Structural Analysis and Experimental Validation for PGFR Roof Slab

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ABSTRACT

This paper covers both theoretical and experimental studies carried out in connection with the design of roof slab for the Prototype Fast Breeder Reactor (PFBR) 500 MW(e) capacity. The roof slab is an annular box type structure made very rigid by circumferential and radial stiffeners and designed to support over 3600 t of load. Theoretical analysis was performed using PAFEC and SAP4 finite element computer codes. Experimental studies on a 1/15 scale model made of acrylic sheets were carried out to validate the theoretical analysis. Deflection and strain measurements were carried out. The results are in good agreement.

1.0 INTRODUCTION

After successful commissioning of Fast breeder test reactor (FBTR), Department of Atomic Energy (DAE) is in the advanced stage of designing a 500 MW(e) Pool type fast breeder reactor named Prototype Fast Breeder Reactor (PFBR).

In PFBR the main vessel and its internals, rotatable plugs, primary sodium pumps and Intermediate Heat Exchangers (IHXs) are supported on a component called roof slab (fig.1). This is an annular box type structure[1] of 15 m O.D. and 6.6 m I.D. made very rigid by circumferential and radial stiffeners. The loads acting on the roof slab are those due to main vessel and its internals (2000 t), rotatable plugs (400 t), pumps and heat exchangers (480 t) and self weight (525 t). The pumps and IHXs are resting on the flanges which are supported by the roof slab through shells. These details have not been included in the model since their contribution to stiffness is negligibly small. The mean temperature of the roof slab is maintained at 383 K (110° C). A temperature difference (ΔT) of 20 K exists between the top and bottom plates. The vertical deflection at the inner edge of the roof slab is of prime importance and it should not exceed 5 mm. This is to aviod possible excessive reactivity addition due to withdrawal of control rods resulting from differential motion of the control rods (supported on roof slab) and the core (supported on the vessel) during a seismic event. The other parameters to be considered are tilting at the pump location and maximum stress. The tilting at these locations should not exceed 15 x 10^{-4} radian. The maximum stress should not exceed the allowable stress value of ASME Code[2].

This paper presents both theoretical and experimental analysis carried out for PFBR roof slab design.

2.0 METHOD OF ANALYSIS

In the method of analysis, the following studies are covered:

i) Structural analysis for roof slab.
ii) Experimental studies.
iii) Theoretical studies for the model.

These are described in the following paragraphs.

2.1 Structural analysis for PFBR roof slab

The PFBR roof slab is shown in Fig.2. Structural analysis in support of the design of roof slab was carried out using the finite element computer codes 'PAFEC'[3] and 'SAP4'[4]. Since the structure is a cyclic symmetric one, 15° sector of the structure was taken for the analysis. Four noded thin facet shell element was used to model the structure. Parametric studies were carried out using SAP4 to decide the number of radial and circumferential stiffeners, depth of the roof slab, and the thickness of the plates. The results indicated that roof slab design with 1.8 m depth, 24 radial stiffeners, 2 circumferential stiffeners and 30 mm plate thickness satisfy the design criteria. In order to reduce the longitudinal temperature gradient in the main vessel near its junction with roof slab, a step is provided near the outer periphery. 624 nodes (2682 degrees of freedom) and 592 elements were used in PAFEC for the final analysis. The finite element mesh with deformed shape (dashed line) and stress contour are shown in figs. 3 & 4. The results are given in Table.I. In order to validate the analysis performed using PAFEC and SAP4, experimental stress analysis has been considered desirable.

2.2 Experimental studies

For experimental purpose the structure has been slightly modified for ease of model fabrication. The stepped portion has been removed and this modified structure is shown in fig.5. The model which has been fabricated using perspex (Acrylic) sheets is a 1/15 scale model of the PFBR roof slab (fig.6). The material properties required for the analysis are found out experimentally and are given below.

Young's modulus = 2800 MPa
Poisson's ratio = 0.379

The boundary condition was simulated by pouring araldite liquid around the periphery of the support skirt and allowed to get hardened. Rotatable plugs load was applied at the inner edge using lever arm method. Pumps and heat exchangers load was applied by suspending lead shot packets at all these locations. Main vessel load was applied by suspending thirty numbers of equal weight lead shot packets around the circumference at equal intervals. Lead shots spread uniformly on the top plate simulated the weight of shielding material.

Dial gauges were used to measure deflection at the inner periphery and at the pump location. The slope at the pump location is calculated from the deflection values. Stress measurement was carried out using strain gauges. Totally 26 gauges were pasted at important locations to measure strains. Some of these strain gauges were used to check symmetricity. The results are given in Table-II alongwith theoretical results which are described in the subsequent para 2.3. The stress results given in Table-II are at few salient points marked in fig.5.

2.3 Theoretical analysis for the model

Theoretical analysis was done for the model using PAFEC and SAP4 computer codes. The model used for the analysis was similar to the one used for PFBR roof slab design. The finite element model used for the 15° sector is shown in fig.7. The results are given in Table-II.

3.0 DISCUSSION

(i) The results from the table-I show that 30 mm thickness of the plates is sufficient for all the parts of the PFBR roof slab including support skirt to satisfy the design criteria.

(ii) In the case of tilting at the pump location the margin between the calculated value and the design limit can be used for accommodating tilt due to thermal loads.

(iii) Table-II shows that there is a good agreement between experimental and theoretical results. This has confirmed the validity of the model used for the PFBR roof slab design.

4.0 CONCLUSIONS

The PFBR roof slab analysis has been performed by validating the theoretical model used with experimental studies. However, aspects like buckling due to shear in radial stiffeners and compression in support skirt are to be seen.

REFERENCE

1. Vaze K.K., Roy B.K., Bhoje S.B. (1982). Conceptual design of roof slab for PFBR - Internal design note (IGCAR).

2. ASME code, Section - III, Division - 1 (1986)

3. PAFEC a general purpose finite element computer code, PAFEC Ltd, Strelley Street, Strelley, Nottingham, U.K.

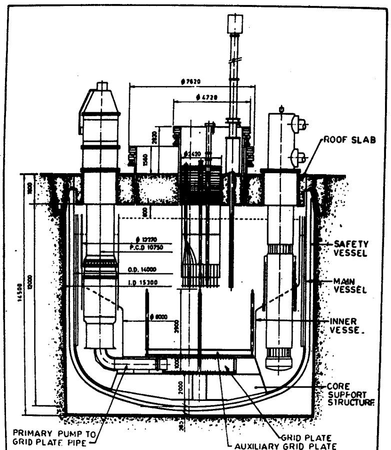
4. Bathe K.J., Wilson E.L., Peterson F.E. SAP IV - A Structural analysis program for static and dynamic response of linear systems.

TABLE-I

Description	Calculated Results	Design limit
Deflection at the inner edge of the roof slab (mm)	4.98	5.0
Tilting at the pump loction ($X10^{-4}$ rad)	9.0	15.0
Maximum stress near the inner edge (Pm+Pb+Q) (MPa)	97.4	330.0

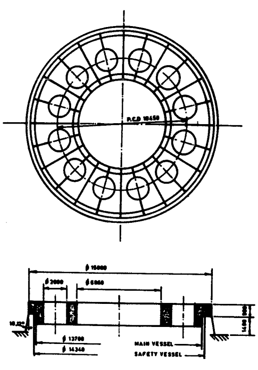
TABLE - II

Description	Experiment results	Analytical results PAFEC	Analytical results SAP4
Deflection at the inner edge	0.267	0.231	0.212
Tilting at the pump location ($X10^{-4}$ Rad.)	6.31	6.15	5.31
Longitudinal stress at A (MPa)	-1.94	-1.65	-1.09
Hoop stress at B (MPa)	0.23	0.23	0.20
Hoop stress at C (MPa)	0.33	0.40	0.35
Radial stress at C (MPa)	0.30	0.20	0.15



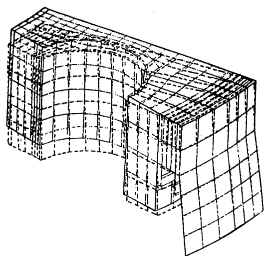
REACTOR ASSEMBLY PFBR

FIG.1



ROOF SLAB

FIG. 2



DEFORMED SHAPE OF THE 15° SECTOR MODEL.

FIG. 3

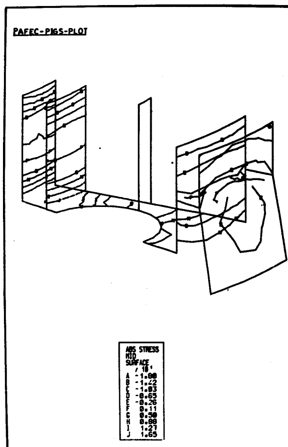
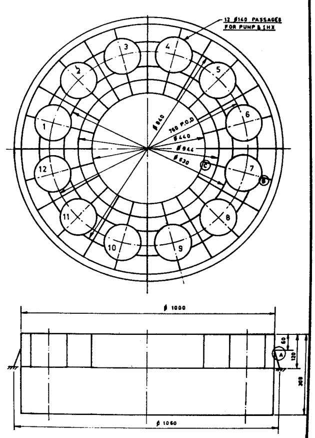
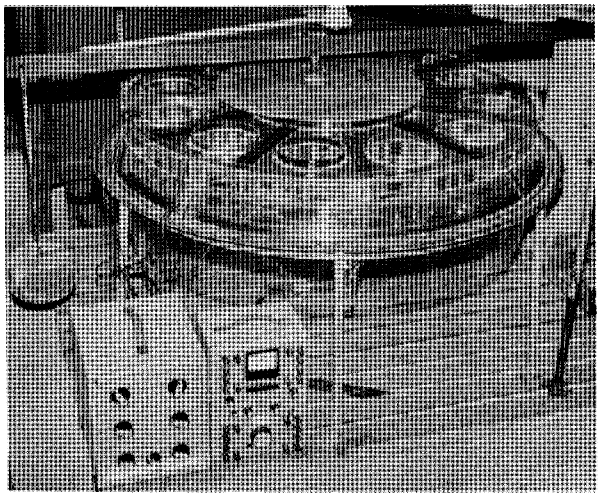


FIG.4



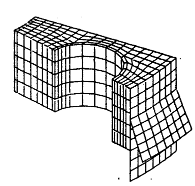
ROOF SLAB-MODEL

FIG.5



ROOF SLAB-MODEL (PERSPEX)

FIG-6



FINITE ELEMENT MESH OF THE 15° OF THE ROOF SLAB MODEL

FIG.7