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MODELLING OF FUELLING MACHINE BRIDGE AND CARRIAGE ASSEMBLIES OF A TYPICAL 500 MWe PHWR SYSTEM FOR SEISMIC QUALIFICATION

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ABSTRACT

Pressurized Heavy Water Reactors (PHWRs) are refuelled on-power using a system of remotely controlled Fuelling Machines. Present paper describes the mathematical modelling and the seismic analysis results for the FM system when it is not coupled to the coolant channel. A great emphasis is laid on the modelling aspects and their validation in this paper. A brief description of the further analysis work when the FM Heads are coupled to the coolant channel is also given here.

1.0 INTRODUCTION:

The Pressurized Heavy Water Reactors (PHWR) are refuelled on-power, with the help of two Fuelling Machines (FM) wherein one FM pushes the new fuel bundles in the channel while the other receives the spent fuel bundles in its magazine which are subsequently transferred to Fuel transfer system. On an average daily two coolant channels have to be refuelled involving a total of 8 to 10 hours. So there is a high probability of F/M system being subjected to seismic loads in the event of an earthquake. Also because of the close proximity of the FM to the reactor face, seismic qualification is necessary even when the FM is not homed to any channel to ensure the integrity of FM and its supports and avoid any damage to the reactor face. The task of seismically qualifying the FM is complicated by the fact that there are 392 possible horizontal channel positions where the FM head can lie during the earthquake. However, with a careful judgment, analysis carried out for a few locations can represent the entire spectrum of loadings. The present paper highlights the analysis work carried out for the FM system in one of its unclamped positions, when FM head is at the top most central channel location, FM head is oriented along the coolant channel axis and is locked in fully retrieved condition. It also describes the scheme of analysis to be adopted for the FM system coupled to the coolant channel.

2.0 SYSTEM DESCRIPTION:

The FM system comprises of four main components namely FM Guide Columns, FM Bridge, FM Carriage and FM Head (Fig.1). FM guide columns extend from elevation 96.5M in FM service area to elevation 110.5M and provide guided movement for FM bridge in vertical direction. In the lowest position of FM bridge, FM head is able to home on to Fuel Transfer Port to receive/discharge new/spent fuel bundles. The guide columns are laterally supported from the nearest wall in FM vault by tie-members and on concrete pedestals at the bottom. At the top of each column, a ball screw support assembly is mounted which supports two ball screws on spherical roller thrust bearings. The ball screw assemblies provide the motive power for transporting FM bridge in the vertical direction. The bridge structure rests over the bridge support assemblies on either side. The bridge support assembly is connected to Y - ball screws and guide columns. To allow thermal expansion of the bridge in X-direction the east side of it rests over Linear bearings. The FM carriage comprises of a trolley, drive plate assembly, top-beam, lower and upper gimbals. The trolley travels horizontally along E-W (X-direction) from the underside of FM bridge. The FM head is fixed to the support frame and gimbal assembly which are supported from the trolley. The movement of trolley provides the X-motion for lateral positioning of FM head across the reactor face.

3.0 FINITE ELEMENT MODELLING:

The functional objective of FM carriage, bridge and column assembly is to transport the FM head to various coolant channel locations and fuel transfer port. As a result, the structural system comprises of number of mechanisms which serve the purpose of imparting three directional movement to the FM head. The major task, therefore, is to construct the realistic mathematical modelling of these mechanisms.

All structural members of FM carriage, bridge and column assembly along with the FM head are modelled by 3-Dimensional beam elements and boundary elements. The FEM model consists of 211 number of nodes and 221 number of 3-Dimensional beam elements and 12 boundary elements (Fig. 2). In addition, there are numerous joints in the FM system which require the release of appropriate degree of freedoms (DOF) at these locations. This task was accomplished by the use of Master-Slave option available in computer code COSMOS (Ref. 3).

4.0 VALIDATION OF FINITE ELEMENT MODEL:

In the event of seismic excitation the FM head will vibrate in all the three directions and, therefore, validation of load transfer paths in all the three directions is essential to judge the adequacy of modelling. Seismic loading induces stresses in the system mainly because of inertia effects which are similar to the dead weight type of loadings in all the three directions. Therefore, three separate static analyses of the model were performed wherein '1g' loading is assumed to act in X, Y and Z directions respectively. These three analyses gave the clear picture of load transfer paths in all the three directions. Since these load transfer paths agree well with the expected design behavior of the system, it was concluded that the mathematical model truly represents the system being analyzed.

5.0 METHOD OF ANALYSIS:

Stress analysis of FM system has been performed using Finite Element software COSMOS. The total response of FM system during the event of seismic motion is evaluated in three steps, viz, inertial response, rigid body response and response due to Seismic Anchor Movements. Inertial response of FM system has been calculated by response spectrum method using the envelope spectrum (Fig. 3) of various support point spectra (Ref. 1). Responses due to various modes in a given direction have been combined using the ten-percent summation method (Ref. 2). The spatial responses have been combined in an SRSS manner (Ref. 2). First 50 modes of structural system (upto ZPA of FRS) have been extracted for the purpose of seismic analysis. However, it needs to be mentioned that the effect of higher modes has been duly accounted for, by applying missing mass correction using Full ZPA method (Ref. 4).

6.0 RESULTS OF ANALYSIS:

The mathematical model has been analysed for self weight and OBE and SSE levels of seismic excitations. The present analysis work carried out is an extension of previous work (Ref.5). The first few important frequencies where significant mass participation is there are shown in Table 1. It can be seen that 39.16%, 46.68% and 59.15% of masses get excited in X, Y and Z directions respectively for the first 50 modes and this mostly corresponds to FM bridge and FM carriage/head assembly.

It is observed that the fourth mode (2.22Hz) corresponds to the bending of spindle and 90 o stop-pin in NS direction. Eleventh mode (5.06Hz) corresponds to the bending of spindle in EW direction and is responsible for major response in the spindle. Other significant modes in EW direction are 39th (21.51Hz) and 40th (23.96Hz) modes. In vertical direction, 15th (7.31Hz) and 23rd (10.52Hz) modes are responsible for causing maximum response. In NS direction, the major contributing modes are 4th (2.22Hz), 7th (2.39Hz), 15th (7.31Hz), 23rd (10.52Hz), 24th (11.99Hz) and 37th (17.44Hz). Looking at the structural response in various components of the system, it was found that the stresses in the 90o stop-pin (60 mm diameter) are more than their allowable value. This is because the mode corresponding to this component is having a frequency of 3.42 Hz in EW direction which lies near the peak region of the spectra. This mode can be avoided either by increasing or reducing the stiffness of the pin. Since increase in the stiffness was still resulting into the peak spectral region, it was decided to reduce the diameter of the pin from 60 mm to 30 mm giving rise to reduction in seismic response on account of shift of frequency from 3.42 Hz to 1.57 Hz.

Similarly, a close look at the column support loads revealed that the axial load on the bottom of the east column is 405 tons which although the column is able to sustain, the floor embedded part is difficult to design for such a load. It was traced that most of this force arises due to seismic anchor movement and can be avoided by removing the support at EL.100 M. on the column, which has no flexibility to absorb the differential SAM movements.

7.0 CONCLUSIONS:

The major task in this exercise has been the realistic modelling of the structural system consistent with the functions of various sliding/rolling joints in sufficient detail. In this analysis it has been found that the stresses and deflections are within allowable limits. It is observed that, reducing the stiffness of 90o stop-pin and removal of support at EL 100M. on east column helps in reducing the seismic response in these components. The analysis for few more locations may be required to get the maximum induced forces in other components like columns and tie-beams etc. Analysis for the case when both the FMs are coupled to the coolant channel is under progress. This model would also include the modelling of calandria-endshield assembly and the concrete structure.

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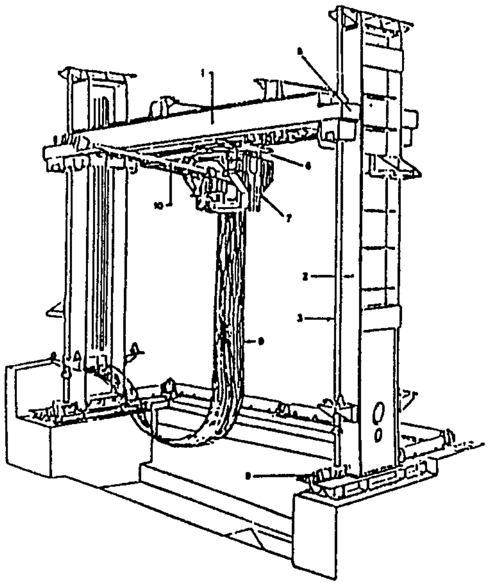

1. FUELLING M/C BRIDGE
2. FUELLING M/C GUIDE COLUMN
3. BALL SCREW ASSEMBLY
4. FUELLING M/C HEAD
5. BRIDGE SUPPORT
6. FUELLING M/C CARRIAGE (TROLLEYS)
7. GIMBALS
8. Y-MOTION DRIVE
9. CABLE CATENARY
10. SUPPORT FRAME

FIG. 1: F. M. CARRIAGE, BRIDGE & COLUMNS

TABLE : 1

First Few Important Frequencies and Mass Participation Factors for the FM Systems.

Mode No.	Freq (Hz)	Mass Factor (%) E-W	VTL	N-S
1	1.57	0.05	0.00	0.01
4	2.22	0.00	0.00	2.49
7	2.39	0.00	0.00	1.27
11	5.06	15.23	0.07	0.00
15	7.31	0.02	8.36	5.48
22	9.02	0.58	0.08	0.01
23	10.52	0.49	32.80	6.40
24	11.99	0.06	1.26	22.93
34	16.23	0.43	0.00	0.08
35	16.29	0.00	0.06	0.51
37	17.39	0.37	0.59	17.44
38	18.63	0.50	0.02	0.08
39	21.51	8.28	0.47	1.10
40	23.96	10.79	2.53	0.10
50	33.61	0.01	0.00	0.03

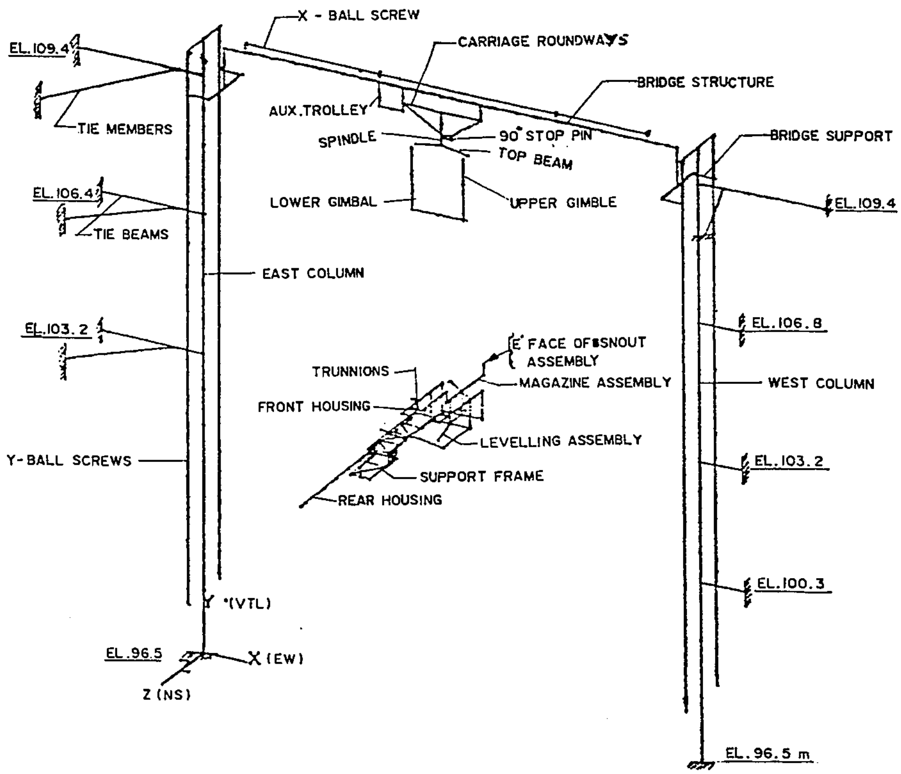

FIG. 2 FINITE ELEMENT MODEL OF FM SYSTEM

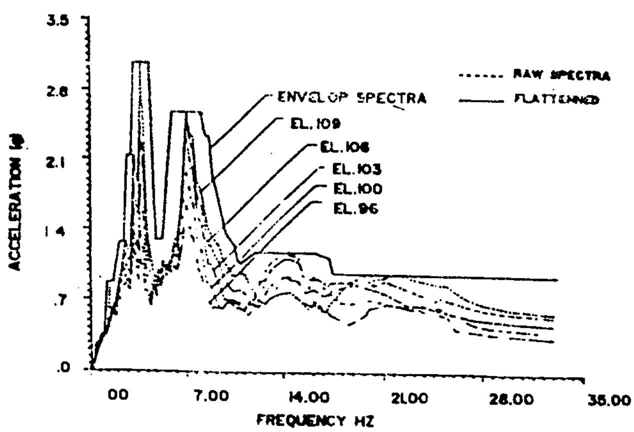

FIG. 3: RESPONCE SPECTRUM (SSE-3%-EW)