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EXPERIMENTAL INVESTIGATIONS OF DYNAMIC CHARACTERISTICS OF 3-STOREYED SPACE AND PLANE FRAMED STRUCTURES

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INTRODUCTION

The normal and easiest method of analysis for any structural frame is by assuming them as plane frame and correspondingly calculating the stiffness and mass matrices. But real representation of any framed structure will be, when analysing them as such i. e. in space. The amount of analytical and experimental data available concerning hysteretic force-deflection relationships of space frame at high dynamic strain levels is meagre. Hanson (1966) reported tests on a number of one storeyed mild steel structures, and concluded that changes in the static and dynamic hysteretic force-deflection characteristics were small. Wen and Farhoomand (1970) have reported analytical expressions of dynamic characteristics of space framed structures, but with no experimental verification. Because of the importance of space framed structures in modern days, it was decided to outline their structural dynamic properties after experimental investigations of model structures. This paper describes a few dynamic characteristics of space framed structures with corresponding static and dynamic measurments. Investigations for lateral force-deformation characteristics, natural frequency and damping in naked plane frames and corresponding space frame have been carried out. Detailed analytical and experimental investigations for tall space framed structures like multistoreyed building, towers etc. are under progress.

EXPERIMENTAL STRUCTURES

To start the investigations on the project of dynamic behaviour of space frame structures a simplified frame was choosen for experimental study. A three storeyed single bay naked steel frame model, as shown in Fig. 1 (a) was fabricated out of steel sections. The columns were made of single channel section of ISLC $75\times40\times6$ mm and beams were of ISA $40\times40\times6$ mm. Fairly rigid base was achieved by welding the bottom of the columns to heavy steel plates 12 mm thick which were bolted to the foundation block made on site available for testing (since there was no reaction floor available). Two plane frames were connected with six connecting members by bolting arrangement resulting in space frame structure made with plane frames.

The loading frame consists of two separate frames (in the vertical directions) which were connected at base and top plates with rivets. Steel base plates 12 mm thick were used and foundations were made on same soil as for model testing. The columns of loading frame were made of two channel of size ISLC $100\times50\times6$ mm as box sections. Other horizontal and diagonal members were of ISA $50\times50\times6$ mm.

EXPERIMENTAL PROCEDURE

The experiments were carried out in two groups, static force-deflection tests and free-vibration tests. Static tests were possible by applying a horizontal force in turn at each floor level and deflections were measured at all the floor levels by dial gauges fitted to the fixed reference surface. The deflections were measured at various stages of a complete one side reversal of applied loads so that hysteretic force-deflection relationships could be obtained. Yielding of foundation in upward vertical direction was noticed. This was due to lateral loading applied on model structure and poor soil characteristics. Amount of yield was also measured with a dial gauge. The testing was done on plane frame I, plane frame II and space framed structures separately.

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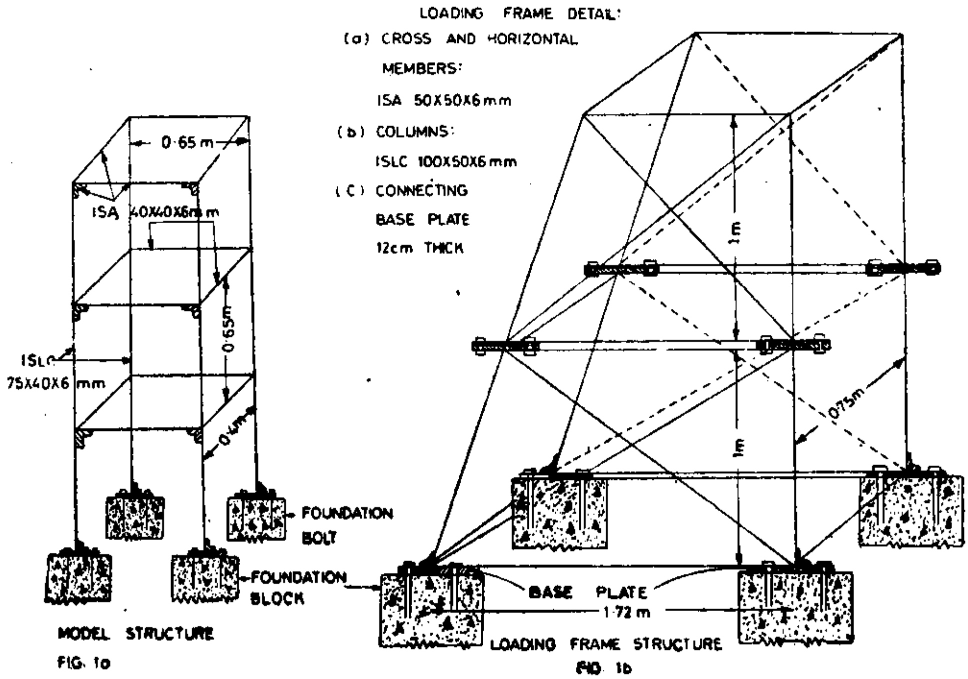


Fig. 1. Experimental Structures.

Structures were subjected to free vibration tests by applying a horizontal pull at top storey level with initial displacement condition on model and suddenly releasing it. The resulting vibrating pattern was recorded on a visicorder. These tests were performed for various intensities of initial pull. The two strain gages (SA–10) were pasted one on each side of bottom of each column, where moment will be maximum to record dynamic strains through multi-channel visicorder system. Each plane frame was tested separately and them combined space frame model was tested.

EXPERIMENTAL RESULTS AND DISCUSSIONS

(A) Static Tests:

For test A–1.1 (notation indicates testing of plane frame I while loading at top floor) all the data point plotted are shown in Fig. 2. The results of tests A–1.2 and A–1.3 are also plotted and shown in Fig. 3 and Fig. 4. In these figures, different hysteresis loops are seen. The nature of curves is softening spring type of characteristics. Here the displacement is maximum at top and it decreases from top to lower floor levels. In all these tests yielding of foundation of model frame structure was appreciable. Hence, it was thought necessary to modify the above results in view of yielding. These modifications of lateral deflections were carried out with the help of following correction factor i.e.

$$\Delta h = \Delta h' - \frac{\Delta V}{L} h.$$

Modified curves have been drawn by taking into consideration the effect of yielding of foundation in the original measured deflections created at different floor levels. They are also shown in Fig. 2, Fig. 3 and Fig. 4 by dotted lines. These curves show slightly improved nature in their characteristics. Displacements are in gradually decreasing order

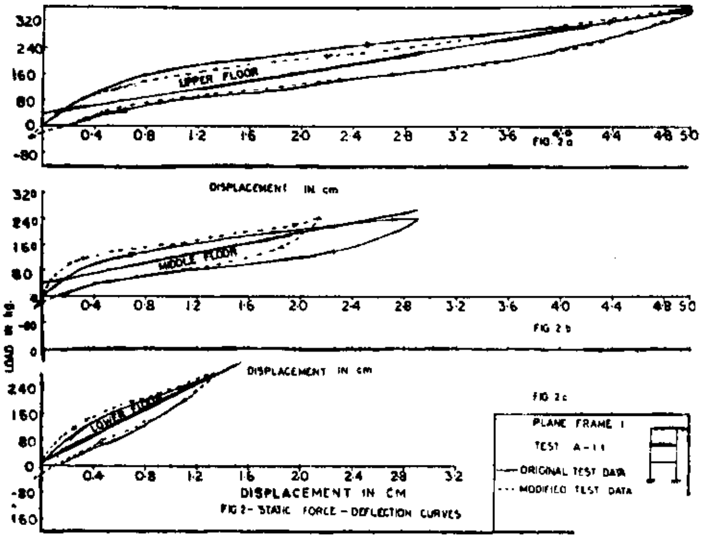
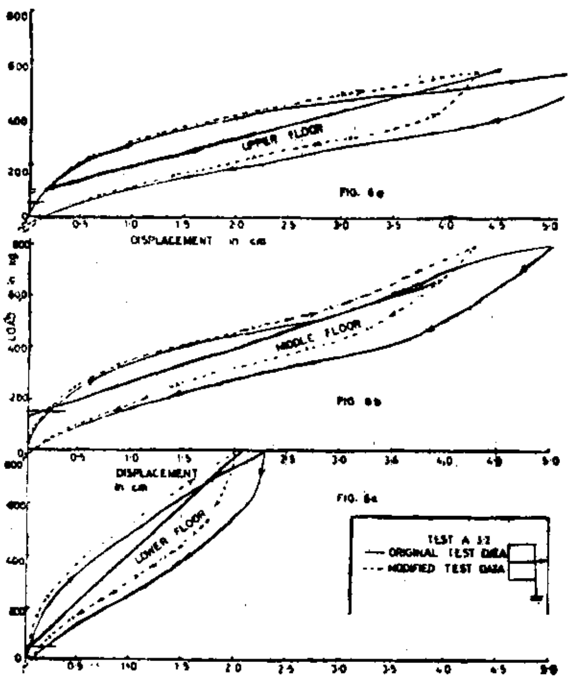


Fig. 2. Static Force-deflection Curves.



Displacement (cu.)

Fig. 3. Static Force-deflection Curves.

from top floor to lower floor level. Little residual deflections were noted at each floor level.

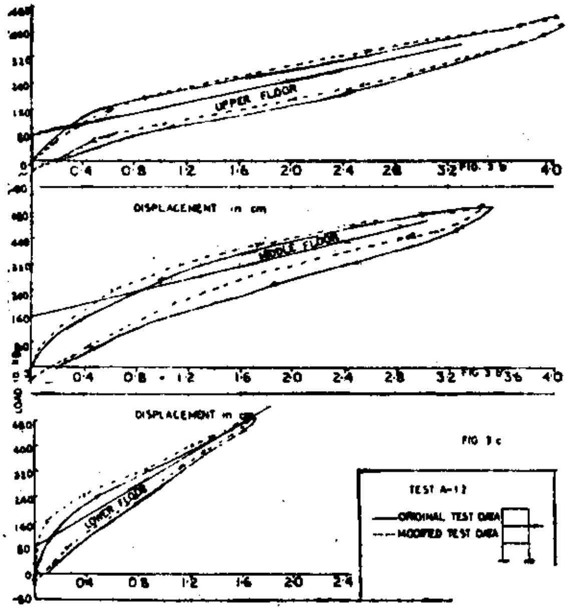


Fig. 4. Static Force deflection Curves.

Similarly the results of tests A–2.1, A–2.2 and A–2.3 were obtained for plane frame II (not shown). Curves of this plane frame case are similar to plane frame I. The results of tests A–3.1 (indicates space frame while loading at top floor). A–3.2 and A–3.3 are plotted and shown in Fig. 5, Fig. 6 and Fig. 7. Modified curves were drawn and are shown in corresponding figures by dotted lines. These modified curves are improved slightly

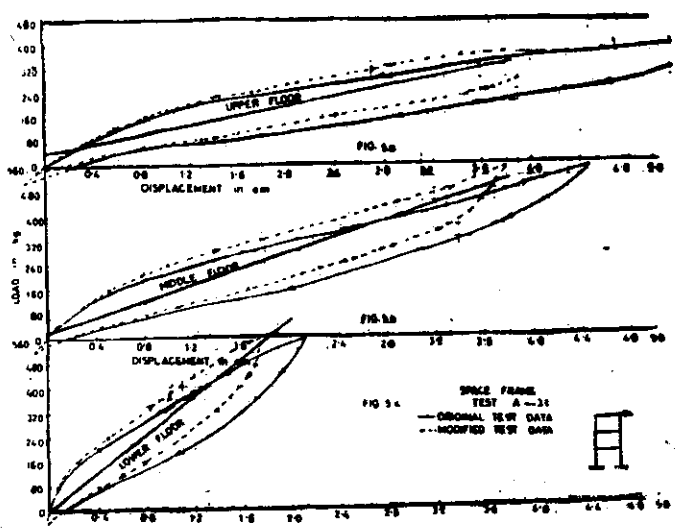


Fig. 5. Static Force-deflection Curves.

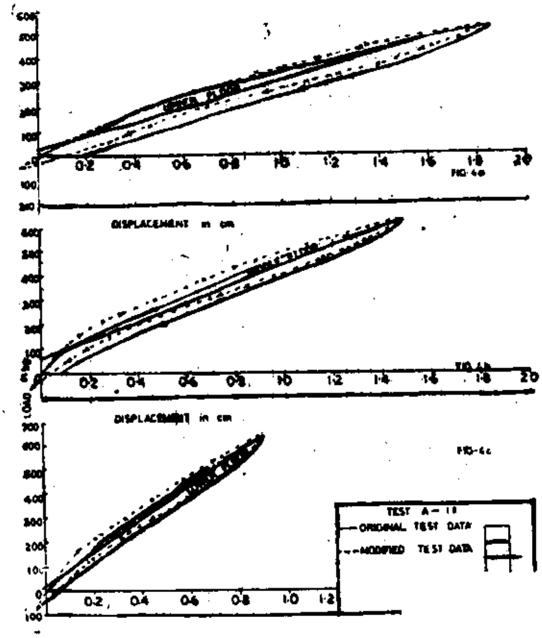


Fig. 6. Static Force-deflection Curves.

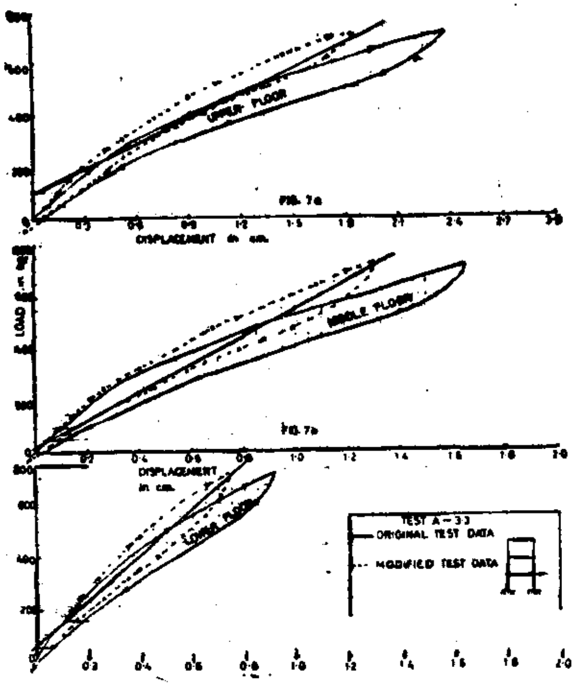


Fig. 7. Static Force-deflection Curves.

as compared to original test curves. Magnitude of residual deflections was not much in all the cases because of low force level.

Hysteretic curves were used to evaluate influence matrix, frequencies and stiffness contribution of each structure for small intensities of lateral loads, where the structure should essentially behave linearly. The influence coefficients were obtained as per the average line of the slope of force-deflection curve leaving the initial wire rope pull adjustment portion of curve. The influence matrices evaluated from experimental results are as follows :—

For plane frame I, $[F]=\begin{bmatrix} .0167 & .0111 & .0037 \\ .0143 & .0100 & .0028 \\ .0050 & .0042 & .0015 \end{bmatrix}$ cm/kg.

For plane frame II, $[F]=\begin{bmatrix} .0143 & .0084 & .0035 \\ .0090 & .0062 & .0030 \\ .0042 & .0028 & .0015 \end{bmatrix}$ cm/kg.

For space frame, $[F]=\begin{bmatrix} .0143 & .0090 & .0030 \\ .0080 & .0084 & .0018 \\ .0033 & .0028 & .0011 \end{bmatrix}$ cm/kg.

CALCULATION OF EQUIVALENT STIFFNESS AND FREQUENCY OF MODEL STRUCTURE

Computer analysis was performed to get the inversion of the above matrices and finally stiffness matrices are obtained. Average stiffness values are shown as 120 kg/cm, 160 kg/cm and 180 kg/cm for plane frame I of top storey, middle storey and lower storey level respectively. For plane frame II, average stiffness values are quite close to the values of plane frame I. The stiffness for space frame model structure are 170 kg/cm, 170 kg/cm. and 202 kg/cm for top storey column level to lower storey column level respectively.

Therefore, the stiffnes of space frame could be defined as a function of plane frame stiffness instead of direct multiple of number of plane frames. It can be given as follows,

$$K_s^{(i)} = K_p^{(i)}\alpha$$

where $K_s^{(i)}$ = stiffness of any storey i of space framed structures.

$K_p^{(i)}$ = stiffness of any storey i of plane framed structures.

α — Multiplying factor.

Present experiments show the factor $\alpha < m$, where m is number of plane frame comprising the space frame. Here the results indicate the factor α of the order of about 1.25.

Solving various flexibility and mass matrices the values of frequencies of different frames are obtained. The mass of the model structure has been considered to be concentrated at the storey level by assuming one third the weight of the columns between adjacent floors to be acting at the floor levels. Three different masses are used and the mass matrices $\begin{bmatrix} \diagdown & & \\ & M & \\ & & \diagdown \end{bmatrix}$ are as follows :—

For plane frames $\begin{bmatrix} \diagdown & & \\ & M & \\ & & \diagdown \end{bmatrix} = \begin{bmatrix} 5.41 \\ 8.36 \\ 8.36 \end{bmatrix} \times 10^{-3}$;

For space frame $\begin{bmatrix} \diagdown & & \\ & M & \\ & & \diagdown \end{bmatrix} = \begin{bmatrix} 13.56 \\ 19.57 \\ 19.57 \end{bmatrix} \times 10^{-3}$ kg.sec^2/cm.

By the usual analysis, frequencies are calculated as 14.5 cps for plane frame I and II, and only 8.8 cps for model space framed structure.

(B) Free Vibration Tests :

The frequencies of vibrations obtained from the free vibration tests are shown in Table 1. The nature of free vibration record is of logarithmic decay type. Therefore, damping was estimated by the method of logarithmic free vibration decay relations. That is, it was calculated by using the formula

$$\zeta = \frac{1}{n\pi} \log (A_1/A_2)$$

It is observed that frequencies decrease a little with increase in lateral load intensity thereby confirming the softening spring type of characteristic.

In plane frame I, average value of frequency is about 15.5 cps., in case of plane frame II it is 15.5 cps., and in space frame model structure, about 13 cps.

Average damping value for plane frames I & II is 1.45% and in case of space frame, about 1.48% of critical damping

TABLE I : FREE VIBRATION TEST RESULTS

	Plane Frame I			*Space Frame*		
Force Kg	*Time per cycle sec.*	*Damping %*	*Frequency cps*	*Time per cycle sec*	*Damping %*	*Frequency cps*
200	.053	1.5	18.7	.070	1.8	14.2
240	.067	1.4	14.9	.071	1.5	14.1
300	—	—	—	.077	0.8	13
500	—	—	—	.076	1.7	13.1

CONCLUSIONS

In all these experimental results, discrepancies are little in comparison with that of conventional results and looking from the point of view of number of variables involved in both the analysis it is not much. Herein the nature of loop does not produce any significant area and its variation amongst various cases is also small, which is a predominant factor in damping calculation during nonlinear analysis approach.

This investigation shows that a plane frame analysis is not of much significance to find out dynamic properties of space framed structures. Because, the stiffness of space framed structure does not seem to be algebraic addition of plane frame I and II stiffnesses. Factor by which net stiffnesses of space frame should be multiplied will need more investigations However, for two identical plane frames, some investigations have been carried out which show a factor of about 1.25. Another factor affecting stiffness of space frame is, length of cross member. Area affected by yielding in the foundation of space framed structure is more than that of the combind area occupied by plane frame I and II structrues separately. Frequencies of plane frames and space frame found from free vibration test are almost similar.

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APPENDIX-NOTATIONS

A_1, A_2	=Two successive peak to peak amplitudes.					
A–1.1	=Testing	of plane	frame I	while	loading at	top floor
A–1.2	= ,,	,,	,,	,,		middle ,,
A–1.3	= ,,	,,	,,	,,		lower ,,
A–2.1	= ,,	of plane frame II		,,		top ,,
A–2.2	= ,,	,,	,,	,,		middle ,,
A–2.3	= ,,	,,	,,	,,		lower ,,
A–3.1	= ,,	of space frame while		,,		top ,,
A–3.2	= ,,	,,	,,	,,		middle ,,
A–3.3	= ,,	,,	,,	,,		lower ,,

[F] =Flexibility matrix

h =Hight of column at each storey level

Δh =Actual modified lateral deformation at each floor level

$\Delta h'$ =Total lateral deflection at each floor level

$K_p^{(i)}$ =Stiffness of any storey i of plane framed structure

$K_s^{(i)}$ =Stiffness of any storey i of space framed structure.

L =Length of bay of model structure in the direction of lateral loading

$\left[\diagdown M \diagdown\right]$ =Mass Matrix

m =Number of plane frames comprising the space frame

n =Number of cycles.

ΔV =Lifting of foundation level in vertical direction

α =Multiplying factor

ζ =Fraction of critical damping value.