Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Seismic Qualification of Coolant Channel Subassembly and Fuelling Machines in Coupled Mode for Indian PHWR

A.K. Vyas, S.M. Ingole, N. Prasad, A.G. Chhatre, H.S Bhambra, K.B. Dixit, A.B. Ghare and A. Sanatkumar

Nuclear Power Corporation of India Limited, India

ABSTRACT

In a PHWR, a pair of remote controlled fuelling machines, one at each end of the reactor coolant channel is used for ON POWER refuelling. The behavior of mass of fuelling machines at two ends of the coolant channel during seismic event on the reactor coolant channel is a concern to the designer. This paper deals with seismic qualification of coolant channel and fuelling machines in coupled mode for ON REACTOR condition.

1. INTRODUCTION

The Indian pressurised heavy water reactors (PHWR) use natural Uranium as fuel. A pair of ON POWER remote controlled fuelling machines, one at each end of the reactor is used to achieve the above purpose. During the process of refuelling the fuelling machines are clamped to coolant channel subassembly and are in hydraulic communication with primary heat transport system after sealing plugs at both ends are removed. Any failure during this condition will affect boundary of primary system.

The fuelling machines used in first generation of Indian PHWRs consisted of two columns mounted carriage fitted with wheels which moves horizontally on rails embedded in the floor. As this configuration is unsuitable for withstanding seismic induced forces and moments, the fuelling machine is redesigned as bridge type with fixed columns for the current generation of 220 MWe PHWRs beginning with Narora Atomic Power Station (fig. 1). The same bridge concept has been adopted for the 500 MWe PHWR as well.

This paper deals with seismic qualification of coolant channel subassembly and fuelling machines in coupled mode for ON REACTOR condition using response spectra method. It also discusses the improvements made in fuelling machine and its support structures from seismic considerations. The paper covers the work related to both 220 MWe and 500 MWe reactors being built in India.

2. DESCRIPTION OF EQUIPMENT

The coolant channel subassembly consists of pressure tube connected to two end fittings by rolled joints (fig. 1). The pressure tube is co-axially supported in the calandria tube by four garter springs. The ends of the calandria tube are rolled in the calandria tube sheet. Each end fitting is supported in the end shield on journal bearings. One of the end fittings is fixed to the end shield by studs fastened to the yoke fitted on the end fitting.

Each fuelling machine (fig. 2) consists of head which contains complicated mechanisms for manipulating the fuel, plugs and other accessories. The front snout of head is provided to couple the head to the end fitting. The head is supported in support frame and gimbal subassembly. The gimbal subassembly consists of upper gimbal, lower gimbal and top beam and is suspended from the trolley. This arrangement provides linear axial movement of head towards and away from the coolant channel and limited angular rotation of head in horizontal and vertical plane. The trolley moves horizontally along a bridge by rack and pinion drive in 220 MWe design and by ball screw drive in 500 MWe design. The bridge is supported on four ball screws and moves vertically along two columns. Each column is supported on the floor and is tied to the nearest wall by tie members. This arrangement of linear movement of head in three directions and angular rotation in vertical and horizontal plane facilitates positioning and coupling of the head to any reactor channel for fuel loading/unloading operations.

After the fuelling machines are positioned, these are axially advanced towards the coolant channel and clamped on to the end fitting. Thereafter the drive is floated to avoid thermal load acting on the coolant channel.

The primary consideration of rigidity has been incorporated in the design of fuelling machines to limit the deflections during normal operating conditions. However, a number of modifications from seismic considerations are made. Some of these are (i) Originally an integral heavy radiation shield on top of the bridge was provided. This is modified and a separate roll-on shield (fig.1) is provided to reduce the weight of bridge. (ii) More tie members to reduce the unsupported lengths of columns are added. (iii) The drive brakes are rated such that the bridge or trolley does not overhaul during the seismic event. Also irreversible gearboxes are introduced in the bridge drive.

3. ANALYSIS OF FUELLING MACHINE AND COOLANT CHANNEL SUBASSEMBLY IN COUPLED MODE FOR 220 MWE PHWR

The seismic behavior of fuelling machines and calandria tube-pressure tube (CT-PT) assembly in coupled mode has been studied for KAIGA site by conducting response spectra analysis and different components checked against seismic induced forces and moments.

In the uncoupled mode analysis the structural integrity of the fuelling machine support structures is the major safety concern. However, in the coupled mode analysis the safety concern is focused on the integrity of (i) clamp between fuelling machine and end fitting (ii) rolled joint between end fitting and pressure tube (iii) pressure tube itself (iv) end fitting and yoke assembly.

3.1 Finite Element Modeling

The finite element model used for the analysis is given in the fig.3. The model has 590 elements and 438 nodes The fuelling machine structural members have been depicted using 3-D beam and spring elements. The CT-PT assembly (fig.4) and fuelling machine pressure components are modeled using pipe and coaxial elements. The fuelling machine is a complex mechanism involving number of joints with end release conditions. The exact end condition and relative motions at various joints like joint between ball screw and column, between ballscrew and bridge, trolley and vertical spindle by which gimbal subassembly is suspended from trolley etc. have been appropriately modeled.

3.2 Loading Conditions

The combined model of fuelling machine and CT-PT assembly has been analysed for dead load, operating basis and safe shutdown earthquake inertial load and seismic anchor moments. The enveloped and broadened response spectra are shown in fig.5 and 6. The loads experienced by the CT-PT assembly under reactor operating conditions viz. buoyancy load on calandria tube, axial force on calandria tube due to irradiation growth and creep, differential thermal expansion have been considered. The analysis also includes impact forces between the vertical reactor control devices and the CT-PT assembly.

3.3 Finite Element Analysis

A multi damping response spectra analysis has been conducted to get the seismic response and extract modal frequencies upto 33 Hz (Table-1). The multi damping analysis was essential as the damping values of fuelling machine structural members and CT-PT assembly (together with fuelling machine pressure retaining components) are different. The analysis also includes seismic anchor movements (SAM). Seismic response for closely spaced modes is accounted using grouping method (Ref. 1). The missing mass response which accounts for the mass which is not excited upto 33Hz has been calculated and is added to the previously calculated response upto 33 Hz by SRSS method to get the total response (Ref: 2).

3.4 Qualification and Results

The qualification of fuelling machine structural members and yoke studs of coolant channel subassembly has been carried out as per ASME section III division 1 subsection NF (Ref: 3). The qualification of CT-PT assembly together with fuelling machine pressure retaining components has been carried out as per ASME section III division 1 subsection NB (Ref: 3). The stresses experienced by the pressure tube and other pressure retaining components are given in Table-3 (Ref.4) The axial force induced in pressure tube during OBE and SSE is 9880 and 12100 kg respectively and meet the design requirements. The stresses experienced by critical structural members are given in Table - 2.

4. WORK RELATED TO 500 MWe PHWR

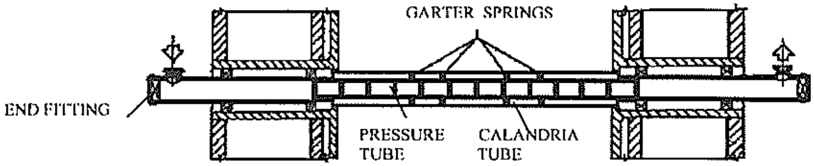
The seismic analysis of 500 MWe PHWR fuelling machine using detailed finite element model in uncoupled mode has been carried out for the Tarapur site and it meets the ASME codal requirements (Ref: 5). The seismic analysis of fuelling machines coupled to coolant channel subassembly using detailed finite element model is in progress. In the meantime, preliminary coupled mode analysis has been carried out for OBE and SSE using 2-D stick model (Ref:6). In this model (see fig. 7) fuelling machines are modeled with equivalent linear and rotational spring stiffness calculated from the uncoupled mode analysis. It is observed from the analysis that snubbers are required to be introduced between the fuelling machine and bridge in order to reduce the axial force in the coolant channel subassembly. The axial force in the pressure tube reduces from 44000 Kg to 11000 Kg. after introduction of the snubber of 14286 Kg /mm capacity. Further optimisation study is in progress.

5. CONCLUSION

Due to the floating condition of the fuelling machine head in axial direction when clamped on to the end fitting, the joint between the fuelling machine head and bridge becomes free in this direction. This results in the heavy mass of fuelling machine head connected at two ends of coolant channel determining the dynamic behavior of coolant channel subassembly during seismic event. In case of 220 MWe PHWR the weight of each head is about 7000 Kg. But in case of 500 MWe, the weight of head has more than doubled to 15000 Kg. The analysis shows that while the 220 MWe PHWR coolant channel meets the qualification requirements without any modification, the 500 MWe PHWR coolant channel meets the qualification requirements after introduction of snubber.

6. REFERENCES

1. Combined modal responses and spatial components in seismic response analysis USNRC RG 1.92.
2. R. P. Kennedy *Paper on response combination* NUREG 1061 vol. 4 APPENDIX-A of SMA 12211.02.R2.0.MARCE, 1984.
3. *ASME Boiler and pressure vessel code section III division-1 subsection-NB, subsection-NF and Appendices, (Appendix N)* 1989.
4. Shri A.K. Vyas et.al. *Qualification of KAIGA Fuelling Machine and Coolant Tube Assembly to ASME requirements* Nuclear Power Corporation of India Ltd. Report no. KAIGA/DC /35000/10, Dec. 1998.
5. Shri T. Purav et.al. *Seismic analysis of fuelling machine bridge and carriage and columns assembly of 500 MWe PHWR in unclamped condition* Bhabha Atomic Research Centre, India report No: BARC/1996/E/005, 1996.
6. *500 MWe NPP-Seismic Analysis of Coolant Channel coupled with FM Heads (Project No: P-568),* Department of Earthquake Engineering, University of Roorkee, India, Report No: EQ-96-07, 1996.



DETAIL OF COOLANT CHANNEL

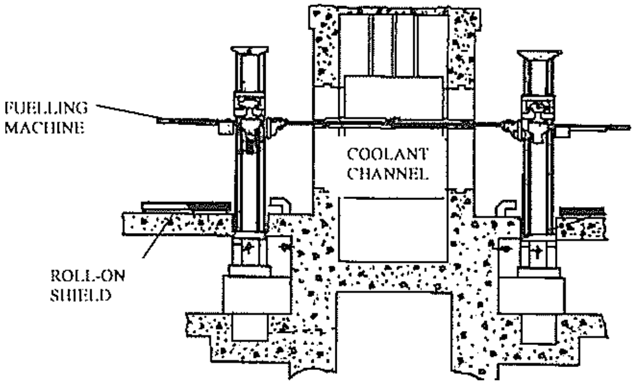


FIG.1 FUELLING MACHINE COUPLED TO COOLANT CHANNEL SUBASSEMBLY

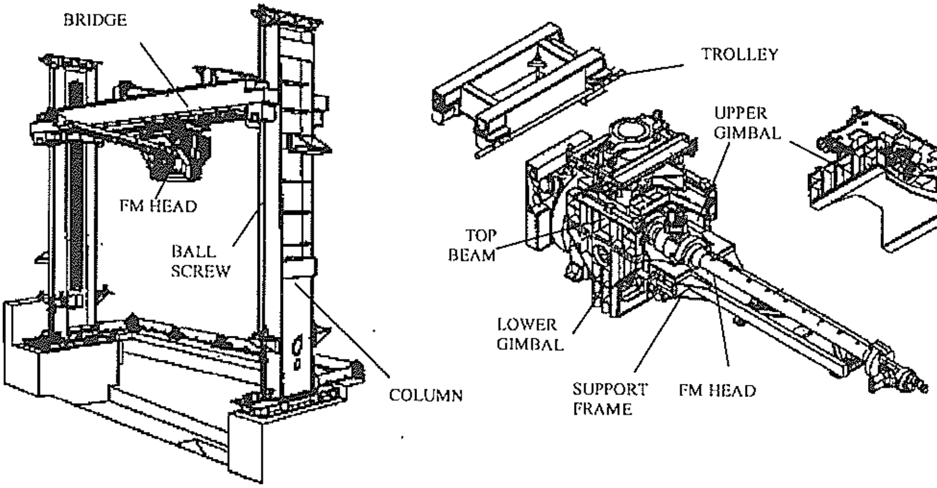


FIG.2 FUELLING MACHINE

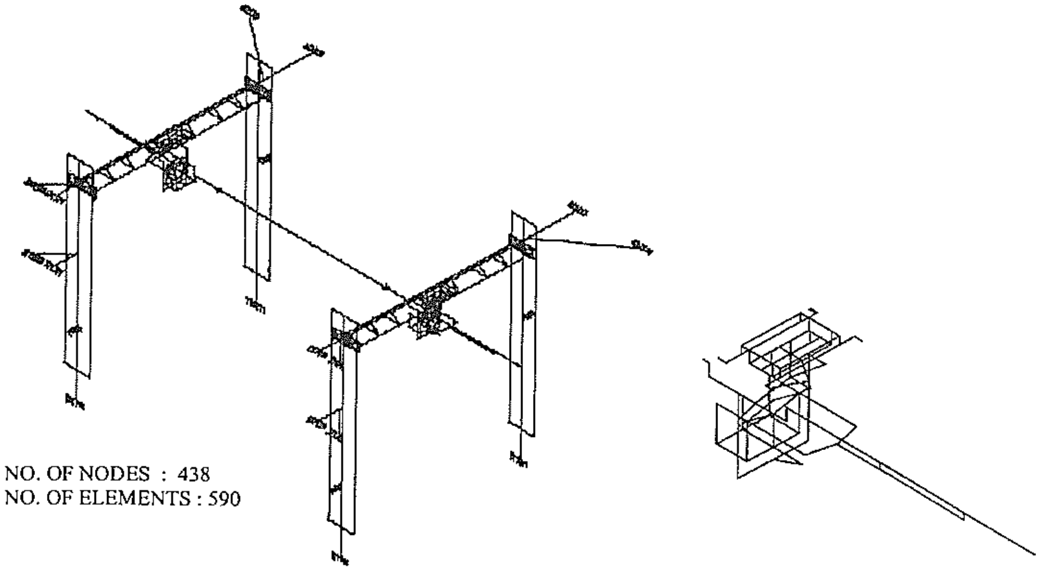

NO. OF NODES : 438
NO. OF ELEMENTS : 590

FIG. 3 FINITE ELEMENT MODEL OF FUELLING MACHINES AND COOLANT CHANNEL SUBASSEMBLY IN COUPLED MODE

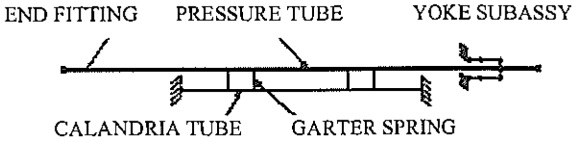


FIG.4 FINITE ELEMENT MODEL OF COOLANT TUBE SUBASSEMBLY FOR 220 MWe

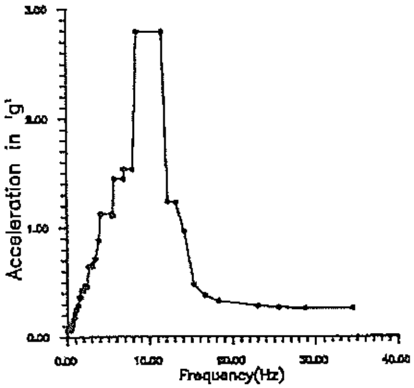


FIG.5 OBE ENVELOP RESPONSE SPECTRA WITH 2 % DAMPING

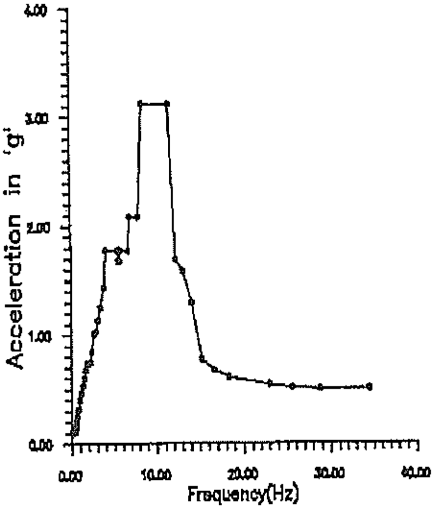
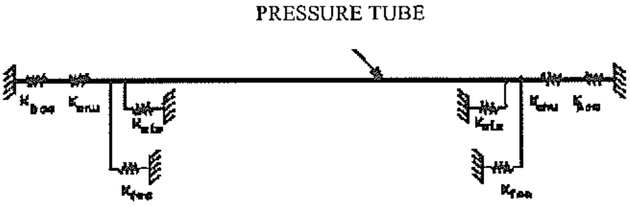


FIG.6 SSE ENVELOP RESPONSE SPECTRA WITH 4 % DAMPING



KBCS = BRIDGE COLUMN STRUCTURE STIFFNESS

KSNU = SNUBBER STIFFNESS

KSTU = YOKE STUD STIFFNESS

KFEE = FEEDER STIFFNESS

FIG.7 SIMPLIFIED FEM OF FUELLING MACHINES COUPLED TO COOLANT CHANNEL ASSEMBLY

TABLE NO: 1
EXTRACTED MODAL FREQ.

N	FREQ.	N	FREQ.	N	FREQ.
1	3.244	**13**	5.713	**25**	8.650
2	3.244	**14**	5.820	**26**	15.02
3	3.247	**15**	6.189	**27**	15.02
4	3.247	**16**	6.189	**28**	15.30
5	3.306	**17**	6.447	**29**	15.56
6	3.306	**18**	8.646	**30**	20.13
7	3.306	**19**	3.308	**31**	21.53
8	3.306	**20**	3.308	**32**	23.88
9	3.307	**21**	3.308	**33**	23.88
10	3.307	**22**	3.308	**34**	24.94
11	3.307	**23**	5.654	**35**	34.59
12	3.307	**24**	5.712		

N=MODE NUMBER FREQ=CYCLES/SEC

TABLE NO: 2
MAXIMUM STRESS VALUES/FACTORS IN STRUCTURAL MEMBERS

TYPE	COMPONENT	DC.	LEVEL C
SHEAR (Kg/cm^2)	TOP BEAM	199.7	255.9
	VERTICAL SPINDLE	84.8	108.2
AXIAL COMPRESSION (Kg/cm^2)	YOKE STUD	2946.3	3612.9
	SUPPORT FRAME	78.2	101.6
	SUPPORT STUD	820.1	964.6
AXIAL TENSION (Kg/cm^2)	YOKE STUD	2966.2	3657.7
	BALL SCREW	116.5	129.3
	SUPPORT STUD	820.1	964.6
AXIAL COMPRESSION & BENDING STRESS FACTOR	YOKE STUD	0.9616	0.7861
	SUPPORT FRAME	0.4504	0.3605
AXIAL TENSION & COMPRESSION STRESS FACTOR	YOKE STUD	0.6401	0.5262
	VERTICAL SPINDLE	0.3280	0.3371

TABLE NO: 3
MAXIMUM STRESSES IN PRESSURE RETAINING COMPONENTS (Kg/cm^2)

LEVEL CONDITION	RAM HOUSING		PRESSURE HOUSING		FUELLING MACHINE SNOUT		END FITTING		COOLANT TUBE		CALANDRIA TUBE	
	S_a	S_{max}	S_a	S_{max}	S_a	S_{max}	S_a	S_{max}	S_a	S_{max}	S_a	S_{max}
DESIGN COND.	3514.5	699.9	3514.5	370.2	3514.5	256.3	3442.5	483.5	2199.0	972.1	2007.0	441.5
LEVEL A	7029.0	1109.4	7029.0	732.3	7029.0	397.3	6885.0	689.6	4398.0	1643.0	4014.0	1206.2
LEVEL B	7029.0	1894.2	7029.0	763.5	7029.0	3014.8	6885.0	3460.3	4398.0	3346.6	4014.0	2467.3
LEVEL C	5271.7	1578.9	5271.7	393.8	5271.7	1981.0	5163.7	2329.3	3298.5	3117.5	3010.5	1935.4

S_a = Allowable stress S_{max}= Maximum induced stress