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Division V

STRUCTURAL ANALYSIS OF ROOF SLAB FOR PROTO TYPE FAST BREEDER REACTOR

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ABSTRACT

Roof slab of prototype fast breeder reactor (PFBR) is situated at the top of reactor and it supports Main vessel and others important components like LRP, SRP, IHX, Pump, complementary shielding etc. The slope and deflection of LRP, Pump, IHX ring flange are important to meet functional requirement of fuel handling system and shutdown & control system. The misalignment of CSRDM grip and control rods at subassembly top level has to be within the acceptable limit to achieve an hassle free performance of reactor shutdown and fuel handling systems. The scope of the present paper is to evaluate the stress to insure the structural integrity during normal and seismic conditions. Slope & deflection of LRP flange, Pump flange and IHX flange to avoid the mechanical interaction with inner vessel.

A full 3-D finite element modeling of roof has been generated using the ABAQUS FE software employing 8-node shell element. Due to thermal loading (linear axial thermal gradient), slope and deflection analysis of top shield has been carried out. The slope at control plug support flange, LRP support-nearest to axis of top roof slab, LRP support-farthest to axis of top roof slab and LRP support are within allowable limit. The mass of concrete shielding of roof slab is lumped on bottom plate. The masses of IHX, pump DND, IFTM etc. are lumped at their respective support flanges. Seismic analysis has been carried out by response spectra method for OBE & SSE. The maximum stress is found in the stiffeners. The stresses and deflections due to self weight and seismic load are within the allowable limits.

INTRODUCTION

Roof slab formed the top cover for reactor assembly. It supports Main vessel, large rotatable plug (LRP), small rotatable plug (SRP), Intermediate Heat Exchanger (IHX), Primary Sodium Pump (PSP), complementary shielding and various other important components. The slope and deflection of LRP, PSP, IHX ring flange are important to meet functional requirement of fuel handling system as well as control & shutdown system. The misalignment of control and safety rod drive mechanism (CSRDM) gripper and control rods at subassembly top level have to be within the acceptable limits to achieve an hassle free performance of reactor shutdown and fuel handling systems.

The mechanical load on roof slab has been revised component that considered of the design stage. The scope of the present design note is to evaluate the stresses at critical locations due to self weight and earthquake load with and without PI flask load at IHX and pump locations for the purpose of structural integrity assessment. Knowledge of slope and deflection of LRP, IHX and Pump support flange locations is essential to ensure that there is no mechanical interaction with inner vessel stand pipes.

MATERIAL AND GEOMETRY

The main material for top shield is carbon steel A48P2 and in some part SS316LN is also used. The material properties at 150°C are given below.

Carbon steel A48P2

Young modulus of elasticity	= 202E+03 MPa
Yield strength	= 240 MPa
Minimum tensile strength	= 450 MPa
Allowable stress (S_m)	= 150 MPa
Poisson ratio	= 0.3

SS316LN

Young modulus of elasticity	= 182E+03 MPa
Poisson ratio	= 0.3

The roof slab is box type structure made of cylindrical shells, flat plate and vertical stiffeners.

MECHANICAL & THERMAL LOAD AND BOUNDARY CONDITIONS

The total self weight of roof slab is 660 t including complementary shielding. Total load on main vessel is 2200 t and total load on roof slab is 4253 t. For the numerical analysis the top of roof slab is arrested in vertical direction. However, top shield is free to move in radial direction. Temperature values of top plate and bottom plate of top shield are 110 ºC and 120 ºC respectively.

STRUCTURAL & THERMAL ANALYSIS

A full 3-D finite element modeling of top shield has been generated using the ABAQUS FE software employing 8-node shell element. The model contains roof slab- outer shell, LRP support shell, top plate, bottom plate, step plate, LRP support flange, pump support shell, IHX support shell, LRP&SRP- support ring, outer shell, outer shell shielding, top plate, bottom plate, intermediate plate (top & bottom) and Main vessel as depicted in Figure 1. The mass of concrete shielding of roof slab is lumped on bottom plate. The masses of IHX, PSP, DND, IFTM etc. are lumped at their respective support flanges.

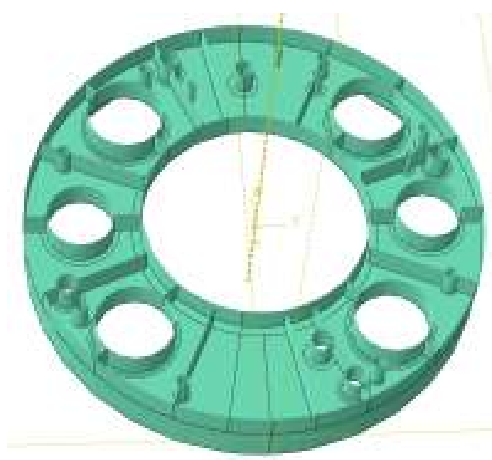

Figure 1. Roof slab section view

Seismic analysis has been carried out by the response spectra method. A typical response spectrum during operation basis earthquake (OBE) condition for 2% damping in the X direction is depicted in Figure 2.

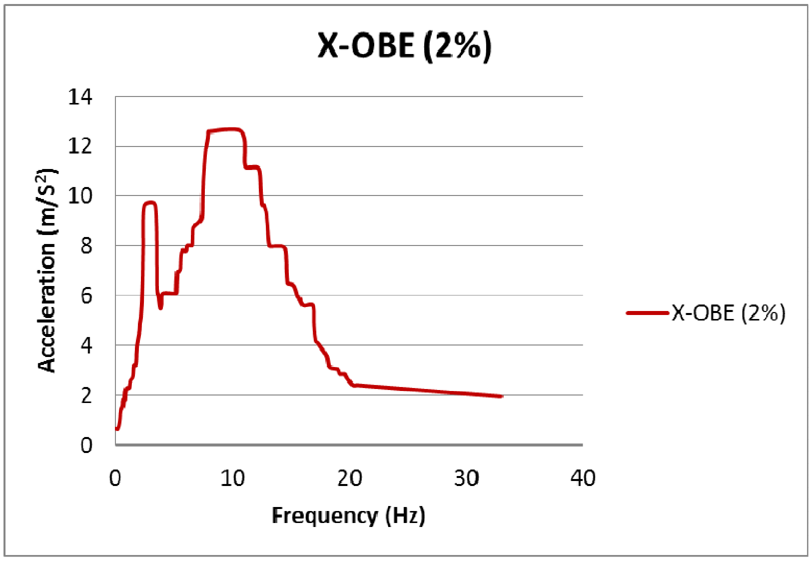

Figure.2 Floor response spectra for OBE in X direction

Various possible mechanical loading combinations in different service levels are:
- Self weight.
- Self weight + OBE
- Self weight + SSE
- Self weight + PI flask on IHX
- Self weight + PI flask on PUMP
- Self weight + OBE + PI flask on IHX
- Self weight + OBE + PI flask on PUMP
- Self weight + SSE + PI flask on IHX
- Self weight + SSE + PI flask on PUMP

The temperature gradient has been considered to be linear.

During PI flask on IHX condition:
Weight on IHX location = PI flask load - IHX complementary shielding load
= 180 t - 42 t
= 138 t.

During PI flask on pump condition:
Weight on single pump location = PI flask load - pump gear box
= 180 t - 45 t
= 135 t.

RESULTS

The von mises stress of roof slab due to self weight + OBE is depicted in Figure 3. The von mises stress in the stiffeners during self weight + SSE + PI flask on IHX is depicted in Figure 4. The vertical deflection of top plate (which consists top plate, LRP flange, IHX flange and pump flange) due to self weight is depicted in Figure 5.

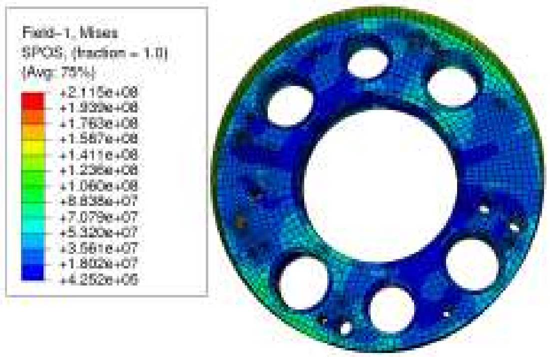

Figure 3. Von mises stress (Pa) in roof slab due to self weight + OBE

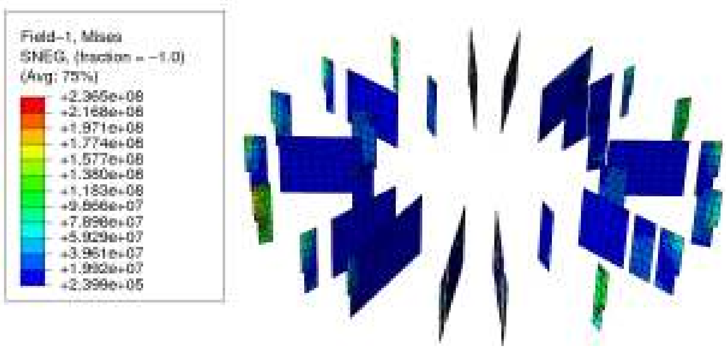

Figure 4. Von mises stress (Pa) in roof slab due to self weight + SSE + PI flask on IHX

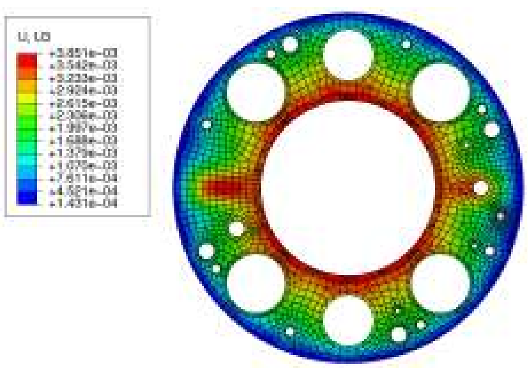

Figure 5. Vertical deflection (m) of top plate due to self weight

The slope of LRP, IHX and pump support flange during various loading combinations is calculated as:

Slope = Difference in diametrically opposite vertical deflection / diameter

The diameters of LRP, IHX and pump support flange are 6.7 m, 2.34 m and 2.048 m respectively. The temperature contour is depicted in Figure 6.

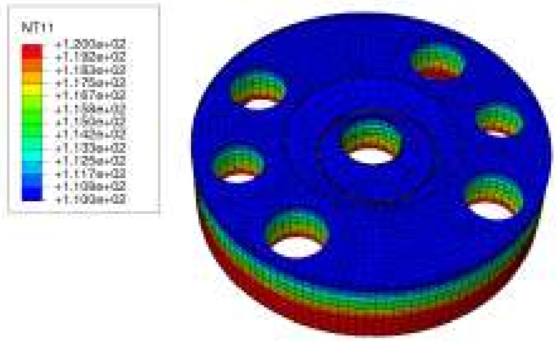

Figure 6. Temperature (ºC) contour of top shield

DESIGN CHECK

The comparison of maximum stress in various components with allowable stresses is provided in Table 1, as per RCC-MR, Section 1. In the stiffener, it is seen that primary membrane stress intensity, P_m, local membrane stress intensity, P_L, local membrane plus bending stress intensity, $P_L + P_b$, are 183 MPa, 230 MPa and 235 MPa respectively due to self weight + OBE + PI flask on IHX. The value of P_m, P_L, and P_L+P_b in stiffener is higher than the allowable limits 150 MPa, 225 MPa and 225 MPa respectively for service level A loading but lower than service level C allowable. Hence it is recommended that stiffeners after self weight + OBE + PI flask on IHX load should be inspected prior to restart the reactor.

Table 1: Comparison of maximum stresses with allowable stress for Level A load as per RCC-MR

Location	Parameters	Self weight	Self weight + PI flask at IHX	Self weight + PI flask at pump	Self weight + OBE	Self weight + OBE + PI flask at IHX	Self weight + OBE + PI flask at pump	Level A allowable	Level C allowable
Top plate	P_m	45	48	48	67	91	85	150	202
	$P_L+ P_b$	51	60	55	86	135	94	225	303
	Shear	25	37	26	43	64	50	90	120
Stiffener	P_m	85	115	105	121	183	134	150	202
	P_L	103	142	114	157	230	175	225	303
	$P_L+ P_b$	104	144	118	162	235	182	225	303
	Shear	44	56	47	61	94	73	90	120
Bottom	Pm	74	77	81	130	137	141	150	202

plate	$P_L + P_b$	83	88	90	184	166	158	225	303
	Shear	42	44	45	54	82	78	90	120

The slope and deflection at control plug support flange location, due to thermal loading, are found to be 7.5 X 10^{-5} radian and 1.7 mm respectively.

CONCLUSION

Structural analysis of roof slab due to self weight including complementary shielding and PI flask during normal operation and seismic condition, the structural analysis has been carried out. It is seen that stiffeners are the critical part of roof slab. The values of P_m, P_L, and P_L+P_b during self weight + OBE + PI flask on IHX exceed the allowable of service level A loading but are less than the allowable of service level C loading. Hence, it is recommended that stiffeners should be inspected prior to restart the reactor, after an OBE with PI flask.

The slopes at LRP, IHX and pump support flanges during normal operation are found to be 2.99 X 10-6 rad, 1.03 X 10-3 rad and 1.04 X 10-3 rad respectively due to the mechanical load. Similarly, the maximum vertical deflection at LRP, IHX and pump support flange during normal operation are found to be 3.88 mm, 3.45 mm and 3.38 respectively due to the mechanical load. The slope and deflections due to mechanical and thermal loadings are within the allowable limits.

REFERENCES

A.L.Kothandaraman, et.al (1999) "*Material properties for design*", Note: PFBR/01000/DN/1000/ Rev-E (internal report).

Drawings (2003), Roof Slab- PFBR/31310/GA/1101/Rev-2 (internal report).

Sriramachandra Aithal, (2007), "*Structural Design of Complementry Shielding Over Top Shield*", PFBR/31300/DN1062/RB (internal report).

RCC-MR, Section 1, Sub section B: Class 1 Components, 2002.