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3-D Structural and fatigue analysis of feeder coupling components

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ABSTRACT: The paper presents 3-D structural analysis of feeder coupling due to various loads, combination of 3-D stresses for different service levels, classification of stresses in to stress categories and usage factor evaluation. Each component of the coupling assembly is qualified separately as per ASME code requirements.

1 INTRODUCTION

In the PHWR, the feeder pipe coupling forms the connection between the feeder pipes and endfitting of coolant channels. There are large number of such couplings in one Indian PHWR. These couplings are part of the primary heat transport (PHT) system. The PHT system is a barrier for release of radioactivity to the containment atmosphere. If any failure takes place it may lead to loss of flow. Hence it can be said that integrity of a feeder pipe couplings have direct effect on overall safety of nuclear power plant. These couplings are classified as safety class 1 components. Therefore the detail structural and fatigue analysis is carried out to have assessment of its structural integrity (Chawla 1993).

2 GEOMETRY AND LOADING

The feeder pipe coupling is assembly of different components. These are feeder hub, sealring, two clamps, endfitting hub and four bolts/studs (Fig.1). The materials for feeder hub, clamp, sealring, endfitting and bolt are SA350LF2, SA479(410SS)Annealed, SA266class3, SA479(403SS) and SA193B7 respectively. The various properties of the materials are taken from (ASME 1986).

The various loads considered in the analysis are internal pressure and thermal load due to PHT system flow, bolt pretightening torque (7604 Kg-mm per bolt), seismic inertial forces, gravity load and feeder pipe rection forces/moments at hub end. The design temperature and pressure of PHT system is 310 deg. cent. and 1.26 Kg/sq.mm.

Seismic acceleration values (SSE/OBE) are taken as 0.4g/0.26g, 0.5g/0.27g and 0.2g/0.12g in N-S(along the channel axis), E-W and vertical direction. The three feeder load sets giving maximum resultant moments are selected for the analysis out of 25 sets available. Table 1 shows one of the feeder load set. The coupling undergoes temp./pressure transients during startup and shutdown. Most severe 5 full cycle transients (table 2) are considered.

3 FINITE ELEMENT MODELLING

It is decided to prepare 3-D finite element mesh due to irregular geometry and three dimensional nature of loads acting on it. The incompatible eight noded solid elements are employed to improve the bending behaviour. Due to symmetricity, the half of the coupling geometry is modelled with appropriate boundary conditions at symmetric plane. The 3-D models of different components of coupling assembly are prepared separately and are assembled to make complete model (Fig.2). The appropriate length of endfitting tube is also modelled so that discontinuity should not affect the stresses, if fixity boundary conditions are provided at endfitting tube ends. The model includes 1882 solid elements and 3192 nodes. Two models are prepared with different boundary conditions at interface of coupling components. Model 1 involves coupled boundary conditions at interface and model 2 uses gap elements at interface.

4 STRESS ANALYSIS

The stress analysis of coupling model is carried out for various loads separately using finite element technique (Nisa 1990). The high stress concentration is noted at junction of endfitting hub with endfitting tube due to internal pressure. Bolt load is simulated by temperature difference. The stresses in coupling components due to gravity load and seismic inertial forces are found to be negligible. The three different feeder pipe reaction forces/moment sets are used for the analysis. The moments are converted in to direct forces. Symmetric or antisymmetric boundary conditions are used wherever required. The static loads are combined with OBE/SSE as per NB-3650 (ASME 1986). Analysis due to thermal expansion is performed in two stages. In first step heat transfer analysis is carried out assuming perfect contact at interface locations. The heat transfer by forced convection at inside and by natural convection at outside is considered. 3-D solid element model is used for steady state heat transfer analysis. While for temperature transient analysis, a simplified axisymmetric finite element model is used. In the second stage thermal stresses are computed using above temperature distribution. Figure 3 shows the stress intensity contours due to thermal expansion in coupling at section 1-1. Sealring experience high thermal stresses in comparison to other components.

5 QUALIFICATION BY ASME CODE

The 3-D stresses obtained due to various loads are combined for different service levels such as normal design condition, Service level A, B, C and hydrostatic test condition. At selected locations the combined stresses are classified in to membrane, membrane + bending and peak stresses. The classified stresses are compared with allowable stress limits for each service level as described in Section III Division 1 NB-3221 to NB-3224, NB-3226 (ASME 1986). The different components of coupling such as feeder hub, clamp, sealring and endfitting are qualified individualy. The bolt/stud is qualified as per NB-3230 (ASME 1986). The stress intensity contours for various service levels are shown in figure 4. Qualification of various components of coupling for Normal design condition is presented in table 3,4.

For different temperature/pressure transients, bolt load, OBE and SSE loads the maximum stress intensities are selected and corresponding fatigue cycles are evaluated using fatigue curves I-9.1, I-9.2 and I-9.4 from Secion III Division 1 Appendices (ASME 1986). Usage factor for different loads and total usage factor is evaluated for each component. Table 5 shows the computation of usage factor for one of the components. Usage factor for all the five components is much less than unity.

6 CONCLUSION

The stresses in different components of feeder pipe coupling assembly are within allowable limit as per ASME section III division 1 NB. Usage factor for all five components are less than unity. Therefore it can be said that design of feeder pipe coupling of Indian PHWR meets ASME Section III Boiler and pressure vessel code.

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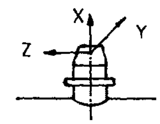

Table: 1 Feeder pipe loads at hub end w.r.to local axis for one of the case considered.

	Fx (Kg)	Fy (Kg)	Fz (Kg)	Mx (Kg-mm)	My (Kg-mm)	Mz (Kg-mm)
Gravity	-19	13	34	18831	-20060	18947
Pr + Th	-41	6	30	33774	-80879	61474
OBE ±	234	130	78	216594	90913	232885
SSE ±	262	144	89	240497	101983	257991

Table 2 temperature and pressure transients

	Temp(deg C)	Pres(Kg/sq.mm)
T1	40--275--40	0--1.16--0
T2	275-304-275	constant
T3	304-295-304	constant
T4	275-304-275	1.01-1.01-1.07
T5	275-304-320-275-275	1.01-1.01-1.17-0.98-1.01

Table 4 Qualification of stud for Normal design condition.

Load	Average axial stress at root dia (Kg/sq.mm)	Design stress (Kg/sq.mm)
Bolt load	7.76	20.0
Bolt load+ pressure	8.64	20.0

Table 3 Stress intensity(Kg/sq.mm) for NDC in coupling.

Location	Maximum Pm M-1	M-2	Allowable Sm	Max. Pm+Pb M-1	M-2	Allowable 1.5Sm
Feeder hub	10.8	10.9	12.54	13.7	12.0	18.81
Sealring	4.81	12.5	14.93	8.03	22.0	22.4
Clamp	7.25	9.14	13.03	15.5	17.3	19.55
Endfitting hub	10.3	10.7	14.93	16.4	17.8	22.4

Note: M1=Model 1, M2=Model 2

Table 5 Usage factor evaluation for clamp.

Type of fluctuating load	Actual cycles n	Max S.I. range (Kg/sqmm)	Fluctuating S.I. (Kg/sqmm)	Fatigue cycles N [1]	Usage factor n/N
Bolt load	25	29.33	14.67	1000000	.0000025
OBE	50	2.93	1.47	1000000	.000005
SSE	10	3.22	1.61	1000000	.000001
Pr+thermal(T1)	1000	19.46	9.73	1000000	.001
Thermal(T2)	2750	6.09	3.05	1000000	.00275
Thermal(T3)	16500	1.31	0.66	1000000	.0165
Pr+thermal(T4)	250	4.48	2.24	1000000	.00025
Pr+thermal(T5)	500	4.67	2.34	1000000	.0005

Total usage factor = 0.0210085

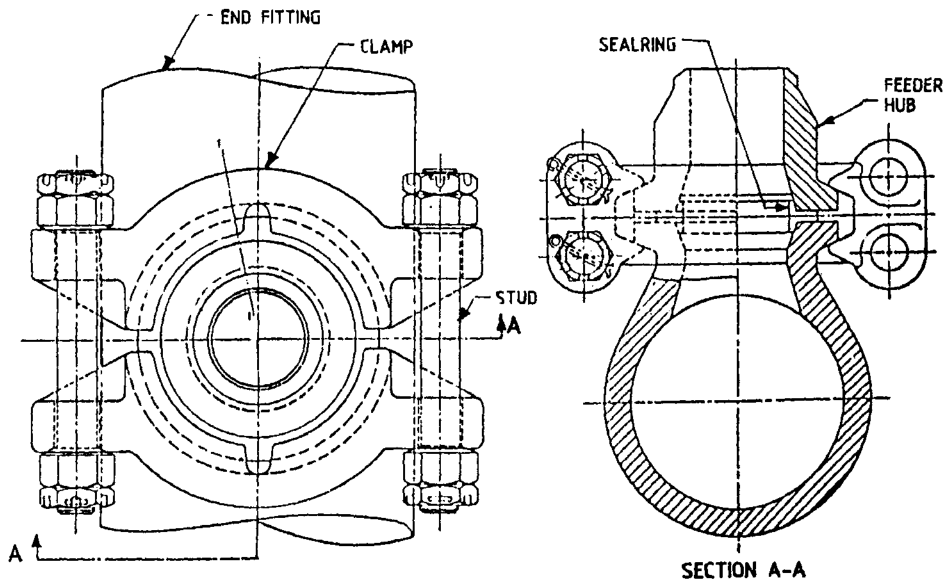

Fig. 1 Two views of feeder pipe coupling of 500 MWe PHWR

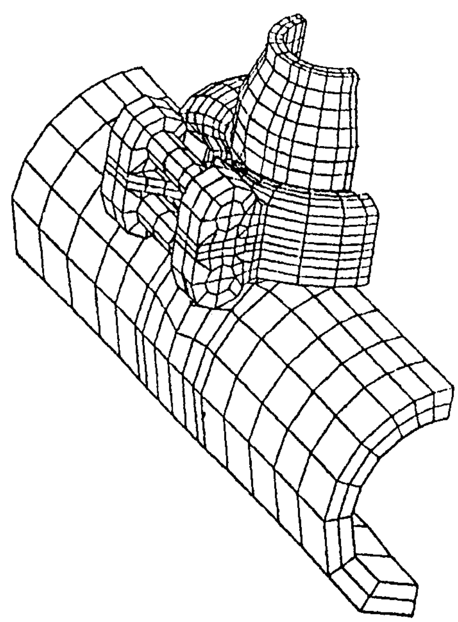

Fig. 2 Finite element model of feeder coupling.

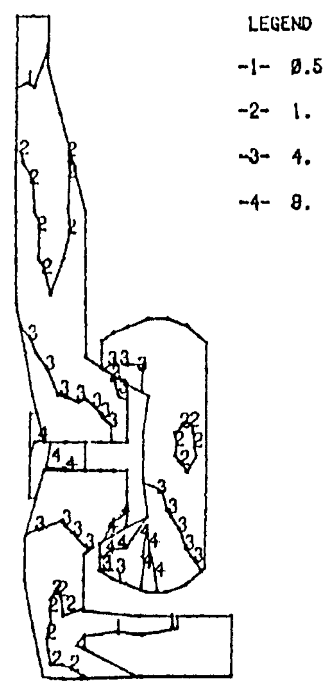

Fig. 3 Stress intensity (Kg/Sq.mm) contour due to thermal expansion at Section 1-1

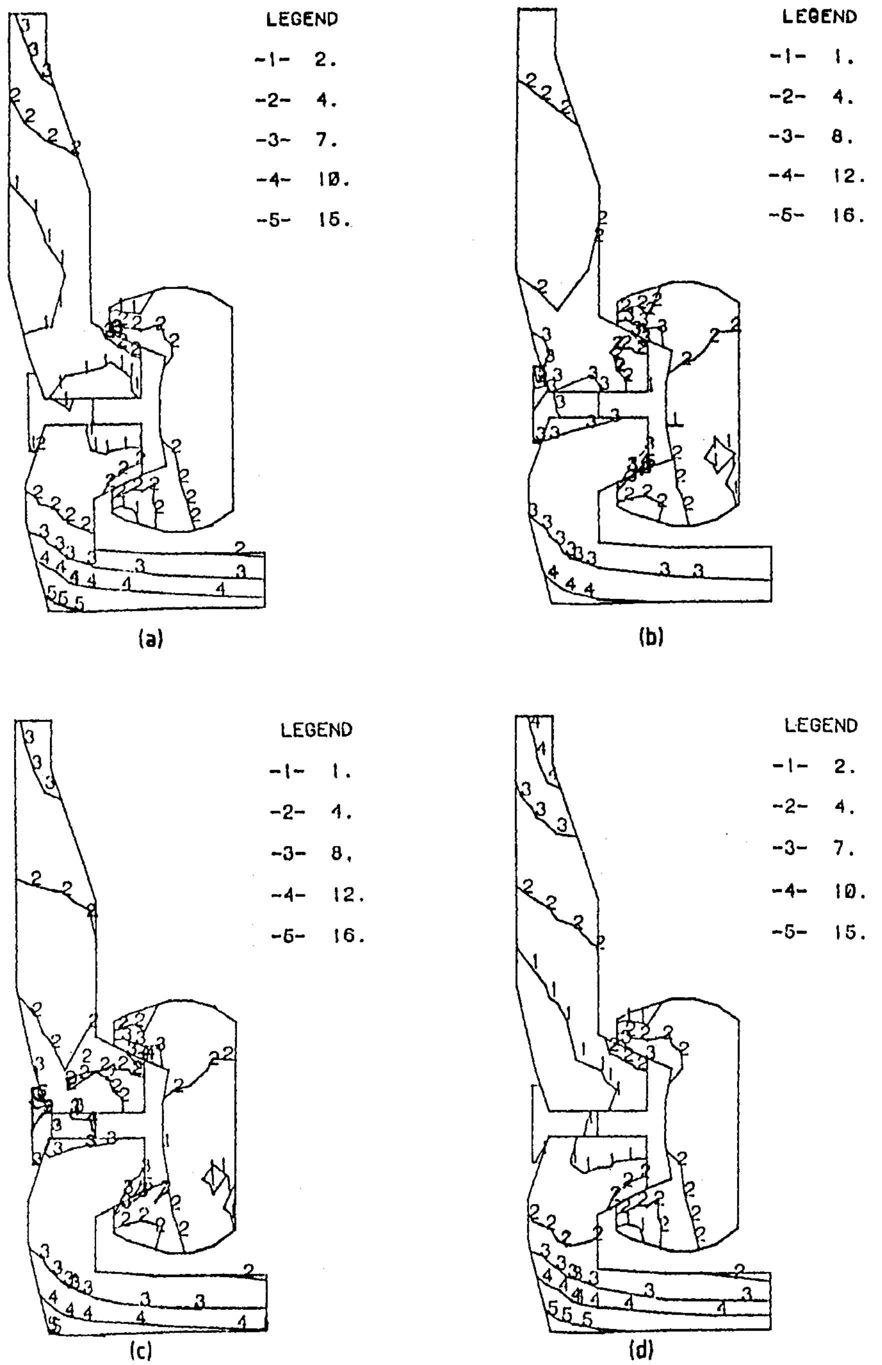

Fig.4 Stress intensity (Kg./Sq.mm) contours in feeder coupling model 1 of section 1-1 for (a) N D C (b) Service level A (c) Service level B (d) Service level C