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CAUTIONS IN USE OF 2-D ANALYSES OF POWER HOUSE STRUCTURES

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SUMMARY

The objective of the paper is to evaluate the practice of analysing power house structures by means of 2-D idealisations. The first part of this study attempts to show up the discrepancies between an extensible and an inextensible planar model when subjected to the same set of loads, whereas the second part attempts to highlight the differences which could arise between a planar (2D) and a three dimensional model (3D) of the power house structure, subjected to modelling practices usually adopted.

INTRODUCTION

Power house structures have been analysed in the past employing 2D analysis of component orthogonal frames (Ref. 1,2). However a three dimensional analysis takes into account the torsional and flexural rigidities of cross members and is advantageous not merely because it considers all possible displacements of the joints but also because it does not require any resolution of frames and loads. The present paper examines this aspect of analytical options through detailed study of a typical power house structure.

In the first phase of this study a comparison has been made of member forces in plane frames by considering and ignoring axial deformations of the members in the analysis. This study reveals that extensibility affects the results of the analysis considerably and hence the conventional moment distribution method which is often adopted in design office, should be used with caution. The second phase of study includes a comparison of 2-D and 3-D analysis for such structures. The forces evaluated from 3-D analysis are found to be generally higher than their 2-D counterparts contrary to popular belief, except for members of flexible central frame wherein the forces are generally lower. Hence, 2-D analysis would not be adequate for such a highly unsymmetrical structure, in which torsion plays a significant role and is normally ignored in a conventional 2-D analysis.

DESCRIPTION OF STRUCTURE

The structure, comprises outer walls monolithic with exterior columns and consists of independent structural units known as 'unit bay' and 'service bay'. Each bay is further subdivided into component frames designated as 'central' and 'end' frames. The structural configuration of a typical frame consists of interconnected beam column assemblages. The frame is monolithic with base of mass concrete and supports a roof truss on top. The construction sequence comprises of mass concreting for unit bays followed by the erection of walls and columns and then the roof structure. The concreting of the interior, depending upon machine installation, forms the final phase of sequence. The construction sequence can be accounted for in the analysis by considering the unit bays in three stages. The service bay may be analysed only for the final phase because heavy machinery units are not present in this bay.

MATHEMATICAL MODELS OF THE STRUCTURE

The structure is idealised as a skeletal system which retains the properties of the original structure. The assumptions involved are essentially such as to facilitate mathematical modelling of real system in a manner that the behaviour of the prototype structure can be simulated.

The plane frame model neglects (a) presence of cross members (b) slab interaction with framework and (c) stiffness contribution of heavy outer walls. The space frame model also neglects the effect of slab and walls and considers only the skeletal frame for analytical purposes. For free vibration analysis lumped mass models have been used. The idealised frames based on the above criteria are shown in Figs. 1 and 2 for plane frame analysis and in Figs. 3 and 4 for space frame analysis (Ref. 3).

TYPES OF ANALYSES CONDUCTED

In order to investigate the behaviour of structure the analyses conducted consisted of following:

1. Static analysis of plane frame model with four sets (described later) of loads.
2. Dynamic analysis of plane frame with horizontal ground motion in transverse (X) and vertical (Y) direction.
3. Static analysis of space frame model with four sets of loads.
4. Dynamic analysis of space frame with ground motion in X and Y direction.

The site dependent spectra for horizontal motion was prescribed and the vertical component was taken as 50% of the horizontal component.

For static analysis, four arbitrary load cases have been assumed in which the horizontal loads represent the static wind etc. while vertical loads represent the dead and live loads, etc. These four loads cases are as follows:

(a) Horizontal loads acting from left to right
(b) Horizontal loads acting from right to left
(c) Vertical loads larger on left side of the structure
(d) Vertical loads larger on right side of the structure.

Each bay of the powerhouse consists of three transverse frames and two longitudinal frames. For the purpose of study only transverse frames have been examined. In first part of study, plane frames were analysed for static and dynamic loading treating the members as extensible, and the effect of axial extensibility was examined. In second part, space frame static and dynamic analysis were conducted for both, service bay and unit bay frames.

EFFECT OF EXTENSIBILITY IN PLANE FRAME ANALYSIS

Dynamic Analysis : Analysis for the component transverse frames has been conducted considering the combined effect of ground motions in transverse (X) direction and vertical (Y) direction. This analysis has been done for extensible as well as inextensible frames and results are presented herein (Ref. 3).

Table 1 shows the dynamic characteristics for first three modes for extensible and inextensible frames of unit bay and for the service bay. It is seen that, in general, mode participation factors (MPF) in both the directions are less in inextensible frames. There is an appreciable change in MPF which is indicative of changes in the pattern of behaviour of the two structural systems.

The SRSS axial forces, shear forces and moments at the two ends of the members for first three modes for the end frame and central frame of unit bay, evaluated from the response spectrum analysis of these frames, indicate that non consideration of axial deformation in frames, in general, increases the shear forces and moments in most of the members.

Static Analysis : It is seen that under the influence of horizontal as well as vertical loads, the forces in most of the members (particularly moments) are under-estimated in inextensible frame when compared to extensible frame (Ref. 3).

COMPARISON OF PLANE FRAME AND SPACE FRAME ANALYSES

Space frame analysis has been carried out for service bay and unit bay. The results obtained from the dynamic and static analysis are compared with corresponding results obtained from plane frame analysis (Ref. 3).

Dynamic Analysis : The dynamic characteristics of the 2-D and 3-D frames are shown in Table 2. It is seen that the fundamental period of space model of service bay lies in between the corresponding values of plane frames, which shows that 2-D analysis underestimates the period of vibration for end frames but overestimates for central frame. This is due to the fact that central frame is relatively flexible compared to end frame in 2-D, while in space frame, presence of cross members make the central frame stiffer. In higher modes, apart from lateral deformation twisting becomes predominent in space frame, while in plane frame only lateral deformations are present. This is one of the reason that values of natural periods of space frame and plane frame are not comparable in higher modes.

The SRSS forces at the two ends of the members in end and central frames of service bay and unit bay have been evaluated. It is seen that forces in end frame of 2-D model are generally less compared to 3-D, while these are seen to be higher in case of central frame. It is obvious from the dynamic characteristics of space frame and plane frames (Table 2) that end frame of 2-D are stiffer compared to space structure, hence subjected to less deformation while central frames are more flexible in 2-D which results in larger forces.

Static Analysis : Static analysis for 3-D model has been carried out for two cases of loading pattern viz. full space frame loaded and only one plane of structure loaded by loads corresponding to 2-D frames.

Comparison of results of 3-D and 2-D analysis does not lead to any set pattern for the increase or reduction in member forces, when the whole space frame is loaded. However, 2-D analysis shows less forces in the end frames and higher in the central frames because of the fact that unit bay is highly unsymmetric and torsion plays a significant role due to which some members show reverse trend also. There is appreciable difference in the results of two analysis under dominant horizontal loads compared to those in which vertical loads dominate.

CONCLUSIONS

Based on the results reported herein, the following conclusions may be drawn:

(a) Inextensibility of members results in shortening of periods of vibration and may increase the total seismic response of the system.

(b) Under the action of dominant vertical loads, member forces (moments) are generally underestimated in inextensible frames. This could have far reaching consequences since dead and live loads are always there as major contributor to design forces.

(c) Periods of vibration of space frame and constituent plane frames are not comparable due to dominance of torsion in higher modes of the former.

(d) Comparison of 2-D and 3-D results for individual frames obtained for some loading patterns, highlights the load dispersion characteristics exhibited by the structure. It is seen that member forces as evaluated by 3-D model could be somewhat higher in flexible frames because of dispersion of load to stiffer frames.

(e) SRSS combination of member force response shows that 2-D analysis may generally yield lower forces compared to 3-D values, except in case of flexible central frames where 3-D values may be lower.

(f) For static loads corresponding to total load of constituent frames member forces are higher in 3-D analysis which may be contrary to the popular belief.

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TABLE 1 : DYNAMIC CHARACTERISTICS OF EXTENSIBLE/INEXTENSIBLE FRAMES

FRAME NAME	MODE NO.	PERIOD (SEC.) EXT.	PERIOD (SEC.) INEXT	MPF (HORZ.) EXT.	MPF (HORZ.) INEXT.	MPF (VERT) EXT.	MPF (VERT) INEXT.
UBCF	1	0.8090	0.8060	1.7168	1.7068	0.0062	0.0000
	2	0.3412	0.3230	0.1034	0.0971	0.0122	0.0000
	3	0.2530	0.2520	0.9156	0.8986	0.0070	0.0000
UBEF	1	0.6410	0.6360	1.8172	1.8070	-0.0012	0.0000
	2	0.2673	0.2368	-0.0613	-0.2284	0.0074	0.0000
	3	0.2017	0.1972	1.1664	0.9434	0.0003	0.0000
SBCF	1	0.7410	0.7366	1.8424	1.8430	-0.0003	0.0000
	2	0.2910	0.2620	0.1109	0.0486	0.0058	0.0000
	3	0.2421	0.2411	1.1825	1.1653	-0.0001	0.0000
SBEF	1	0.5890	0.5860	1.8130	1.8080	-0.0005	0.0000
	2	0.2410	0.2110	0.0782	-0.0532	0.0110	0.0000
	3	0.1920	0.1910	1.1269	1.0550	0.0014	0.0000

UBCF : Unit Bay Central Frame
UBEF : Unit Bay end Frame
SBCF : Service Bay Central Frame
SBEF :Service Bay End Frame
MPF : Mode Participation Factor

TABLE 2 : DYNAMIC CHARACTERISTICS OF SPACE FRAME AND PLANE FRAME

ANALYSES CONDUCTED	MODE NO.	TIME PERIOD (SEC.)	MODE PART FACTOR TRANS.	VERT.	LONG.
3-D UNIT BAY	1	0.4911	2.32	-0.001	0.364
	2	0.3360	-0.528	-0.001	1.297
	3	0.3007	-0.264	0.002	1.310
2-D UNIT BAY END FRAME	1	0.3950	2.220	-0.004	-
	2	0.2230	1.356	-0.003	-
	3	0.1300	0.005	0.021	-
2-D UNIT BAY CENTRAL FRAME	1	0.8090	1.716	0.002	-
	2	0.3410	0.103	0.012	-
	3	0.2530	0.915	0.007	-
3-D SERVICE BAY	1	0.5720	2.210	-0.006	0.304
	2	0.3801	0.013	0.001	0.304
	3	0.2830	0.112	0.004	1.427
2-D SERVICE BAY END FRAME	1	0.3710	2.250	0.001	-
	2	0.2122	1.390	0.000	-
	3	0.1278	-0.033	0.225	-
2-D SERVICE BAY CENTRAL FRAME	1	0.7410	1.840	-0.000	-
	2	0.2900	1.111	-0.006	-
	3	0.2420	1.183	-0.000	-

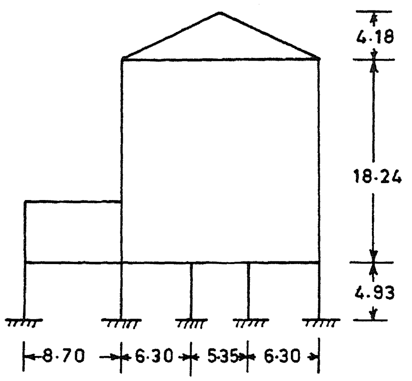

FIG. 1 _ MATHEMATICAL MODELS OF UNIT BAY (END FRAME) AND SERVICE BAY (END FRAME / CENTRAL FRAME). DIMENSIONS IN METERS

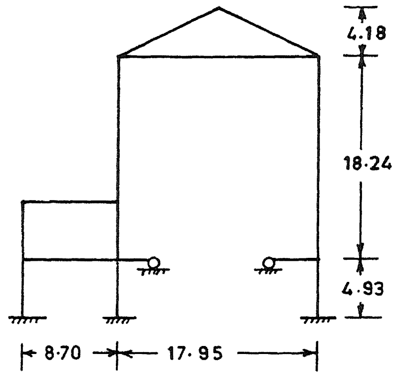

FIG. 2 _ MATHEMATICAL MODEL OF UNIT BAY (CENTRAL FRAME). DIMENSIONS IN METERS

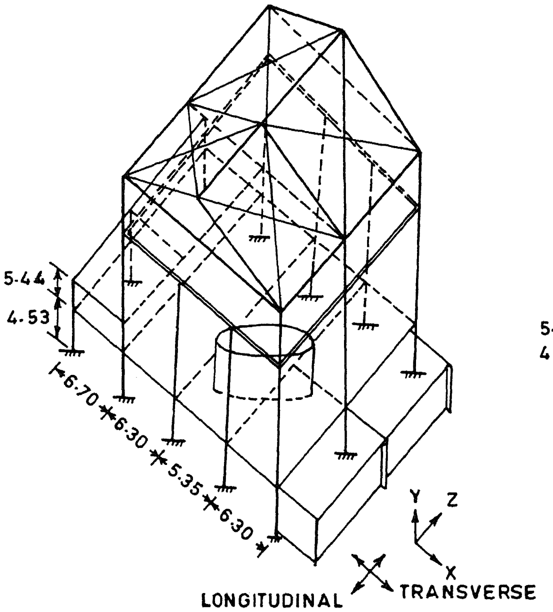

FIG. 3 _ MATHEMATICAL MODEL OF UNIT BAY. DIMENSIONS IN METERS

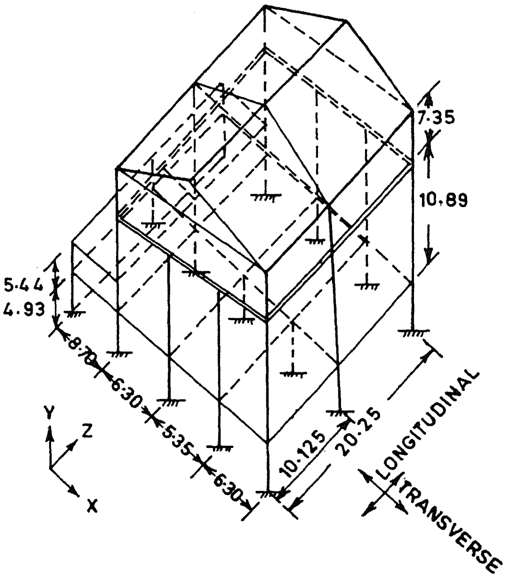

FIG. 4 _ MATHEMATICAL MODEL OF SERVICE BAY. DIMENSIONS IN METERS