Modelling of Internal Structure in Seismic Analysis of a PHWR Building

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1 ABSTRACT

Seismic analysis of complex and large structures, consisting of thick shear walls, such as Reactor Building is very involved and time consuming. It is a standard practice to model the structure as a stick model to predict reasonably the dynamic behaviour of the structure. The Internal Structure of Reactor Building consists of massive walls with complex geometrical configuration such as overhanging of one section over the other. It is required to determine approximate equivalent sectional properties of Internal Structure for representation in the stick model. Standard formulae are available for determination of the sectional properties such as cross sectional area, shear areas, moments of inertia, centre of rigidity and torsional inertia etc. These sectional properties depends very much upon the constraints like rigidity of slab, length of section etc. The restraint to warping can change the stress distribution thus affecting the centre of rigidity and torsional inertia. Hence, standard formulae does not hold good for determination of sectional properties of the Internal Structure. In this case the equivalent sectional properties for the Internal Structure are calculated using a Finite Element Model (FEM) of the Internal Structure and applying unit horizontal forces in each direction. A 3-D stick model is developed using the guidelines given in references. (Subramanian et.al.) Using the properties calculated by FEM and also by standard formulae, the responses of the 3-D stick model are compared.

2 INTRODUCTION

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. (Fig.1) 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 (Ref. Fig. 2-5). 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.

3 EVALUATION OF SECTIONAL PROPERTIES

The basic data required for the analysis is cross sectional properties, lumped masses and mass moments of inertia. Once these properties are available, a mathematical model of a structure can be developed. The cross sectional properties consist of cross sectional area, shear area, moments of inertia, centre of rigidity and torsional inertia. The cross sectional properties for OCW ,ICW, CV and RAFT elements are calculated using standard formulae as these are well defined standard sections. The calculation of cross sectional properties for Internal Structure is described below.

3.1 CENTRE OF RIGIDITY AND TORSIONAL INERTIA

The centre of rigidity of a section can be defined as a point in the plane of the section about which a transverse load when applied at that section, produces only bending deflections and no twist of the section. The torsional centre is defined as that point in the plane of the section where a twisting couple produces only rotation of the section about this point and no deflection (Young-1989). By Betty Maxwells law in linear domain, the centre of rigidity and torsional centre are the same point on the cross section. There are two ways of locating the centre. A horizontal force along each horizontal direction can be applied and the centre is located using the deflections and the torsional rotation. Alternatively, a torsional moment is applied by using two equal and opposite forces and the centre is located as the point in the cross section where both the horizontal displacements are zero. This method has been applied in this investigation.

Different sections of Internal Structure are modelled by FEM, considering slab at top and fixed at bottom. A torsional moment is applied by applying two equal and opposite forces on each section. The centre of rotation where the horizontal displacements are zero, is located by ploting the displacements of the section at slab level. The torsional inertia is calculated using the torsional rotation of the section and eq. 1.

$$\text{Torsional inertia } (J) = T\ L\ /\ G\ \theta \qquad \text{--- (1)}$$

Where T = Applied torsional moment
L = Length of member
G = Modulus of rigidity
θ = Torsional rotation

3.2 CROSS SECTIONAL AREA, SHEAR AREA and MOMENT OF INERTIA

After preliminary study of Internal Structure,it can be seen that the sections below EL 100000 are massive, consisting of closed boxes. The sectional properties of these sections are calculated by standard formulae about centre of rigidity. Above EL 100000 upto EL 130000, the structure consists of two open sections, partially supported by section below (Ref. Fig.1). To represent these sections at centre of the stick model it is necessary to calculate equivalent sectional properties. The Internal Structure above EL 100000 is modelled by FEM. The structure is modelled by using 4 noded flat shell element. A load in each direction is applied as different load cases. The load is applied such that the resultant will pass through the centre of rigidity located as per section 3.1. After plotting the horizontal and vertical displacements for each load case, the average displacement and rotation of the section is calculated. Using these displacement and rotation, the properties like shear area and moment of inertia are calculated by using stiffness matrix (eq.2) of member with shear area and moment of inertia as unknown for horizontal load cases. Using vertical deflections, obtained from application of vertical load, the cross sectional area are calculated using eq-3. The comparision of these properties with the standard properties are given in TABLE-1.

$$\frac{EI}{L^3(1+\phi)}\begin{bmatrix} 12 & 6L & -12 & 6L \\ & (4+\phi)L^2 & -6L & (2-\phi)L^2 \\ & & 12 & -6L \\ & & & (4+\phi)L^2 \end{bmatrix}\begin{bmatrix} \delta i \\ \theta i \\ \delta j \\ \theta j \end{bmatrix} = \begin{bmatrix} Pi \\ Mi \\ Pj \\ Mj \end{bmatrix} \quad \text{--(2)} \qquad \begin{bmatrix} \frac{AE}{L} & \frac{-AE}{L} \\ & \frac{AE}{L} \end{bmatrix}\begin{bmatrix} \delta i \\ \delta j \end{bmatrix} = \begin{bmatrix} Pi \\ Pj \end{bmatrix} \quad \text{- (3)}$$

Where $\phi = 12\ E\ I\ /\ G\ As\ L^2$
As= Shear area
EI= Flexural rigidity
AE= Axial rigidity
δ = Displacements
θ = Rotations
P = Applied shear forces
M = Applied Moments

4 ANALYSIS

A 3-D stick model is developed using the sectional properties calculated by FEM and standard formulae. The model adopted is in line with the equivalent model developed (Subramanian et.al.). In this model, the stick is represented along the centre of rigidity and the masses are lumped at the mass centre. (Ref. Fig.6) The mass nodes are connected to stick nodes by rigid links. Model-A is the 3-D stick model using the properties calculated by standard formulae and model-B is the 3-D stick model using properties calculated by FEM as described in para 3.1 and 3.2.

The response spectrum analysis is performed for both the models using program SAPIV (Bathe et.al.). There frequency results are tabulated in TABLE-2 and the comparision of results for few important elements is done in TABLE-3.

5 CONCLUSIONS

It has been seen that the sectional properties of internal structure are different from those calculated using standard formulae due to the effect of short height of section, slab rigidity, offset in the sections etc. It has been observed that the dynamic characteristics of the two equivalent structural systems (model-A and model-B) are widely different as features like offsets, hanging sections, shear lag effect etc. influences very much the structural behaviour. These can only be established with a 3-D FEM for computation of the equivalent stick properties.

6 ACKNOWLEDGEMENT

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7 REFERENCES

Subramanian,K.V., Ingle,R.K., Kushwaha,H.S., Vaze,K.K., Reddy,G.R., Dec. 1990, Conversion of 3-D Structure Into 3-D Stick Model,Ninth Symposium on Earthquake Engineering.

Young,W.C., 1989, ROARK's Formuale for Stress and Strain, Singapore, McGraw- Hill Book Co.-Singapore.

Bathe,K.J., Wilson,E.L., Peterson,F.E., 1973, SAPIV A Structural Analysis Program for Static and Dynamic Analysis of Linear Structural Systems, College of Engineering, University of California, Berkeley, EERC Report.

TABLE-1 COMPARISION OF SECTIONAL PROPERTIES FOR INTERNAL STRUCTURE

SECTION		SHEAR AREA NS m^2	M. OF INERTIA @ EW m^4	SHEAR AREA EW m^2	M. OF INERTIA @ NS m^4	SECTION AREA m^2	TORSIONAL INERTIA m^4	RIG. CENTRE NS m	EW m
EL085000	FORM.	272.90	21064.6	264.60	46030.6	430.30	1010.00		
-089000	FEM						55460.00	0.0	-0.50
EL089000	FORM.	306.00	24184.0	277.10	53781.6	475.95	56369.00		
-093000	FEM						87930.60	0.0	0.00
EL093000	FORM.	218.50	16351.9	182.70	41299.5	334.96	33515.00		
-096000	FEM						57200.00	0.0	-2.03
EL 96000	FORM.	156.30	11639.9	113.90	40353.5	233.70	121.58		
-100000	FEM						36577.63	0.0	-2.37
EL100000	FORM.	123.65	5514.9	97.30	9131.8	192.13	120.15		
-104500	FEM	97.36	3197.2	63.60	4051.1	192.06	33890.16	0.0	-2.37
EL104500	FORM.	121.36	5164.4	28.50	3378.3	150.69	92.41		
-109000	FEM	87.74	3526.3	19.20	1396.1	60.08	21410.00	0.0	-0.42
EL109000	FORM.	129.01	5303.5	28.50	3378.3	152.66	108.17		
-115500	FEM	104.35	5812.1	31.60	3378.3	147.08	20627.74	0.0	-0.42
EL115500	FORM.	41.86	551.2	56.40	3712.4	90.02	1260.90		
-130000	FEM	33.15	491.7	38.80	3407.6	102.01	1600.00	0.0	0.47

TABLE - 2 DYNAMIC RESULTS FOR MODEL-A and MODEL-B

MODE	FREQ	MODAL P. F. MODEL-A			MODE	FREQ	MODAL P. F. MODEL-A			MODE	FREQ	MODAL P. F. MODEL-B			MODE	FREQ	MODAL P. F. MODEL-B		
1	1.45	0.3	.00	0.0	21	12.7	.37	-.3	.07	1	3.62	0.0	1.6	-.1	21	14.2	0.0	-.9	.03
2	2.42	.03	.01	0.0	22	12.8	-.7	-.3	0.0	2	3.95	1.8	.01	0.0	22	14.8	.36	0.0	-.1
3	3.47	.12	.15	0.0	23	12.9	.14	-.7	.08	3	4.79	0.0	1.2	.03	23	17.6	0.0	.10	0.1
4	3.76	0.0	1.7	-.1	24	13.2	0.0	0.0	0.0	4	4.80	1.0	0.0	.00	24	18.4	.07	.03	.02
5	3.79	.82	0.0	0.0	25	14.0	.02	.39	-.2	5	6.73	.05	.73	.12	25	19.5	0.0	.51	.31
6	4.01	.42	0.0	0.0	26	14.4	0.0	-.1	.08	6	6.92	1.6	-.1	.05	26	19.8	.25	.10	.03
7	4.46	-.9	0.0	0.0	27	14.7	-.7	.03	-.1	7	7.78	.15	.03	.02	27	20.3	-.1	.14	.27
8	4.78	.20	0.0	0.0	28	15.7	.49	.02	-.1	8	8.22	-.3	.03	-.3	28	20.6	-.1	-.3	.53
9	4.79	0.0	1.1	0.0	29	16.5	0.0	0.0	0.0	9	8.62	0.0	0.0	0.0	29	20.7	.33	-.1	.24
10	4.82	0.6	0.0	0.0	30	18.1	.16	0.0	0.0	10	9.22	-.2	0.0	-.4	30	21.1	0.0	-.3	.40
11	7.26	2.3	0.0	.09	31	18.6	0.0	0.0	.16	11	9.35	.14	.52	-2.	31	21.9	0.7	-.0	.06
12	7.48	0.0	.78	.11	32	19.1	0.0	0.0	0.0	12	9.73	-.1	.68	2.5	32	23.1	-.0	.09	-.2
13	7.97	0.0	0.0	0.0	33	20.2	.02	-.5	-.3	13	11.1	0.0	0.1	-.9	33	23.2	.14	.03	-.1
14	8.63	0.0	0.0	0.0	34	20.5	.05	-.2	.11	14	12.2	.16	-.1	.36	34	23.5	.03	0.0	.01
15	8.83	1.1	0.0	-.3	35	20.9	.12	.02	-.3	15	12.6	.27	-.0	.16	35	24.3	.03	-.1	-.2
16	9.72	.09	.57	-2.	36	21.0	.11	.06	.16	16	12.7	-.7	-.1	.01	36	24.9	-.1	0.0	0.0
17	10.1	-.1	.24	2.3	37	21.6	0.0	.11	.21	17	12.9	.07	-.9	.02	37	25.7	.73	0.0	0.0
18	11.9	0.0	0.0	-.5	38	21.7	0.0	-.3	.55	18	13.1	-.1	0.0	.02	38	26.0	0.0	.83	.09
19	12.1	0.0	0.0	0.0	39	22.9	-.4	0.0	-.1	19	13.6	.14	.45	-.1	39	26.7	0.0	0.0	.08
20	12.6	.16	-.2	-.1	40	24.1	.74	-.2	.09	20	13.6	-.6	.09	-.1	40	28.3	0.0	-.5	.02

TABLE -3 COMPARISION OF FORCES FOR 2-D AND 3-D STICK MODELS UNITS: T-m

ELE	DIR	AXIAL FORCE		SHEAR (EW)		SHEAR (NS)		TORSION		MOMENT @ EW		MOMENT @ NS	
		MOD-A	MOD-B	MOD-A	MOD-B	MOD-A	MOD-B	MOD-A	MOD-B	MOD-A	MOD-B	MOD-A	MOD-B
23	NS	3195	3312	1137	623	6918	7238	6247	23640	3.1e5	3.1e5	18210	11940
	EW	3472	1694	6790	7141	1134	574	6662	4303	17890	11990	3.0e5	3.1e5
	VT	4217	4097	575	602	362	349	1587	15060	13530	13380	24540	27950
121	NS	2156	2342	1037	1174	12780	15760	29380	67960	6.1e5	7.4e5	25580	19480
	EW	2952	2005	15700	16610	996	609	29370	15050	19490	15220	7.4e5	7.8e5
	VT	5769	5691	941	987	473	389	2557	31220	13920	14610	42860	65630
206	NS	1500	1417	835	612	4654	4655	21400	6002	68070	68140	8736	9666
	EW	2632	2458	3719	2470	499	386	16640	1674	3224	5655	74040	58980
	VT	4174	4567	1718	2971	500	399	598	6719	4429	6745	29520	40400
216	NS	4804	4285	733	1666	17260	19070	1.6E5	94670	4.4e5	4.9e5	15270	27220
	EW	7558	7897	18660	17080	1020	2259	4107	27190	11400	33620	4.8e5	4.1e5
	VT	16340	17180	4334	6326	1677	2124	946	91390	24130	36200	97700	1.4e5
310	NS	539	586	432	571	4801	3713	36640	4739	65990	49260	6755	7909
	EW	1330	1601	3189	3227	173	458	629	1076	1670	6419	45340	45220
	VT	1679	2100	4607	5240	428	650	124	1438	7013	10230	64870	72770
402	NS	3109	3797	3081	2520	29210	33190	1.8E5	1.5e5	1.2e6	1.3e6	36620	27070
	EW	7848	10860	32990	31650	3078	2510	33520	35820	30130	37310	1.4e6	1.3e6
	VT	26090	26270	4967	6877	1976	2411	3580	59170	27410	36600	11680	1.5e5

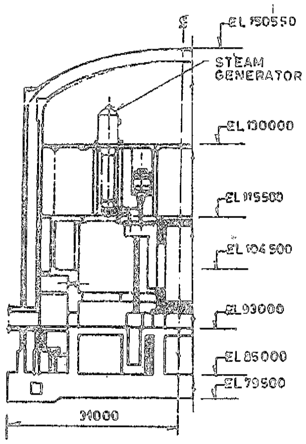

FIG-1
HALF SECTION OF REACTOR BUILDING

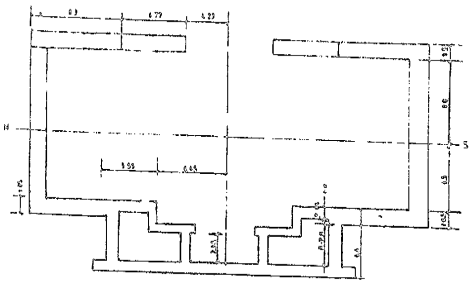

FIG-4
PLAN AT ELEVATION 100·00

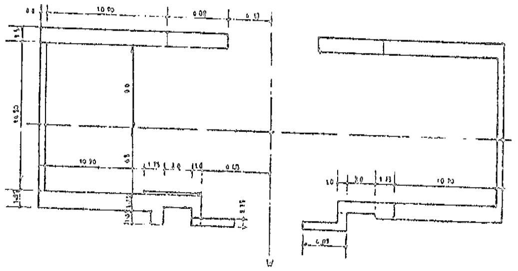

FIG-5
PLAN AT ELEVATION 104·5

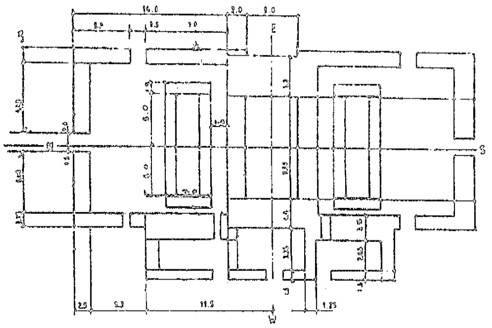

FIG-2
PLAN AT ELEVATION 85·0

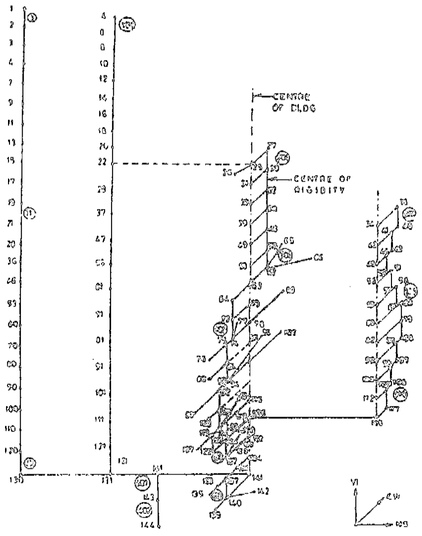

FIG-6
3-D STICK MODEL

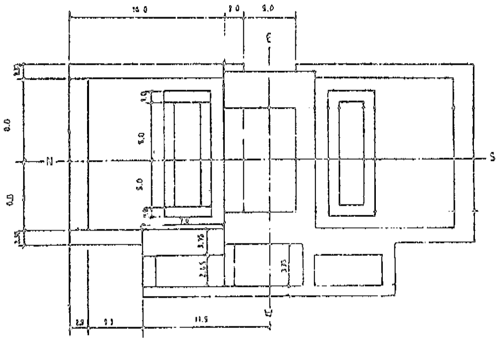

FIG-3
PLAN AT ELEVATION 89·0