Seismic Analysis of Pressurised Heavy Water Reactor Building Using 3-D Stick Model

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1 ABSTRACT

Generally, the dynamic analysis of Reactor Building is performed using a stick model, neglecting the unsymmetricity of the structure and eccentricity of masses. This is basically a 2-D model (hereafter 2-D model) in which the responses to the 3 components of earthquake acting on the three component axes are assumed to be uncoupled. This type of modelling does not reflect the coupling of response due to the non-symmetric configuration and the eccentricity of masses. To cater for any coupling, a revised stick model (hereafter 3-D model) taking care of such eccentricities, is proposed in this paper. The response of 2-D and 3-D stick models using the response spectrum method is compared in this paper.

2 INTRODUCTION

In dynamic analysis of Reactor Building , it is usual to consider a planar beam model (2-D stick) of the structure in each of two orthogonal directions and to independently analyse the response of each model for each component of ground motion. However, it is strictly valid only for structures where the centre of mass and centre of rigidity coincides. If this is not the case, the translational and torsional responses of the structure are coupled. The conventional approach of a 2-D stick model may be reasonable for small eccentricities and when the natural frequencies of the lower modes are well separated.

The Reactor Building consists of an Internal Structure (IS) and Calandria Vault (CV) contained in coaxial Inner and Outer containment walls (ICW & OCW) cast monolithically with a circular raft. The OCW consists of cylindrical shell supporting a torispherical dome made up of reinforced concrete. ICW also consists of cylindrical shell supporting a torispherical dome made of prestressed concrete. The Internal Structure is a complex three dimensional structure consisting of shear walls, columns and beams, supporting massive floors. The geometry of Internal Structure and Calandria vault is not symmetric along NS axis. The Internal Structure is a closed hollow rectangular box from EL 85000 to EL 100000 and an open section from EL 100000 to EL 115500. The Internal structure is symmetric about EW axis but unsymmetric about NS axis. Above EL 115500 it consists of two boxes, housing the Steam Generator (S.G.). The Internal structure and Inner

Containment wall are connected by an annular steel plate at EL 130000 as the Internal Structure is flexible above EL 115500. This link permits transfer of lateral force but allows the two structures to rotate independent of each other.

The floors of Reactor Building are loaded with self weight and heavy equipments. The mass distribution is not uniform because of cutouts in the floors, variation in density of concrete, unsymmetric sections etc. Further the Internal Structure is not symmetric about NS axis. This results in the eccentricity of the mass with respect to the centre of rigidity of the structure.

3 MATHEMATICAL MODEL

For the purpose of dynamic analysis it is necessary to evolve a suitable mathematical model with certain assumptions. Alternate mathematical models were formulated and the response compared to the 3-D Finite Element (FEM) idealisation of the structural system (Subramanian et. al.). Studies on these alternate models were conducted on a two storied unsymmetric box structure. The alternatives considered are briefly described here.

3.1 Model-A

This is a simple model which ignores the eccentricity between mass centre and centre of rigidity. The stick is represented along the centre of structure and the masses and rotational inertia are also lumped at the centre of structure.

3.2 Model-B

In this model,the stick is represented along the centre of structure but masses, mass moment of inertia are lumped at mass centre. The mass nodes are connected to the stick by rigid beam elements.

3.3 Model-C

In this model, the stick is represented along geometric centre (centre of area) and masses, mass moment of inertia are lumped at mass centre. The mass nodes are connected to the stick nodes by rigid links.

3.4 Model-D

In this model the stick is represented along the centre of rigidity and the masses and mass moment of inertia are lumped at mass centres. The mass nodes are connected to stick nodes by rigid links.

3.5 Model-E

This model makes use of the master and slave option of program SAPIV (Bathe et. al.). The stick is represented along the centre of rigidity, but the stick nodes are connected to centre of structure by master and slave option, defining nodes along centre as master and nodes along stick as slave . The masses are lumped at mass centre, connected to centre of structure by rigid links.

3.6 Model-F

In this model, a transformation matrix, is used to transfer the stiffness of stick from centre of rigidity to centre of structure . The masses are lumped at mass centre and are connected to centre of structure by rigid links. The disadvantage of using this model is that the program computes the forces at global location for these elements, which are less relevent to the design engineer. It requires additional calculations to compute forces at local position.

3.7 Model-G

In this model, the stiffness of stick at the centre of rigidity is transferred to the centre of structure using appropriate transformation matrix and the masses are lumped directly at the centre of the building, by modifying the rotational inertia by mass times the square of distance between mass centre and centre of structure. In this model the off diagonal terms of transferred mass matrix are neglected.

3.8 Model-H

In this model the masses and mass moment of inertia are lumped at the centre of the structure and the stiffness of structure is located at a distance given by the difference between mass centre and centre of rigidity.

4 CHOICE OF ANALYTICAL MODEL

Out of these models, the responses for the excitation in the three directions for Model D,E and F are comparable with the FEM model. In this study, it was found that when mass is eccentric, the horizontal excitation generates torsion along with shear and moments in stick member. Also coupling is observed for vertical excitation. To confirm the correctness of the model, simple equivalent studies for vertical response were carried out, which confirmed the findings. It was thus concluded models D,E and F are appropriate. Of these three models, model-D was selected where the stick is running through centre of rigidity and major masses are located at their respective mass centres and they are connected to centre of structure by rigid links.

5 DESCRIPTION OF ANALYTICAL MODEL

The 2-D and 3-D stick model as proposed for seismic analysis of Reactor Building is shown in Fig. 1. The OCW is represented by 23 elements and ICW is represented by 21 elements. The Internal Structure is represented by 16 elements and calandria vault by 10 elements. The raft is represented by two elements and the transverse, vertical, rotational and torsional springs are applied at raft level to cater the effect of soil structure intraction. These are computed using impendance functions (ASCE 4-86), with a limitation to the values at 20%, 30% and 7% for horizontal, vertical and rotational/torsional soil springs.

The sectional properties for OCW, ICW, CV and RAFT are calculated using standard formulae. The sectional properties such as cross sectional area, shear areas and moments of inertia for Internal Structure are evaluated using the Finite Element Model (Reddy et. al.) In this, horizontal forces are applied and the average displacement and rotations are worked out in the direction of applied force. Using these displacements and rotations in the beam stiffness matrix, the sectional properties are calculated. The centre of rigidity for each section of the internal structure is evaluated applying equal and opposite forces forming a couple. This is the point on the structure where applied horizontal force will not produce any rotation about vertical axis. The twist of the section is computed to evaluate the equivalent torsional inertia of the section.

All the substructures are represented at the centre of building. The connection between Internal Structure and Inner containtmant wall, at elevation 130000 is modelled by using springs representing the stiffness of the connecting link at the two respective nodes. Modal damping has been considered for dynamic analysis computed using the weighted energy principle. Damping of 7% has been considered for OCW, IS, CV, RAFT and 5% damping has considered for ICW which is of prestressed concrete. 3% damping has been used for the link element connecting the ICW and IS.

6 ANALYSIS

Both 2-D and 3-D stick models were used for seismic analysis of Reactor Building. Dynamic analysis has been carried out for both 2-D and 3-D stick models using computer program SAPIV (Bathe et.al.). The results such as natural frequencies and modal participation factors are tabulated in TABLE-1 for 2-D and 3-D stick models. The comparision of forces for 2-D and 3-D stick models are tabulated in TABLE 2, for few important elements.

It can be seen from TABLE-2, that there is quite a large variation between 2-D and 3-D response. There is notable torsional response and the coupling of response between horizontal and vertical directions. The torsional response is predominent for NS direction. This is essentially due to unsymmetric nature of the structural system.

7 CONCLUSIONS

It has been seen that considerable coupling exists in the structure if the rigidity centre and the mass centre does not coincide. It can be thus concluded that a complex unsymmetric structure consisting of thick shear walls, such as Reactor Building needs to be represented as a 3-D stick model. The model with the stick represented along the rigidity centre and masses lumped at mass centre, connecting to the stick by rigid elements, represents a suitable 3-D stick model of the Reactor Building system.

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TABLE - 1 DYNAMIC RESULTS FOR 2-D AND 3-D STICK MODEL

MODE	FREQ 2-D	MPF NS
1	3.95	1.79
2	4.79	1.03
3	7.04	1.93
4	8.33	-0.6
5	12.6	-0.7
6	13.0	-0.2
7	14.0	-0.5
8	15.0	0.54
9	20.0	0.00
10	20.7	0.31
11	22.2	-0.4
12	23.5	0.39
13	26.1	0.71
14	28.4	-0.7
15	29.8	0.18
16	33.2	0.04
17	34.2	-0.2
18	37.2	-0.2

MODE	FREQ 2-D	MPF. EW
1	3.62	1.63
2	4.77	1.22
3	6.77	0.73
4	9.56	1.18
5	11.0	0.14
6	12.8	-0.9
7	13.5	0.46
8	14.2	-0.9
9	17.6	0.11
10	20.	-0.5
11	20.4	0.37
12	21.1	-0.4
13	22.8	0.24
14	24.5	0.17
15	26.4	0.81
16	28.4	-0.6
17	29.8	-0.2
18	32.5	-0.1

	2-D VT	
1	9.97	1.74
2	12.2	0.29
3	12.6	0.18
4	20.5	1.11
5	29.5	-0.9
6	33.4	0.28
7	38.2	0.13

MODE	FREQ	MODAL PART. F. 3-D		
1	3.62	0.0	1.62	-.07
2	3.95	1.79	0.01	0.0
3	4.79	0.0	1.22	0.03
4	4.80	1.04	0.00	0.00
5	6.73	0.05	0.73	0.12
6	6.92	1.62	-.11	0.05
7	7.78	0.15	0.03	0.02
8	8.22	-0.3	0.03	-.28
9	8.62	0.00	0.00	0.00
10	9.22	-.18	0.00	-0.4
11	9.35	.137	.522	-2.1
12	9.73	-0.1	0.68	2.45
13	11.1	-0.0	0.10	-.92
14	12.2	0.16	-.07	0.36
15	12.6	0.27	-.03	0.16
16	12.7	-0.7	-.07	0.01
17	12.9	0.07	-.96	0.02
18	13.1	-0.1	0.0	0.02
19	13.6	0.14	0.45	-.06
20	13.6	-0.6	0.09	-.06
21	14.2	0.0	-.94	0.03
22	14.8	0.36	0.0	-.08
23	17.6	0.0	0.10	0.10
24	18.4	0.07	0.03	0.02
25	19.5	0.0	0.51	0.31

MODE	FREQ	MODAL PART. F. 3-D		
26	19.8	0.25	.098	0.03
27	20.3	-.03	.143	.273
28	20.6	-0.1	-.26	.529
29	20.7	.325	-.08	.242
30	21.1	0.0	-.27	0.40
31	21.9	0.70	-.00	0.06
32	23.1	-.02	.095	-.17
33	23.2	.137	.025	-.03
34	23.5	0.03	0.00	0.01
35	24.3	.028	-.09	-.18
36	24.9	-.03	0.00	0.00
37	25.7	.729	0.00	0.00
38	26.0	0.00	.825	.090
39	26.7	0.00	0.00	0.08
40	28.3	0.0	-.46	.019
41	28.4	-0.7	.014	0.00
42	29.2	0.02	0.05	0.09
43	29.3	0.00	-.11	-1.0
44	29.5	0.0	-.25	-.01
45	32.3	0.04	-.19	.179
46	32.6	0.07	.036	0.16
47	32.9	-.14	0.00	-.09
48	33.3	0.00	0.00	.015
49	33.9	0.00	-.23	-.02
50	34.2	-0.3	.004	.013

TABLE -2 COMPARISION OF FORCES FOR 2-D AND 3-D STICK MODELS Units: tm

ELE	DIR	AXIAL FORCE VT		SHEAR FORCE EW		SHEAR FORCE NS		TORSION		MOMENT @ EW		MOMENT @ NS	
		2-D	3-D	2-D	3-D	2-D	3-D	2-D	3-D	2-D	3-D	2-D	3-D
23	NS	-	3312	-	623	7060	7238	-	23640	3.1e5	3.1e5	-	11940
	EW	-	1694	7149	7141	-	574	-	4303	-	11990	3.1e5	3.1e5
	VT	3775	4097	-	602	-	349	-	15060	-	13380	-	27950
121	NS	-	2342	-	1174	15730	15760	-	67960	7.4e5	7.4e5	-	19480
	EW	-	2005	16620	16610	-	609	-	15050	-	15220	7.8e5	7.8e5
	VT	5198	5691	-	987	-	389	-	31220	-	14610	-	65630
206	NS	-	1417	-	612	4874	4655	-	6002	69850	68140	-	9666
	EW	-	2458	2730	2470	-	386	-	1674	-	5655	58620	58980
	VT	4122	4567	-	2971	-	399	-	6719	-	6745	-	40400
216	NS	-	4285	-	1666	19170	19070	-	94670	4.9e5	4.9e5	-	27220
	EW	-	7897	17050	17080	-	2259	-	27190	-	33620	4.1e5	4.1e5
	VT	17520	17180	-	6326	-	2124	-	91390	-	36200	-	1.4e5
310	NS	-	586	-	571	4217	3713	-	4739	56000	49260	-	7909
	EW	-	1601	3289	3227	-	458	-	1076	-	6419	46270	45220
	VT	1953	2100	-	5240	-	650	-	1438	-	10230	-	72770
402	NS	-	3797	-	2520	33180	33190	-	1.5e5	1.3e6	1.3e6	-	27070
	EW	-	10860	31680	31650	-	2510	-	35820	-	37310	1.3e6	1.3e6
	VT	23910	26270	-	6877	-	2411	-	59170	-	36600	-	1.5e5

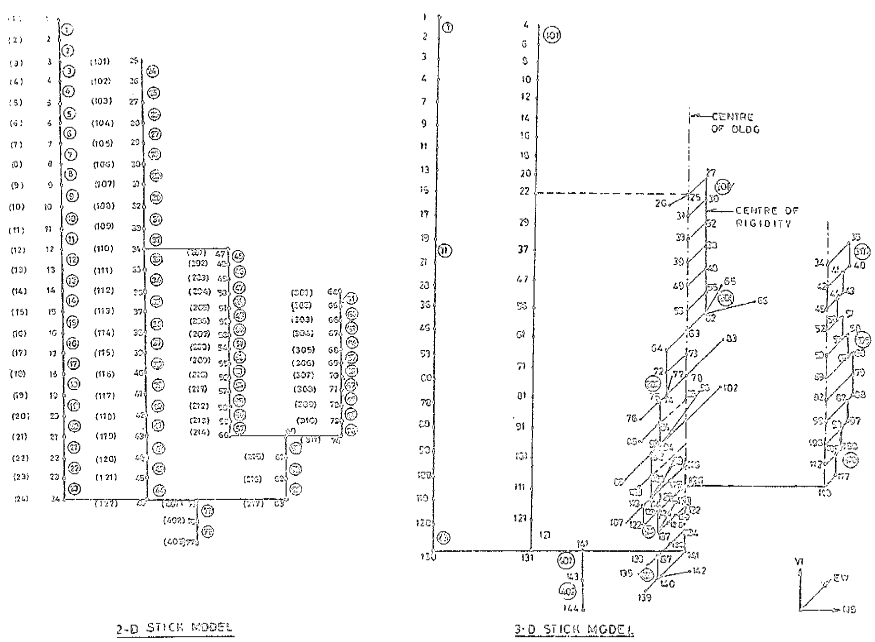

FIG 1 IDEALIZATION OF RB FOR DYNAMIC ANALYSIS