SEISMIC ANALYSIS OF A COMPLEX TURBO-GENERATOR BUILDING INCLUDING TORSION

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SYNOPSIS

A turbogenerator building with complex frames has been studied for seismic forces, using three analytical models. The effects of joint rotations and axial deformations on the dynamic characteristics and the seismic response are studied. Suitability of block model and plane frame models for seismic analysis of such buildings is examined.

INTRODUCTION

A multistoreyed reinforced concrete building with complex frames such as involved in a large capacity turbogenerator building presents many problems in the analysis for earthquake forces. The rigorous method considering all possible degrees of freedom including torsion in the dynamic response computations is rather complicated and therefore not suitable for preliminary design purposes. An approximate method is therefore resorted to in practical problems which provides for the torsional shears in the structure on account of unsymmetrical configuration of the structure elements. Results of analysis of a typical building of this type are presented to demonstrate the procedure. The building has been considered as a block and also an assemply of set of plane frames. The block analysis assumes floors as rigid elements and considers only the stiffness of columns. Individual frames are studied using two analytical models - one assuming girders to be infinitely rigid elements and the other considering joint rotations and also axial deformations. The results obtained in the three cases are compared.

THE SEISMIC ANALYSIS

Ground floor plan of the building chosen for study is shown in Fig 1 and typical cross frame elevations in Fig 2 & 3. For the purpose of dynamic analysis, the building is considered in two ways - one treating the entire building vibration as one block in any direction and the other considering the individual frames as independent units. The two models thus assume different action of the horizontal diaphrams between the frame grids.

The stiffness matrix for the block analysis could be assembled straightway since floors were assumed rigid and hence the column stiffnesses were lumped together. In the case of individual frames, however, it is not possible to organise the stiffness matrix as easily since the beam flexibility permits joints to rotate. The generalized stiffness matrix works out much larger in size which is not convenient for the purpose of determination of first few frequencies. For this purpose the flexibility coefficients at certain selected points of mass concentration (floor levels) were obtained from the generalized flexibility matrix of the structure. This reduced flexibility matrix was then used to compute the frequencies and mode shapes of the frames.

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Computation of Seismic Shears: Modal shears corresponding to the design earthquake spectra, in the first three modes were computed and combined using the quadratic law. If the frames or the block elements were regular and symmetrical, member forces could be easily obtained from these shear forces. However, since generally it is not so, corrections must be made on account of torsion resulting from unsymmetry. An approximate method for working out additional shears due to this is explained in brief, in the following para.

Figure 4 shows a typical plan at any storey level in a framed building. Assuming that the floor girders are rigid element, the center of gravity ($\bar{X}_F$) of total seismic shear ($\bar{S}$) in the storey is worked out from the origin, as shown. The center of rigidity of columns in a storey is worked out as $\bar{X}_G$ and eccentricity is obtained as $(\bar{X}_G - \bar{X}_F)$. The design eccentricity e, is taken as 1.5 times this value. Additional shear on any column line or frame is computed as,

$$S_{t,x} = \frac{S.e(X - \bar{X}_G)\lambda x}{I_p} \quad \ldots (1)$$

in which I_p is the polar stiffness of the system and λx is the stiffness of column line or frame, situated at distance X from origin. The values $S_{t,x}$ computed from eqn 1 are then added to original values of shear to get increased shears on account of torsion. Reduction in shear as would be indicated by a minus value of $S_{t,x}$ is usually ignored for design purposes.

PRESENTATION OF RESULTS AND DISCUSSION

Complete modal analysis of the building (Fig 1,2 and 3) was carried out as mentioned earlier. The natural periods for the block model and those for the individual frames in the first three modes, in the two directions are given in Table-I. It is seen that the block analysis gives shorter periods throughout compared to the periods of individual frames when calculated considering joint rotations and axial deformations. However, the individual frames without joint rotation indicate periods which are considerably shorter. For some frames the periods work out even shorter than the one given by block analysis. The reason for this feature is that these frames have very stiff columns as compared to others and as such demonstrate the effect of joint rotation at girder levels. It is observed that the frames have some variations in the periods in both the directions and the scatter is of the same order.

Shear forces obtained from modal analysis are modified to take into account the effect of torsion as explained above. It is seen that the maximum increase in shear in end frames could be as much as 30%. This value however, is very much related with the floor plan of the building.

Seismic forces computed for the individual frames are combined appropriately in order to obtain the shears for the entire building. These are then compared with the results obtained from the block analysis in the transverse and longitudinal direction. Table-II demonstrates this comparison wherein seismic shears for the three analytical models are shown, in the longitudinal and the transverse directions. It is seen that block analysis gives higher seismic shears compared to those obtained from assembly of individual frames. The effect of joint rotation in frames as exhibited in Table-I is present in Table-II also and the shears do get affected on account of the changes in period. The consistent comparison in the seismic shears in both the directions is interesting.

It may, however, be pointed out that if seismic forces obtained from block analysis, are distributed to various frames, in proportion to stiffness at each level, and then compared with the forces obtained for these frames considering them as individual units, the situation may be quite different. In fact, seismic forces in the two cases viz. block analysis and individual frame analysis work out very differently. However there is a good and consistent comparison between the results of individual frame analysis with and without joint rotation. The reason for variation of seismic force in the two cases is the non-uniform distribution of masses associated with individual frames at various storey levels.

CONCLUSIONS

The analysis of building as presented in this paper shows that the two analytical models lead to different natural periods and seismic forces for the building. It is seen that the effect of joint rotations and axial deformations is to elongate the periods which do affect the seismic response considerably. This aspect is quite significant and must be included in the analysis. Torsion due to unsymmetrical configuration of structural elements must be considered for determining final shears in the frames and therefrom the member forces. In choosing the model for determination of member forces, much will depend on the type of framing and concentration of loads over the building at various floors.

ACKNOWLEDGEMENTS

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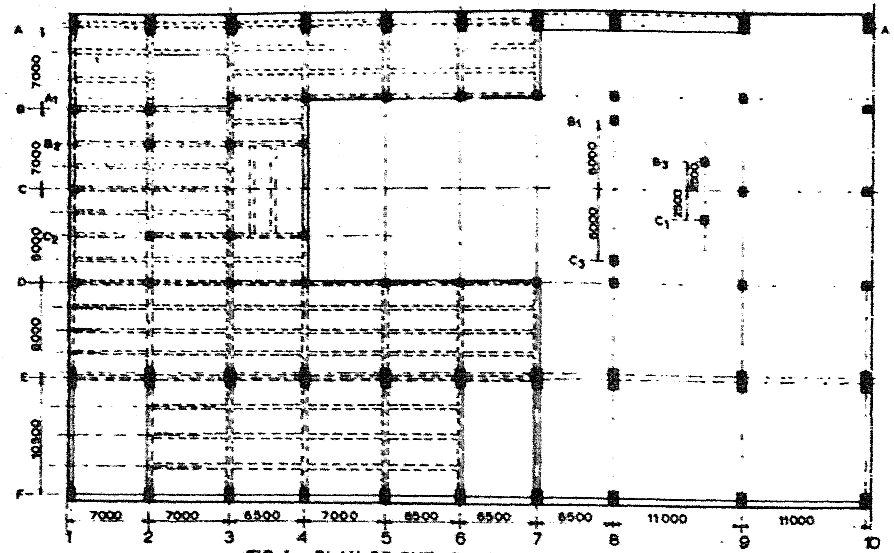

FIG. 1 _ PLAN OF THE BUILDING AT EL. 100,000

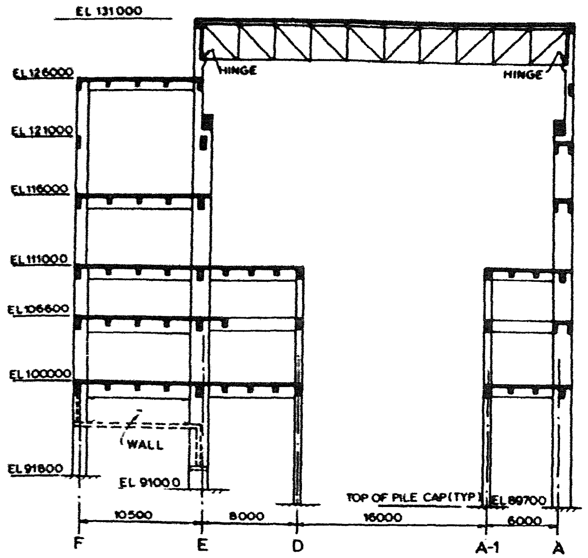

FIG. 2 _CROSS-SECTION OF THE BUILDING ALONG GRID-6

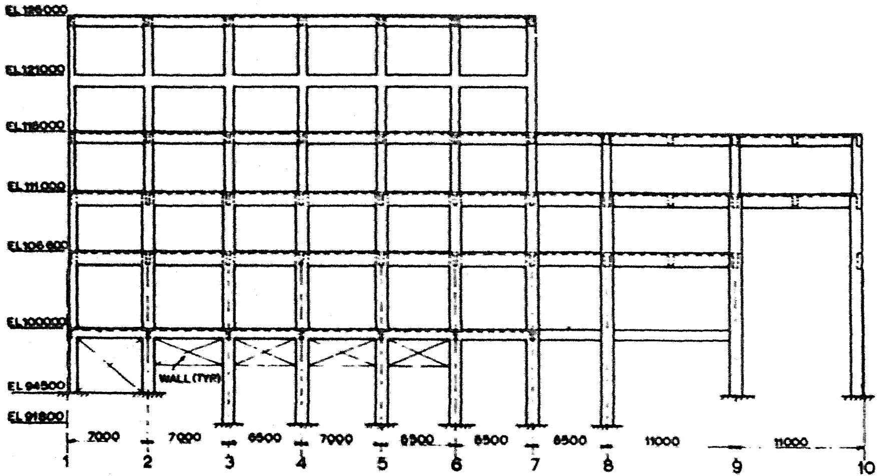

FIG. 3 _CROSS-SECTION OF THE BUILDING ALONG GRID F

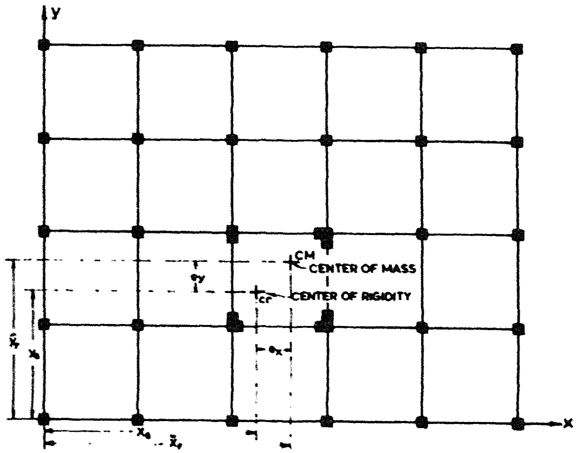

FIG. 4 _TYPICAL PLAN OF A STOREY IN A FRAMED BUILDING SUBJECTED TO TORSION

TABLE I - NATURAL PERIODS OF VIBRATION FOR THE BUILDING USING VARIOUS ANALYTICAL MODELS

LONGITUDINAL DIRECTION

Mode No.	Block period with floors taken rigid	Periods of Grids A to F (floors taken rigid)						Periods of Grids A to F (axial def.& Jt.Rotation included					
		A	B	C	D	E	F	A	B	C	D	E	F
1	0.883	0.84	1.44	1.43	1.62	0.91	0.69	1.26	1.46	1.49	1.65	1.11	0.86
2	0.348	0.29	0.36	0.41	0.44	0.33	0.25	0.45	0.39	1.29	0.47	0.49	0.33
3	0.215	0.19	0.14	0.17	0.19	0.20	0.16	0.26	0.15	1.05	0.22	0.25	0.20

TRANSVERSE DIRECTION

Mode No.	Block Period with floors taken rigid	Periods of Grids 1 to 10 (floors taken rigid)										Periods of Grids 1 to 10 (axial deformation & joint rotation included)									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	0.754	0.55	0.89	0.93	0.90	0.93	0.90	0.68	1.68	1.79	1.32	1.09	1.17	1.30	1.22	1.38	1.20	1.20	1.87	1.95	1.47
2	0.475	0.25	0.46	0.50	0.56	0.57	0.54	0.54	1.01	0.74	0.52	0.42	0.63	0.66	0.65	1.02	0.83	0.90	1.11	0.91	0.64
3	0.203	0.15	0.23	0.23	0.27	0.55	0.49	0.36	0.66	0.11	0.08	0.23	0.22	0.28	0.29	0.67	0.59	0.50	0.82	0.19	0.15

TABLE II COMPARISON OF SHEAR (IN TONNES) AT VARIOUS LEVELS

LONGITUDINAL DIRECTION

Elev. (m)	Block Ana. floors Taken rigid Shear in Grids A to F						SUM	Grid Ana. floors taken rigid Shear in Grids A to F						SUM	Grid Ana. axial defor.,Jt.Rot. incl. Shear in Grids A to F						SUM
	A	B	C	D	E	F		A	B	C	D	E	F		A	B	C	D	E	F	
131.00	182	-	--	-	182	-	364	161	-	-	-	147	-	308	127	-	-	-	160	-	287
126.00	241	-	-	-	244	154	639	230	-	-	-	269	94	593	175	-	-	-	282	89	546
121.00	405	-	-	-	405	170	980	373	-	-	-	367	163	903	267	-	-	-	356	146	769
116.00	590	-	-	-	590	368	1548	467	-	-	-	618	438	1523	328	-	-	-	549	356	1233
111.00	515	113	89	113	1034	776	2640	675	108	85	112	904	668	2552	459	108	84	112	765	530	2058
111.00	-	-	17	-	-	-	17	-	-	28	-	-	-	28	-	-	28	-	-	-	28
111.00	-	-	5	-	-	-	5	-	-	1	-	-	-	1	-	-	2	-	-	-	2
106.60	677	132	121	82	1151	1025	3188	754	134	139	147	1088	854	3116	516	142	131	68	915	672	2444
106.60	-	-	5	48	-	-	53	-	-	7	-	-	-	7	-	-	32	89	-	-	121
100.00	1099	133	76	63	1046	1281	3698	853	228	178	182	1104	955	3500	596	229	179	198	938	729	2869

TRANSVERSE DIRECTION

Elev. (m)	Block Analysis floors taken rigid Shear in Grids 1 to 10										SUM
	1	2	3	4	5	6	7	8	9	10	
131.00	245	136	136	136	136	136	136	27	27	27	1142
126.00	816	81	72	64	61	61	412	-	-	-	1567
121.00	591	-	-	-	-	-	464	-	-	-	1055
116.00	227	191	182	174	165	158	158	158	158	158	1729
111.00	213	281	281	94	94	97	98	107	302	311	1878
111.00	-	-	-	15	4	-	-	-	-	-	19
111.00	-	-	-	-	4	-	-	-	-	-	4
111.00	-	-	-	172	172	177	178	184	-	-	883
106.60	313	414	414	414	275	297	319	73	227	194	2940
106.60	-	-	-	-	157	170	183	65	-	-	575
100.00	725	969	336	336	214	214	214	-	-	-	3008
100.00	-	-	-	-	74	74	74	-	-	-	222

Elev. (m)	Grid Analysis floors taken rigid Shear in Grids 1 to 10										SUM
	1	2	3	4	5	6	7	8	9	10	
131.00	49	66	84	74	68	63	85	54	49	37	629
126.00	200	107	133	110	99	92	94	-	-	-	835
121.00	194	-	-	-	-	-	127	-	-	-	321
116.00	362	226	228	165	158	90	169	36	51	37	1522
111.00	472	455	350	53	64	56	60	92	262	162	2026
111.00	-	-	-	87	26	-	-	-	-	-	113
111.00	-	-	-	-	12	-	-	-	-	-	12
111.00	-	-	-	156	170	133	236	91	-	-	786
106.60	468	524	355	314	224	227	349	137	359	202	3159
106.60	-	-	-	-	113	93	113	112	-	-	431
100.00	509	640	476	448	301	334	420	-	-	-	3128
100.00	-	-	-	-	163	129	136	-	-	-	428

Elev. (m)	Grid Ana. axial defor., Jt. Rot. incl. Shear in Grids 1 to 10										SUM
	1	2	3	4	5	6	7	8	9	10	
131.00	35	74	61	64	42	55	54	52	56	43	536
126.00	157	135	111	110	72	94	68	-	-	-	747
121.00	124	-	-	-	-	-	91	-	-	-	215
116.00	243	252	236	176	149	99	111	37	39	32	1374
111.00	298	327	313	44	25	31	32	69	169	121	1429
111.00	-	-	-	54	7	-	-	-	-	-	61
111.00	-	-	-	-	18	-	-	-	-	-	18
111.00	-	-	-	165	158	127	142	77	-	-	669
106.60	254	312	286	239	193	190	217	109	233	148	2181
106.60	-	-	-	-	39	55	67	70	-	-	231
100.00	270	368	339	313	233	244	251	-	-	-	2018
100.00	-	-	-	-	51	64	70	-	-	-	185