the RS

For applying the load conditions, weights of main components are converted as an equivalent pressure on the RS upper flange and then they are applied to the area where they are installed. The RS design pressure is determined in accordance with eq. (1).

$$M_{all} = 1,691,355 kg$$
$$P_{RS} = M_{all} \times 9.8 / A_{flange}$$
$$= 1,691,355 \times 9.8/7.30364 = 2,269,427,7 Pa \qquad (1)$$

Figure 2 shows the configuration of the RS half symmetric 3D finite element was modeled by using the FEA software ANSYS [4].

Figure 3 shows structure boundary conditions. For the calculation, SOLID186 element was used and total number of nodes and elements were 43,581 and 9,051 respectively.

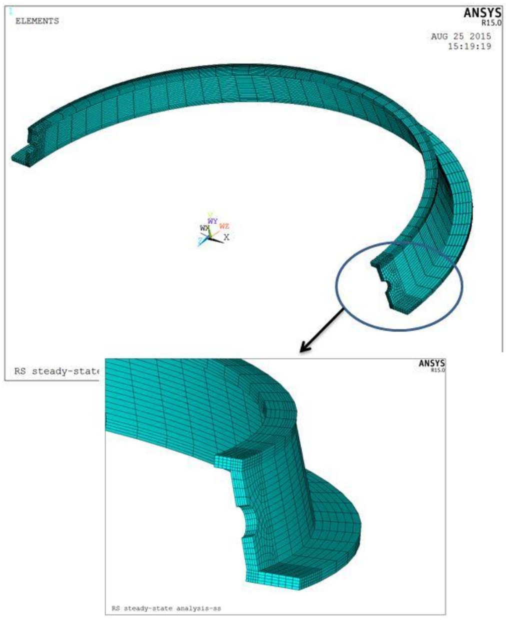

Fig. 2 Finite element model of the RS

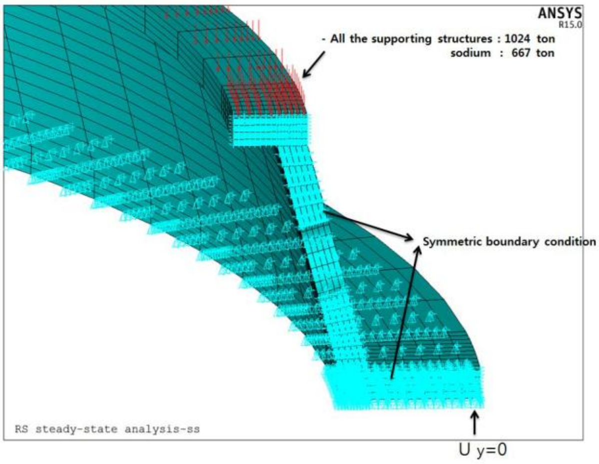

Fig. 3 Boundary conditions of the RS

2.1 Stress Analysis Result

The primary stress analysis is carried out for the design condition. Figure 4 represents the stress intensity distribution due to the design condition. As shown in Figure 5, the maximum stress intensity is 56.6MPa at the ISI hole region.

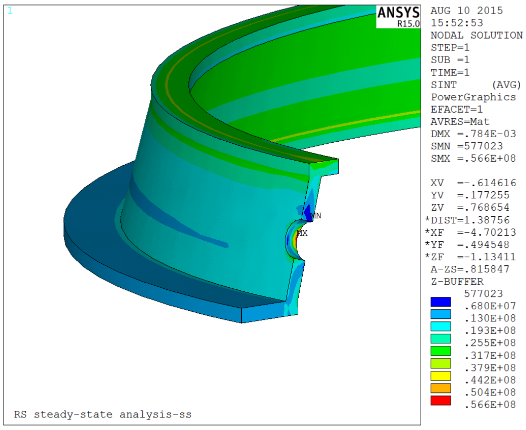

Fig. 4 Primary stress intensity for distribution of RS

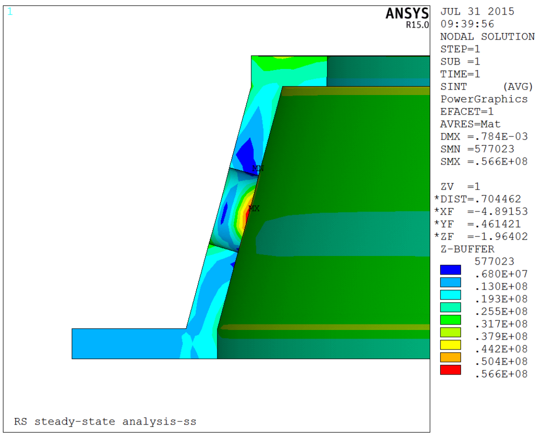

Fig. 5 Maximum stress intensity of the RS

The thermal stress within the support describes that Subsection HF need not be evaluated. Therefore, the service level A stress result is the same as the design condition stress result.

3. Structural Integrity Evaluations

The structural integrity of the RS was evaluated for the design condition and service level A according to ASME Section III, Division 5 Subsection HF.

3.1 Evaluation Sections

In order to evaluate the structural integrity of the RS, the locations of maximum stress region are chosen as an evaluation section. Figure 6 shows the evaluation cross section of the RS.

- Section A: maximum primary stress region, N16714-N6861.

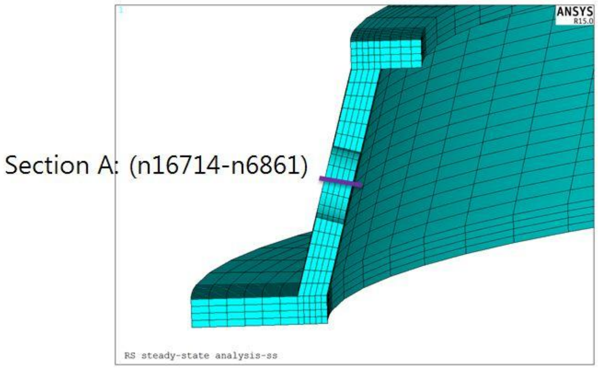

Fig. 6 The section for structural integrity evaluation of the RS

3.2 Design Condition

Table 1 shows the results of structural integrity for the design condition. The results of the section with the minimum design margin are as follows.

- ➢ Section-A, Inner(16714), (temperature=263℃)
- Pm = 20.4 MPa < Sm = 124 MPa: satisfied. (design margin ≒ 5.1)
- PL+Pb = 58.4 MPa < 1.5Sm = 186 MPa: satisfied. (design margin≒ 2.2)

The results reveal that all primary stresses in the section are satisfied with the design criteria for the design condition.

Table 1 Structural integrities under design condition

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin	Temperature (ºC)	C&S
Section-A	Inner (16714)	Pm	20.4	Sm = 124	5.1	263	ASME Sec III Div5-HF
		PL + Pb	58.4	1.5Sm = 186	2.2		
	Outer (6861)	Pm	20.4	Sm = 124	5.1	263	ASME Sec III Div5-HF
		PL + Pb	17.9	1.5Sm = 186	9.4		

3.3 Service Level A condition

The service level A condition of the RS should be satisfied with Table 2.

Table 2 Design by analysis evaluate rules for Class 1 Plate and shell type supports.

Table NF-3221.2-1
Elastic Analysis Stress Categories and Stress Limit Factors for Class 1 Plate- And Shell-Type Supports Designed by Analysis

	Stress Limit Factors for Loading Categories [Note (1)]					
Stress Category	Design	Service Level A	Service Level B [Note (2)]	Service Level C [Note (3)]	Service Level D	Test Loadings
Primary stresses [Note (4)], [Note (5)]	$K_m = 1.0$	$K_m = 1.0$	$K_m = 1.33$	$K_m = 1.5$	...	$K_m = 1.33$
	$K_v = 1.0$	$K_v = 1.0$	$K_v = 1.33$	$K_v = 1.5$	...	$K_v = 1.33$
	$K_{bk} = 1.0$	$K_{bk} = 1.0$	$K_{bk} = 1.33$	$K_{bk} = 1.5$	Use Appendix F	$K_{bk} = 1.33$
	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	but stress ≤ ½ of critical buckling stress	...	but stress ≤ ½ of critical buckling stress
Primary plus secondary stresses [Note (5)], [Note (6)]	Evaluation is required for critical buckling for all loading categories. The requirements of this Subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTE:
K_{bk} = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (compression only)
K_m = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (see NF-3221.1 and NF-3221.2)
K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3223.2)

NOTES:
(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.
(2) K_m, K_v, and K_{bk} = 1.0 for design of snubbers and dampers.
(3) Stress shall not exceed 0.7 S_u.
(4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.
(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.
(6) Service Levels A and B, primary plus secondary stresses shall be limited to a range of $2S_y$ or S_u at temperature, whichever is less for component supports only.

3.3.1 Primary Stresses

Primary stresses must meet stress limit the considering stress limit factor. All stress limit factors of the design condition and service level A are 1 as shown in Table 2. Therefore, evaluate results of primary stresses are equal to section 3.2 of this paper.

3.3.2 Critical Buckling

Evaluation is required for critical buckling for all loading categories. The linear critical buckling is calculated by the following equation (2).

$$([K]+\lambda[S])\{\oint\}=0 \qquad (2)$$

λ : Buckling load multiplier
$\oint$: Buckling mode shape

The buckling load multiplier and buckling mode shape can be determined through a linear critical buckling applying the unit load. The result can be obtained with critical buckling loads.

$$\text{Critical Buckling Load} = \lambda \times \text{Unit Load} \qquad (3)$$

Figure 7 shows the linear critical buckling result of the RS. Unit load is applied to the design pressure 2.27 MPa. As a result, The design pressure of the critical buckling load is 514.75 MPa. The critical buckling stress applied to the critical buckling load is shown Figure 8.

- ➢ Section-A, Inner(16714), (temperature=263℃)
- Pm_{-cb} = 4,574.4 MPa
- $PL_{-cb} + Pb_{-cb}$ = 13,186 MPa

The primary stress must meet less than half the critical buckling stress and the secondary stress should meet the critical buckling stress.

☞ Maximum primary stress region

- ➢ Section-A, Inner(16714), (temperature=263℃)
- Pm_{-p} = 20.4 MPa ≤ 2287.2 MPa: satisfied.
- $PL_{-p} + Pb_{-p}$ = 58.4 MPa ≤ 6,593 MPa: satisfied.

☞ Maximum primary plus secondary stress region

- ➢ Section-A, Inner(16714), (temperature=263℃)
- Pm_{-ps} = 20.4 MPa ≤ 4574.4 MPa: satisfied.
- $PL_{-ps} + Pb_{-ps}$ = 58.4 MPa ≤ 13,186 MPa: satisfied.

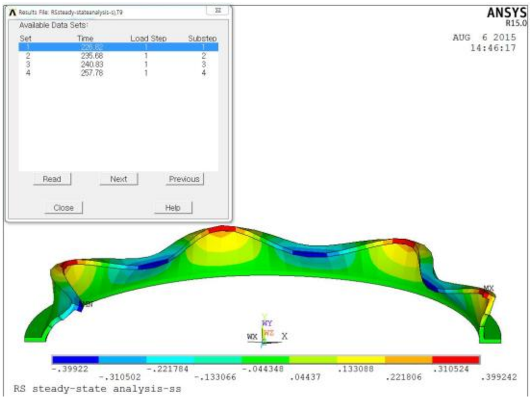

Fig. 7 Buckling mode shape of the RS

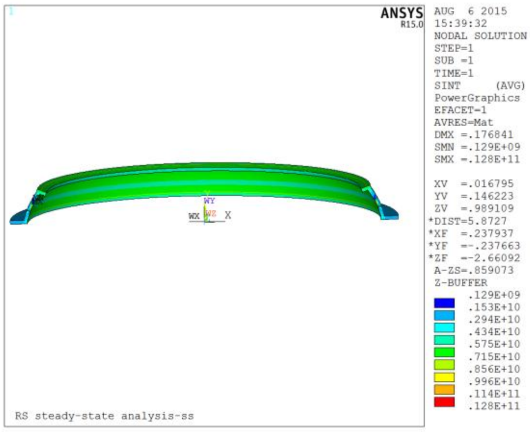

Fig. 8 Critical buckling stress of the RS

3.3.3 Primary Plus Secondary Stresses

Primary plus secondary stresses of the service A shall be limited to a range of $2S_y$ or S_u at temperature, whichever is less for component supports only.

- S_u = 495 MPa (temperature=263℃) [5]
- $2S_y$ = 275 MPa (temperature=263℃)

➢ Section-A, Inner(16714)
- PL+Pb = 58.4 MPa ≤ 275MPa : satisfied.

4. Conclusions

In this paper, the structural integrities of the RS under the design condition and service level A condition have been assessed according to ASME code. As a result, the RS structure satisfied with design criteria for both design condition and service level A. For the future work, a transient analysis and a seismic analysis need to be performed by combining the different design loads.

Acknowledgement

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