Comparison Of Design Of A Reactor Building Raft Of A Typical Indian PHWR Using The Provisions Of French Code RCC-G And ASME Code

Roy Raghupati, Verma U.S.P. & Warudkar A. S. [1],
Mapari H. A., Palekar S. M. & Subramanian K. V. [2]

1) Nuclear Power Corporation of India Limited, Mumbai, India
2) TCE Consulting Engineers Limited., Mumbai, India

ABSTRACT

This paper compares the design philosophies of the French code, RCC-G with that of ASME Section III Div. 2 and presents the comparison of the designs of a Reactor Building (RB) Raft of a typical Pressurised Heavy Water Reactor (PHWR) under construction in India performed according to these two codes.

INTRODUCTION

Reactor Building Raft is classified as a safety related structure as it forms a part of the primary containment system. It is designed in accordance with the provisions of ASME Boiler & Pressure Vessel Code Section-III Div. 2. The inner and outer containment structures are designed as per the provisions of the French code, RCC-G. The boundary regions between the raft and the containment structures where elements are designed by different codes are required to be checked with the provisions of the other code. Further, since Raft is not provided with metallic or non-metallic liner on the top surface, it is required to be designed as a leak tight structure. With the above considerations, design of raft, though performed as per ASME Section III, Div. 2 is, further, required to be checked using the provisions of French code, RCC-G. This paper presents a comparison of the design philosophies of the French Code RCC-G with that of ASME Section III Div. 2. The design provisions of the above two codes are also compared with the help of summarised results of typical design calculations pertaining to the Reactor Building Raft.

GEOMETRY OF RAFT

The PHWRs under construction in India have a double containment system where the inner containment structure is in prestressed concrete and the outer containment structure is in reinforced concrete. Both the Containment structures along with the Internal Structures are supported on a single circular reinforced concrete raft foundation. Top of raft is located about 15 metres below Ground Level and the raft is founded on competent rock strata. The raft has a diameter of 62.0 metres and a uniform thickness of 5.5 metres. The concrete for the raft has 28 days compressive cube strength of 60 MPa.

LOADING ON RAFT

The following loads are considered for the design of the reactor building raft.

1. Dead load comprising of self weight of the raft and dead load of the superstructures.

2. Live load comprising of the live load acting on the raft and live load transferred from the superstructures. Seismic loads are obtained by considering 50% live load in the mass lumping calculations for dynamic analysis. Seismic load combinations are also performed without live load.

3. Test pressure loads on Inner Containment Wall (ICW) are transferred to the raft. Test pressure load on the surface of the raft, within ICW, is applied directly on FEM model of the raft.

4. Accident pressure loads on ICW and OCW are transferred to the raft. The load on the surface of the raft, within ICW, is applied directly on FEM model of the raft.

5. Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE) comprise of three components, one each along East-West and North-South axes and one vertical component. Vertical and horizontal forces and moments due to the earthquake loads on superstructures are transferred to the raft.

6. External water pressure due to the subsoil water is considered.

7. Active earth pressure due to embedment is considered on the OCW and the reactions are transferred to the raft.

8. Loads due to dynamic increment in active earth pressure (due to earthquake) are considered.

9. Pool swelling loads due to accident condition are considered.

10. Thermal loads due to accident condition are considered.

11. Wind loads are ignored, as reaction due to wind loads on raft is much smaller than that due to seismic loads.

IDEALISATION OF RAFT

The raft is analysed using thick shell idealisation for all load combinations. The raft is divided into a number of quadrilateral finite elements. The finite element used here is an eight noded isoparametric structural shell element having both in-plane and out of plane capabilities. The element has six degrees of freedom per node (three translations and three rotations). Effects due to shear deformations are included in the analysis. Raft being supported on soil springs, is analysed for a combined effect of load cases with unity load factor for each load combination. For the purpose of design, maximum load factor for any load case in a load combination is taken as the load factor for that load combination.

DESIGN PHILOSOPHY OF ASME SECTION III DIV. 2

The design philosophy of the ASME code is based on allowable stress method wherein the design of the containment is checked both for unfactored service load combinations as well as factored load combinations for the strength requirements. The stress calculation in the concrete as well as in the reinforcing steel is carried out considering linear analysis of the section. Cracked section philosophy as adopted for normal reinforced concrete section design under flexure in allowable stress approach is followed. Tensile strength of concrete is neglected in flexural calculations. The shear design is carried out comparing the developed nominal shear stress with the allowable shear stress specified in the code. The service load combinations pertaining to the design of raft include construction, normal operating and test conditions. Factored load combinations cover the load combinations under abnormal, severe environmental, abnormal & severe environmental, extreme environmental and abnormal & extreme environmental situations. Table-1 gives the typical load combinations considered in the design of the RB raft as per ASME, section-III, Div. 2. Each seismic load combination listed in the table is analysed for two component (one horizontal and one vertical) and three component earthquake motions at the input level. Method of linear combination (100-40-40 method) has been used for analysis purpose.

DESIGN PHILOSOPHY OF FRENCH CODE RCC-G

The design philosophy of the French code RCC-G(1) is based on limit state concept where the response of the structure both under load combinations pertaining to limit state of serviceability and limit state of strength are checked. The various limit states specified in the French code RCC-G(1) along with the supporting document BAEL(2) are adopted for designing the structural elements. The various load cases and load combinations given in RCC-G are reviewed and the relevant combinations are summarised in Table-2. Half SSE load case mentioned in RCC-G is treated as equivalent to OBE load case considered in the design of raft as per ASME. It may be observed that RCC-G considers load combinations pertaining to abnormal, OBE, SSE and a combination of abnormal and extreme environmental load combinations as service combinations.

Table 1. Load Combinations as per ASME

SL.No.	Design Condition	Dead Load	Live Load	Test Pressure & Temperature	Operating Temperature	Peak Accident Pressure	Accident Temperature	OBE	SSE	Pool Swell	Uplift Water Pressure
SERVICE LOADS											
1	Construction	1.0	1.0								1.0
2	Normal	1.0	1.0		1.0						1.0
3	Test	1.0	1.0	1.0							1.0
FACTORED LOADS											
4	Abnormal	1.0	1.0			1.5	1. 0			1.0	1.0
5	Severe Environmental	1.0	1.3		1.0			1.5			1.0
6	Abnormal & Severe Environmental	1.0	1.0			1.25	1.0	1.25		1.0	1.0
7		1.0	1.0		1.0			1.0			1.0
8	Extreme Environmental	1.0	1.0		1.0				1.0		1.0
9	Abnormal & Extreme Environmental	1.0	1.0			1.0	1.0		1.0	1.0	1.0

Notes:

1. Each design condition is analysed for appropriate cases of uplift water pressure (a)Normal (b)Zero uplift water pressure.

2. Load combination Sl.No.5 is more severe in comparison to Load combination Sl.No.7. Hence the Load combination Sl.No.7 is ignored for the purpose of analysis.

3. Peak Accident Pressure effects are not considered along with Accident Temperature effects in a combination because their peak effects occur at two different time instants.

4. Prestress effect from ICW is included in Dead Load.

The design of sections under limit state of strength is based on the assumption of linear strain distribution across the section in which the maximum strain in bending in the extreme compression fibre is limited to 0.0035. The partial safety factors for concrete and reinforcing steel are 1.5 and 1.15 respectively. A rectangle-parabolic compressive stress block is considered in the design of section under flexure. The design against shear as per RCC-G is accomplished only under limit state of strength. The factored developed shear stress is compared against the allowable stress.

COMPARISON OF DESIGNS OF RB RAFT AS PER ASME AND RCC-G WITH RESPECT TO CRITICAL DESIGN CONDITIONS

LOAD COMBINATIONS FOR STRENGTH DESIGN

It is observed that load combinations as per RCC-G are closely matching with those as per ASME except a few static load combinations that have higher load factors as per RCC-G. For each RCC-G combination, a corresponding ASME combination is identified and indicated in Table- 3 along with its load factor. The same ASME combinations but with RCC-G load factors are then checked as per strength design method of RCC-G. It could be noted that load factors for OBE and accident conditions is 1.35 as per RCC-G as against 1.5 as per ASME.

Table 2. Load Combinations as per RCC-G

COMBINATIONS AS PER RCC-G													
SRNO	DESIGN CONDITION	EQUATION No	DEAD LOAD	LIVE LOAD	TEST PRESSURE	OPERATING TEMPERATURE	ACCIDENT PRESSURE	ACCIDENT TEMPERATURE	OBE	SSE	POOL SWELL	UP-LIFT
1	Construction	1.4.3a	1.35	1.50								0.00
2	Construction	1.4.3a	1.00	0.00								1.30
3	Operation	1.4.3b	1.35	1.50		0.80						0.00
4	Operation	1.4.3b	1.00			0.80						1.30
5	Half-SSE I.e. OBE	1.4.3e	1.35	1.30		0.80			1.35			0.00
6	Half-SSE I.e. OBE	1.4.3e	1.00			0.80			1.35			1.30
7	Highest Water Table	1.4.3f	1.35	1.30		0.80						0.00
8	Highest Water Table	1.4.3f	1.00			0.80						1.50
9	Test	1.4.4a	1.35	1.30	1.00							0.00
10	Test	1.4.4a	1.00		1.00							1.30
11	Accident - LOCA	1.4.4b	1.35	1.30			1.35	1.35			1.35	0.00
12	Accident - LOCA	1.4.4b	1.00				1.35	1.35			1.35	1.30
13	SSE	1.4.3g	1.00	1.00		0.50				1.00		0.00
14	SSE	1.4.3g	1.00			0.50				1.00		1.00
15	SSE + acc LOCA	1.4.3m	1.00	1.00			1.00	0.50		1.00	1.00	0.00
16	SSE + acc LOCA	1.4.3m	1.00				1.00	0.50		1.00	1.00	1.00

Notes :

1] Wind and snow load cases are not considered.
2] Half SSE load effects are treated equivalent to OBE load effects
3] LOCA / MSLB effects are treated equivalent to accident pressure effects
4] Accident Temperature load also includes effect of operating temperature
5] Pool swell effects are considered alongwith accident condition.
6] Each of SSE and OBE combination is expanded to include all combinations due to 3-component as well as 2-component motion.
7] Prestress is considered as a part of Dead Load.

Table 3. Comparison of Load Combinations as per RCC-G and ASME

SRNO	DESIGN CONDITION	RCC-G COMBINATIONS		CORRESPONDING ASME COMBINATIONS	
		EQUATION No	MAXIMUM FACTOR	COMBINATION No	MAXIMUM FACTOR
		FROM TABLE-2		FROM TABLE-1	
1	Construction	1.4.3a	**1.50**	1	1.00
2	Construction	1.4.3a	**1.30**	1	1.00
3	Operation	1.4.3b	**1.50**	2	1.00
4	Operation	1.4.3b	**1.30**	2	1.00
5	Half-SSE I.e. OBE	1.4.3e	1.35	5	**1.50**
6	Half-SSE I.e. OBE	1.4.3e	1.35	5	**1.50**
7	Highest Water Table	1.4.3f	**1.35**	2	1.00
8	Highest Water Table	1.4.3f	**1.50**	2	1.00
9	Test	1.4.4a	**1.35**	3	1.00
10	Test	1.4.4a	**1.30**	3	1.00
11	Accident - LOCA	1.4.4b	1.35	4	**1.50**
12	Accident - LOCA	1.4.4b	1.35	4	**1.50**
13	SSE	1.4.3g	1.00	8	**1.00**
14	SSE	1.4.3g	1.00	8	**1.00**
15	SSE + acc LOCA	1.4.3m	1.00	9	**1.00**
16	SSE + acc LOCA	1.4.3m	1.00	9	**1.00**

LOAD COMBINATIONS FOR SERVICEABILITY

It is observed that the serviceability combinations are same as per both ASME and RCC-G except SSE combinations. Hence, all ASME combinations are checked (load factor is taken as unity) as per serviceability criteria of RCC-G. It could be noted that SSE seismic combinations are treated as service combinations as per RCC-G whereas they are not service combinations as per ASME.

DESIGN FOR FLEXURE

ASME uses working stress method for arriving at flexural reinforcement requirement whereas as per RCC-G, calculations for reinforcement are performed based on BAEL Rules employing limit state method. Strength design is performed for maximum positive and negative principal bending moments obtained from static, SSE and OBE combinations. It is observed that the area of reinforcement obtained as per RCC-G is less than that as per ASME design. A comparison of design results with respect to some critical design conditions is presented in Table-4.

DESIGN FOR SHEAR

Shear strength of concrete is taken into account by ASME but it is neglected by RCC-G. As per RCC-G, calculations for reinforcement are performed based on BAEL Rules. As per BAEL, when a slab includes reinforcement against shear forces and when cracking is considered to be detrimental, the limiting value of nominal shear stress is calculated as 3.00 MPa. Also, BAEL specifies a maximum limit on spacing of shear reinforcement bars as 0.9 times effective depth of section or 400 mm. But it also recommends that the limit of 400mm should be increased in the case of exceptionally deep beams. It is observed that maximum nominal shear stress in concrete is 1.28 MPa as against allowable shear stress of 3.00 MPa. Since the raft is cast in six layers, it is required to provide shear reinforcement from interface shear considerations. The requirement of minimum shear reinforcement as per provisions of BAEL is taken into account while performing calculations for shear reinforcement. It is observed that shear check is satisfied as per RCC-G and the shear reinforcement obtained as per RCC-G is less than that as per ASME design.

SERVICE STRESS CALCULATIONS

It is observed that load combinations as per RCC-G are matching with those as per ASME except the SSE combinations. The SSE combinations are classified as service combinations as per RCC-G whereas as per ASME they are not treated as service combinations. For construction stage, stresses in concrete are calculated by assuming that the

Table 4. Comparison of Results of Critical Design Conditions

SRNO	DESIGN CONDITION	ASME	RCC-G
1	**Flexure**		
	Method used	Working Stress Method	Limit State Method
	Area of tension reinforcement	10058 mm^2	9325 mm^2
2	**Shear**		
	Maximum allowable shear stress	1.54 MPa	3.00 MPa
	Maximum shear reinforcement	2.41 mm^2 / mm	2.32 mm^2 / mm
3	**Serviceability**		
	Allowable compressive stress in concrete	21.6 MPa	24.0 MPa
	Allowable tensile stress in steel	207.5 MPa	260.0 MPa

section is uncracked. The stress is calculated as service moment divided by uncracked section modulus. The calculated stresses are checked with respect to allowable stresses and found to be within limits. Stresses in concrete and reinforcement steel are calculated for service stage combinations. Allowable stresses are obtained from crack-width considerations as per BAEL. The section is assumed to be cracked. The location of neutral axis is determined by equating area-moments on compression and tension sides. In a small localised zone of the raft, the reinforcement provided as per ASME fails to satisfy serviceability criteria of stresses as per RCC-G. This is because of the fact that SSE combinations, giving high stresses and hence being critical, are considered as service combinations as per RCC-G whereas as per ASME, SSE combinations are not treated as service combinations. Further, the allowable tensile stress in steel for service combinations from cracking considerations is 260 MPa as per RCC-G whereas as per ASME, for factored combinations, it is 373.5 MPa. To overcome this problem, the diameter of reinforcing bars is increased in this localised zone of the raft to get additional area of reinforcing steel. The calculated stresses in concrete and steel are found to be within limits.

SUMMARY AND CONCLUSION

This paper presents a comparison of the design philosophies adopted in RCC-G and ASME code in details and also compares the various design and analysis parameters for the various applicable loads. The design provisions of the above two codes for the different actions under various load combinations are also compared with the help of typical design calculations pertaining to the Reactor Building raft of a typical PHWR being designed and constructed in India. The critical provisions in both the codes, which govern the design, are identified and discussed in the present paper.

It is observed that load combinations as per RCC-G are closely matching with those as per ASME except a few static load combinations that have higher load factor as per RCC-G. RCC-G treats SSE combinations as service load combinations whereas as per ASME, SSE combinations are not treated as service combinations.

Philosophies for evaluating area of reinforcement as per RCC-G in case of flexure as well as shear are different than those as per ASME. Flexural analysis of a section is performed by limit state method as per RCC-G whereas as per ASME, it is performed by working stress method. The area of reinforcement obtained as per RCC-G is less than that as per ASME design.

As per ASME, shear strength of concrete is taken into account whereas as per RCC-G, it is neglected. It is observed that shear check is satisfied as per RCC-G and the shear reinforcement obtained as per RCC-G is less than that as per ASME design.

Under serviceability check, it is observed that in a small localised zone of the raft, the reinforcement provided as per ASME fails to satisfy serviceability criteria of stresses as per RCC-G. This is because of the fact that SSE combinations, giving high stresses and hence being critical, are considered as service combinations as per RCC-G whereas as per ASME, SSE combinations are not treated as service combinations. Further, the allowable tensile stress in steel under service condition from cracking considerations is 260 MPa as per RCC-G whereas as per ASME, under fatored load combinations, it is 373.5 MPa. To overcome this problem, extra reinforcement is required in this localised zone.

ACKNOWLEDGEMENT

The authors are grateful to the management of Nuclear Power Corporation of India Ltd. and TCE Consulting Engineers for their constant encouragement and for kindly giving permission to publish this paper.

REFERENCES

1. Design and Construction Rules for Civil Works of PWR Nuclear Islands : RCC-G Vol-1 : Design , by EDF, July 1988 Edition

2. Technical Rules for design and calculation of reinforced concrete structures and buildings using limit states method : B.A.E.L., by AFNOR, October 1983 Edition

3. ASME – Boiler and Pressure Vessel code Section III, Div 2-1989 Edition