Transactions, SMiRT 19, Toronto, August 2007 Paper # F03/2

ANALYSIS AND DESIGN OF PFBR RAFT FOR TEMPERATURE LOADS

H.I.Abdul Gani[1], Ramanjaneyulu K.V.S.[2], C.Sivathanu Pillai.[3]
Civil Engineering Division, Reactor Engineering Group, Indira Gandhi Centre for Atomic Research, India

ABSTRACT

PFBR, prototype fast breeder reactor, is a 500 MW(e) fast reactor meant for power generation on commercial scale. It is the first breeder reactor in India. Various safety related buildings in the complex of PFBR are interconnected to enhance Safety, Strength and economy, resulting in a large shear wall framed structure, referred as Nuclear Island Connected Buildings (NICB).

NICB comprises of Reactor Containment Building (RCB), Steam Generator Buildings (SGB 1 & 2), Fuel Building (FB), Rad Waste Building(RWB), Electrical Buildings(EB 1 & 2), and Control Building (CB). NICB is 83.2 m (East – West direction) X 92.6 m (North south direction) in plan, with varying heights for different buildings, all of which are founded on a 3.5 m thick common base raft, at 18m below finished ground level. Predominantly, it comprises of raft and shear walls as structural elements, besides few beams and trusses. For analysis, a three dimensional finite element model of the structure consisting of plate elements, beam elements, mass elements and spar elements is developed. Main loads for analysis are dead loads, imposed loads, seismic loads, accident loads and temperature loads due to operation. As the structure is large, effects of shrinkage too are considered for design.

Salient aspects regarding analysis and design for temperature loads and shrinkage effects, with reference to raft and shear walls are discussed in this paper.

INTRODUCTION

In India, expansion joints are provided if the structure's size exceeds 45 m. For structures of size less than 45 m, operating temperatures due to solar radiation as well as shrinkage effects are ignored. As the size of NICB structure for PFBR is more than 45m, it is required to account the stresses due to temperature and shrinkage.

Analysis and Design for temperature loads is different from that of conventional loads. For conventional loads such as dead loads, imposed loads, earth pressure loads, seismic loads, and accident loads, analyses are performed and stress resultants are obtained for each analysis. These stress resultants are combined to compute design stress resultants. Reinforcement is computed for the design stress resultants. This method of arriving at reinforcement for design stress resultants is conservative, with temperature loads.

Analysis for temperature loads result in stresses in members. For typical shell elements, it results in membrane stresses and bending stresses. These stresses comprise of two components. Stresses due to restraints from other members, and stresses developed to restrain other members from compatibility. For simplicity, first category of stresses are termed as temperature stresses, while the second category are termed as compatibility stresses.

Temperature stresses depend on the temperature rise/drop of the fiber as well as the restraint condition. If a fiber, be it concrete or steel, is subjected to a temperature rise and it is prevented from expansion the fiber will be in compression. On the other hand, if a fiber is subjected to temperature drop and prevented from compression, the fiber will be in tension. As both steel and concrete have near equal thermal expansion coefficients, there is no force transfer from steel to concrete or concrete to steel, which is not the case for non temperature loads. Estimation of stresses in reinforcement in concrete section due to temperature loading, involves estimation of strain at the location of reinforcement, and multiplying the strain with Young's modulus of steel. In case of non temperature loads, reinforcement is to be computed assuming a neutral axis, ignoring concrete section on tension side, and maintaining equilibrium of the section with the above assumptions.

Temperature stresses are independent of percentage of reinforcement provided in a section. In case of non temperature loads, stress in reinforcement decreases for higher reinforcement which is not true for temperature loads. Thus, for temperature loads, stresses alone can be estimated and does not involve computation of reinforcement.

Estimation of stresses due to shrinkage is a two step process as RCC is composed of materials of different shrinkage characteristics, viz., concrete and steel. Concrete sections of different sizes undergo shrinkage of different magnitudes, resulting in interaction effects. Besides this, at the locations of restraints (due to geometry as well as soil resistance), further stresses develop in concrete. However, reinforcement placed inside concrete does not undergo any inherent shrinkage. Thus, shrinkage of surrounding concrete is an externally applied loading. To estimate stresses in reinforcement due to shrinkage, a two step process is involved. First step is analyzing the structure for shrinkage effects of concretes. This analysis results depict the post shrinkage look of the structure. Now, these deformations are to be imposed on the original structure, which represent the reinforcement inside the structure, to elicit the stresses in reinforcement.

Raft of PFBR is a massive structural member where the effects of temperature as well as shrinkage are of considerable magnitude.

DESCRIPTION OF NICB

Key plan of NICB is shown in fig.1. Three dimensional finite element model of the same for analysis is shown in fig.2. Elastic properties of various materials used in the analysis are furnished in table 1. Analysis is carried out by two independent agencies, one with a refined model and the other with a coarse model. Coarse model is used for verification of the analysis. Fig.1 as well as Fig.2 are from coarse model.

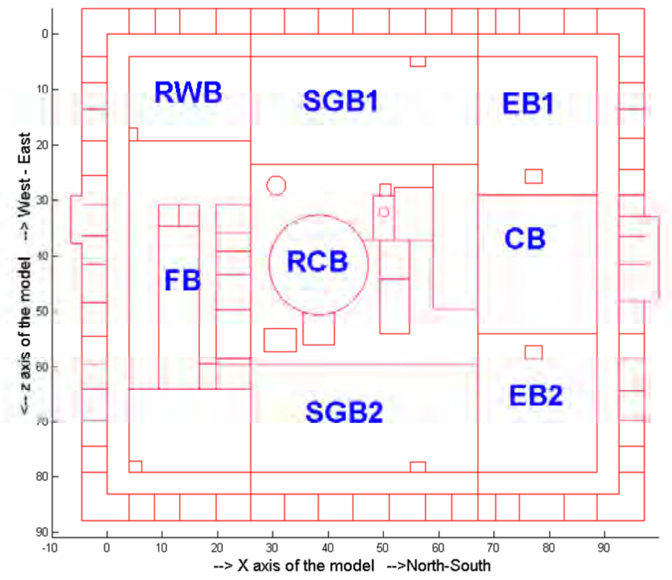

Fig.1 Key plan of NICB

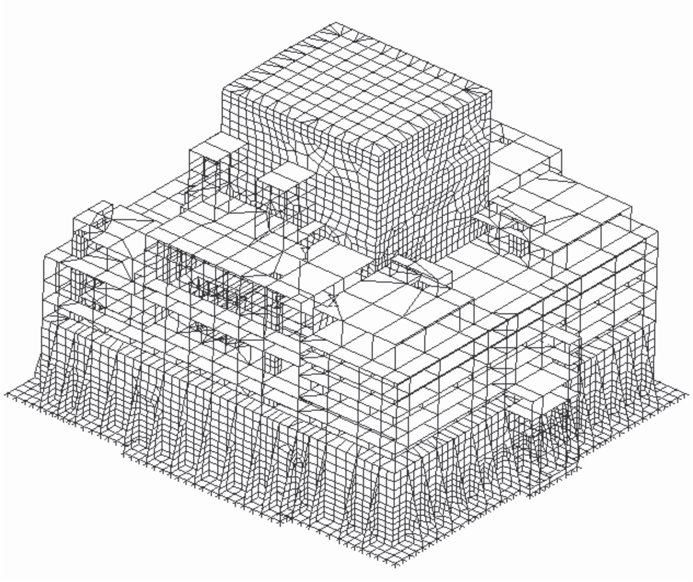

Fig.2 Finite element model of NICB

Table1 . Elastic properties of various materials

Sl. No	Material	Elastic modulus (kPa)	Poisson's ratio	Coefficient of thermal expansion
1.	Reinforced concrete of M30 grade	27.4×10^{6}	0.2	$9.5 \text{ X } 10^{-6}$
2.	Reinforced concrete of M45 grade	$33.54 \text{ X } 10^{6}$	0.2	$9.5 \text{ X } 10^{-6}$
3.	Heavy concretes (grade H30 / SH30)	27.4×10^{6}	0.2	$11 \text{ X } 10^{-6}$
4.	Structural steel	2×10^{8}	0.3	$12 \text{ X } 10^{-6}$

STRENGTH DESIGN

The design shall satisfy the requirement of strength by complying with the following criteria, as per AERB code[1]

$F_{sd} \leq R_{sd}$

(1)

Where,

Fsd = design value of applied loading for a particular failure mode of a given limit state

Rsd = design value of structural resistance of members

Design load for i^th^ load combination is given by the following expression:

$F_{sdi} = \Psi_i \Sigma \gamma_{fij} F_{ij}$

(2)

Where,

Ψ_i = load combination factor,

γ_{fij} = partial safety factor of load(shown in the table below)

F_{ij} = j th characteristic load for i th combination obtained from analysis

Table 2 shows the load combination factors to be used for design

Table 2 load combination factors for design

	Load factors γfij								partial safety factors for materials	
Load combination	**Comb factor Ψi**	**Dead Loads**	**Loads (full and zero)**	**Temperature Loads**	**OBE/ Severe wind**	**SSE / extreme wind**	**Accident Loads**	**Aircraft impact missiles**	**concrete**	**steel**
Normal Load combination (LC1)	1.00	1.4	1.6						1.50	1.15
	0.75	1.4	1.6	1.4						
Severe Environmental Load combination (LC2)	1.00	0.9			1.6					
	1.00	1.4	1.6		1.6					
	0.75	1.4	1.6	1.4	1.6					
Extreme environmental Load combination (LC3)	1.00	0.9				1			1.30	1.00
	1.00	1.0	1.0			1				
	1.00	1.0	1.0	1		1				
Abnormal load combinations (LC4)	1.00	1.0	1.0				1.25			
	1.00	1.0	1.0	1				1		

From the load combination factor in the table above, it is clear that for normal and severe environmental load combinations, inherently a safety margin of 25% on stresses are apportioned for temperature stresses. If permissible stresses allowed are 360N/mm^2 for normal and severe environmental load combinations, inherently 25% of 360 N/mm^2, i.e., 90 N/mm^2 is apportioned for temperature loads.

Each degree rise/fall in temperature at reinforcement location, when fully restrained, results in a stress of E (Young's modulus) times α (coefficient of thermal expansion), which is equal to 2.24 N/mm^2. Other wise, Normal and severe environmental load combinations implicitly accommodate a temperature rise/fall of at least 40^0 (90/2.24). This is a fairly large number. If stress free temperature is assumed as 30^0, then for temperatures up to -10^0, temperature stresses would not govern for normal and severe environmental load combinations. For extreme environmental load combinations, temperature stresses influence the design provided the design is governed by this load combinations.

ANALYSIS FOR OPERATING TEMPERATURE SUMMER

Raft temperatures assumed for analysis is shown in Fig.3 Bottom surface is assumed to be at a temperature of 303 K. Interior of the buildings is assumed to be maintained at respective temperatures shown in the fig.3 from ventilation considerations. Same way, temperatures are applied on the walls, columns and beams also. Average rise in temperatures for raft is approximately, 4.3 K, which shall result in a maximum deformation of 2.06 mm in un restrained condition. Maximum deformation from analysis is 1.546mm. Deformation plot is shown in Fig.5. Further, membrane stress resultants for this load case, are compressive in nature, indicating that raft is restrained from it's expansion. These stresses predominantly are due to temperature, but not from compatibility.

ANALYSIS FOR OPERATING TEMPERATURE WINTER

Raft temperatures assumed for analysis is shown in Fig.4. Bottom surface is assumed at a temperature of 290 K. Interior of the buildings are assumed to be maintained at 302 k from ventilation considerations. Same way, temperatures are applied on the walls, columns and beams also. Average drop in temperatures for raft is approximately, 7 K, which shall result in a maximum deformation of 3.325 mm in un restrained condition. Maximum deformation from analysis is 2.4mm, shown in Fig.6. Further membrane stress resultants for this load case are tensile in nature, indicating that these stresses are developed due to restraint offered from soil. These stresses are predominantly due to temperature, but not from compatibility.

ANALYSIS FOR SHRINKAGE AND CREEP

Shrinkage and creep effect is simulated by a uniform drop in temperature of 3.5 K. Deformations for the above drop in temperature, from analysis is 1.2 mm. Raft, as a whole is contracting towards the centre. Deformation plot for shrinkage effects look similar to Fig.6. Net size of the raft is decreased, which imply that steel would be in compression. As the membrane stress resultants from analysis are tensile in nature, these values need not be taken in to account for design. Maximum moments in N-S and E-W directions are 1466 and 1444 kNm/m respectively.

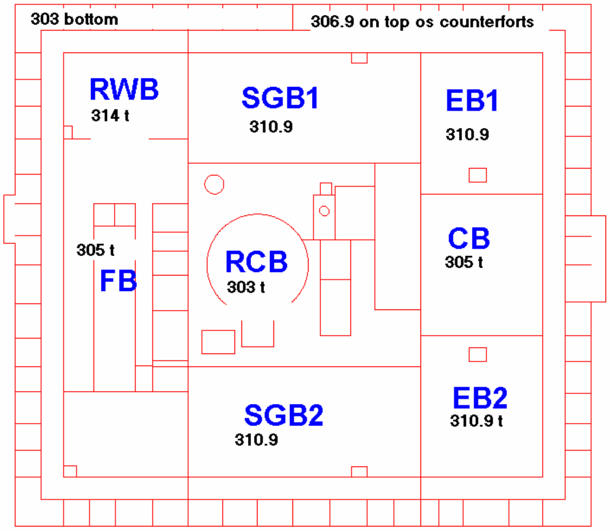

Fig.3: Temperatures during summer

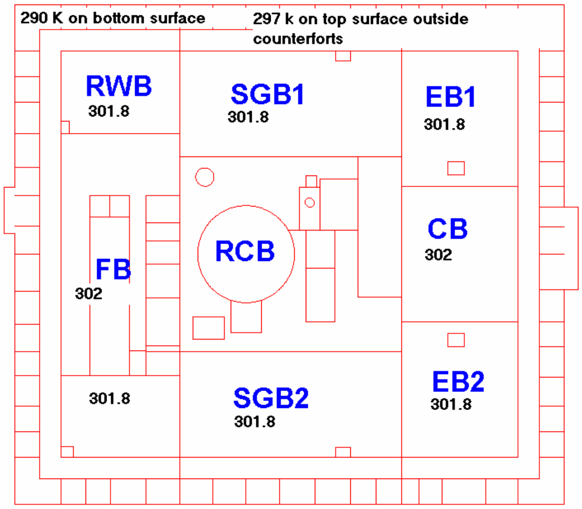

Fig.4 Temperatures during Winter

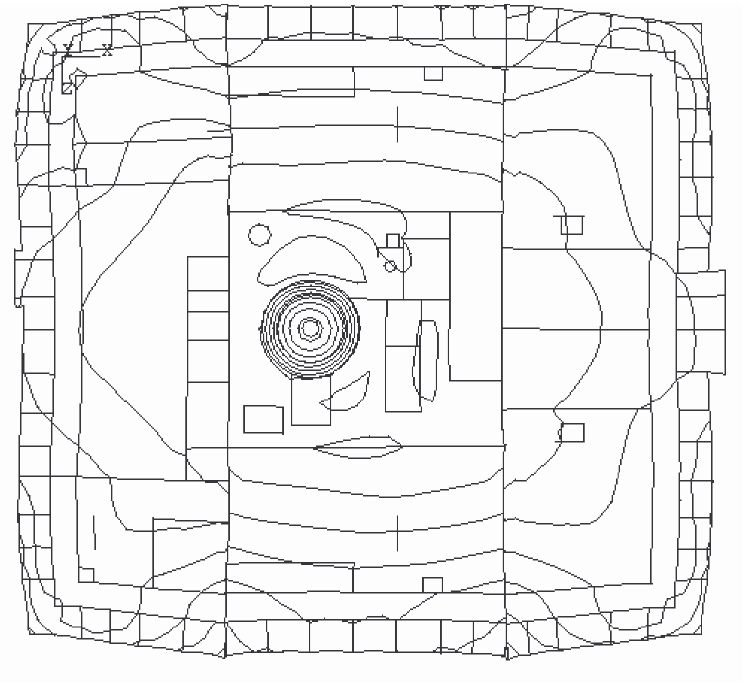

Fig. 5 Deformation of raft for Operating Temperature (Summer)

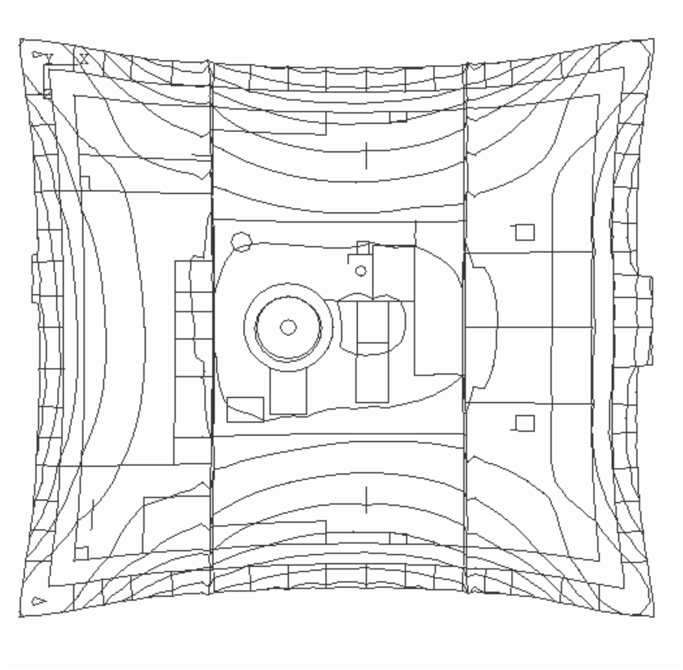

Fig.6 Deformation of raft for Operating Temperature (Winter)

DESIGN

To study the influence of operating temperatures and shrinkage, design is carried out excluding temperature load combinations. For this case, severe environmental load combinations govern the design for nearly 65% of the elements. Minimum reinforcement as per [1] of 0.18% is adequate for all the elements from strength considerations.

Design is carried out including temperature load combinations in conventional way. Briefly, the procedure is, combine stress resultants of all the load cases, including temperature load cases, to result in design stress resultants and obtain reinforcement. This steel is used for detailing. With this method, LC2 combinations govern the design for all the elements. For a typical element, reinforcement demand from gravity, uplift, Temperature, shrinkage, operating basis earth quake (OBE)/ safe shutdown earthquake (SSE), accident, and descritisation margin is shown in Fig.7. Reinforcement from design is more than minimum reinforcement for all the elements.

Design is also carried out with temperature load combinations, ignoring membrane stress resultants of temperature load cases. For the typical element, reinforcement demand from gravity, uplift, Temperature, shrinkage, OBE/SSE accident, and descritisation margin is shown in Fig.8. Reinforcement from design is less than minimum reinforcement for most of the elements.

Design is also carried out by keeping stress margin from temperature load cases. For the typical element, stresses in reinforcement from strain considerations is worked out for summer temperature loading, winter temperature loading and shrinkage effect are 0.35 N/mm2, 1.1 N/mm2 and 2.2 N/mm2, (Total 3.65 N/mm^2) which are negligible. Reinforcement demand for this negligible stresses, for the typical element is shown in Fig.9 for the element. Theses stress could enhance the steel demand for LC3 load combinations by a maximum of 2%. Fig.9 is the reinforcement demand for the typical element from this method. With this method, reinforcement requirement for PFBR raft, from strength combinations is lower than minimum reinforcement specified in ref.1 for all the elements. However, extreme environmental load combinations, LC3 govern the design for 96% of the elements.

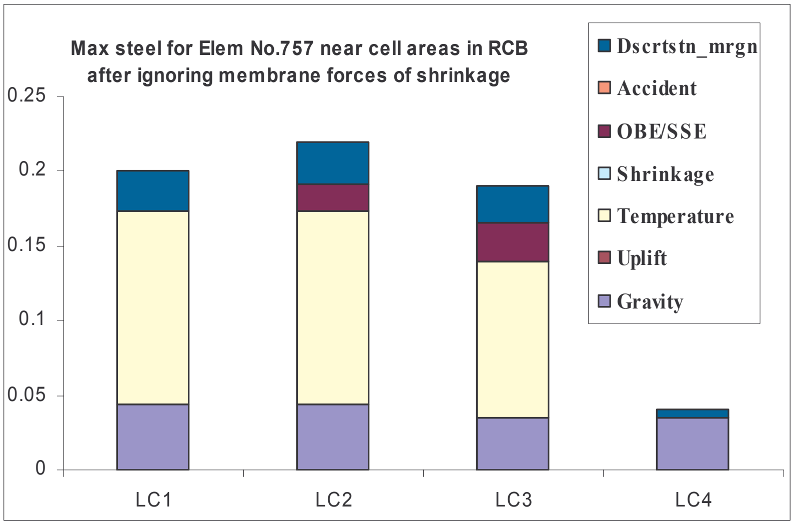

Fig.7 Reinforcement demand from various load cases for a typical element (Conventional method)

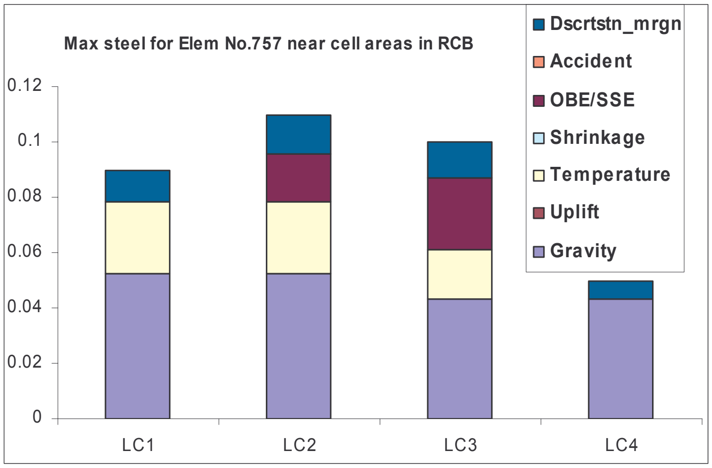

Fig.8 Reinforcement demand from various load cases for the typical element (Conventional method, ignoring membrane stress resultants due to temperature and shrinkage load cases)

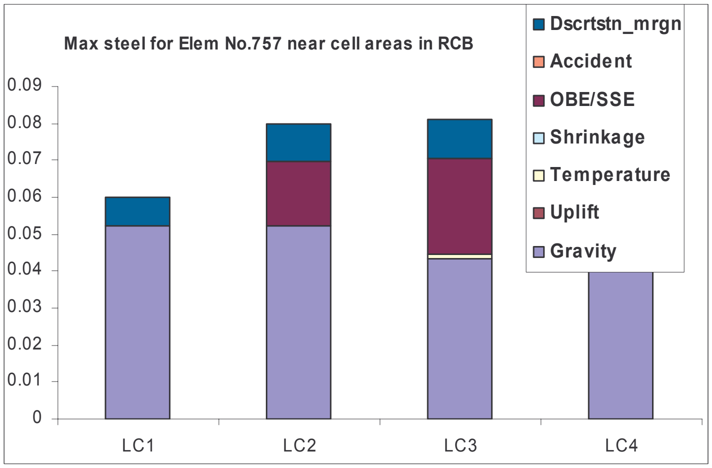

Fig.9 Reinforcement demand from various load cases for the typical element (by keeping stress margin)

CONCLUSIONS:

Aspects concerning design for temperature loads are explained. Design of massive reinforced concrete elements, such as PFBR raft, for temperature loads and shrinkage involve proper understanding of the analysis results. For normal and severe environmental load combinations, temperature loads, including shrinkage do not govern the design for base raft of PFBR, if stress margin approach is adopted. For extreme environmental load combinations, Temperature loads have an influence in increasing the steel to the extent of 2%. With stress margin approach for temperature loads, reinforcement demand for PFBR raft is lower than the minimum requirement. For PFBR raft, detailing of reinforcement is done in extremely conservative way.

REFERENCES:

AERB safety standard, AERB/SS/CSE-1, “Design of concrete structures important to safety of nuclear facilities”