Geotechnical application of Free Vibration Testing of A Steel Frame

M. Satish

Abstract

Free vibration of a steel frame with varying mass at top has been carried out using Ranger Seismometers. A Single storied one bay frame is used in this study to compare its analytical and experimental fundamental time periods. Free vibration is carried out by hammer hits at top with a wooden hammer. Mass is varied with the help of pre-cast Concrete Slabs. Free vibration records were obtained in both Longitudinal and Transverse direction of the frame. The predominant frequencies of vibration have been obtained with the help of FFT of the free vibration record in every direction. The Steel frame has also been modeled as a 3D space frame in STAAD Pro 2005 and Modal Analysis has been carried for both the longitudinal and transverse directions to obtain the natural frequencies and mode shapes of the structure. Time periods were observed in both the directions assuming a 2D shear frame and compared. Damping of the structure has also been obtained from the free vibration records of all cases and is compared. The observations made and findings in the study are applicable in the design of structures which are resistant to seismic events.

Introduction

The effect of a force on a body or frame or any structure depends mainly on its time-period for which it is acting. But the time-period in turn depends on mass or load on the structure and its stiffness. The time-period is directly proportional to the square root of the mass and inversely proportional to the square root of its stiffness. In this experiment the variation of time-period with varying mass or load is seen, according to which the relevant modifications could be made to complex structures, which further can help in monitoring their reflexes during seismic events. in turn can lead in earthquake resistant structures.

Free vibration

Free vibration is a type of vibration when a mechanical system is set off with an initial input and then allowed to vibrate freely. It occurs when system is set off with an initial input and then allowed to vibrate freely. The number of independent displacements required to define the displaced positions of all the masses relative to their original position is called the number of degrees of freedom (DOFs) for dynamic analysis. More DOFs are typically necessary to define the stiffness properties of a structure compared to the DOFs necessary for dynamic analysis. Consider the one-story frame to move only in the direction of the excitation as shown in figure (1). The static analysis problem has to be formulated with three DOFs-lateral displacement and two joint rotations. In contrast, the structure has only one DOF-lateral displacement-for dynamic analysis if it is idealized with mass concentrated at one location, typically the roof level. Thus it is

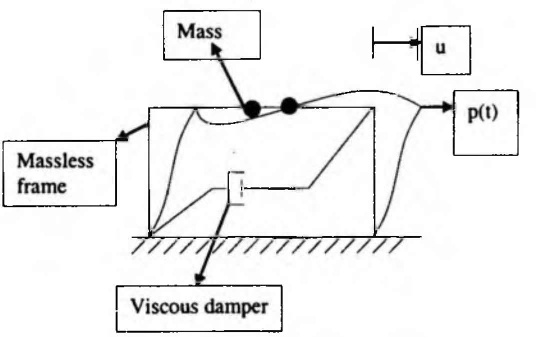


Fig. 1. Single degree of freedom system due to some applied force p(t).

Department of Civil Engineering, National Institute of Technology, Durgapur, West Bengal

said to be a single degree of freedom (SDOF) system. Hence the steel fame is assumed to have single degree of freedom (SDOF) as, only the lateral displacement is observed.

Linear elastic systems

For a linear system the relationship between the lateral force 'f_s' and deformation 'u' is linear, that is,

f_s = ku (1)

where 'k' is the lateral stiffness of the system; its units are force/length. Implicit in the equation (1) is the assumption that the linear f_s-u relationship determined for small deformations of the structure is also valid for larger deformations. Because the resisting force is a single valued function of 'u', the system is elastic; hence it is termed as linearly elastic system.

Description of the Sensors used in free vibration testing

The sensors which are used in the free vibration testing are called as 'Ranger Seismometers' with a recorder named as 'Solid State Recorder (SSR)'. SSR is a 6 channel portable digital event recorder, whose rate of acquisition is 200 samples per second per channel. The communication between SSR and laptop computer is performed through Quick Talk Software supplied with the equipment. The recording and processing of data is done with 'seismic work station software' as shown in figure (2).

Fig. 2. A picture showing 'Quick Talk software', and Seismic work station processing in a computer.

Description of the steel frame used in the free vibration testing

The steel frame is initially fixed rigidly to the ground. Figure (3) shows the steel frame with 4 slabs (400 kgs) with sensors placed at the top.

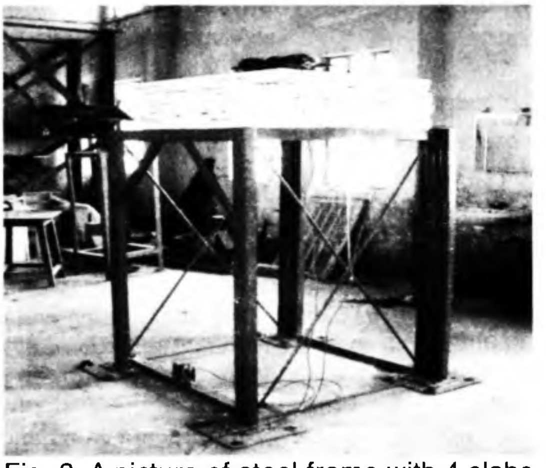


Fig. 3. A picture of steel frame with 4 slabs and sensors at the top.

Plan of the frame

The figure (4) shows the plan of the steel frame with the dotted lines representing the slabs.

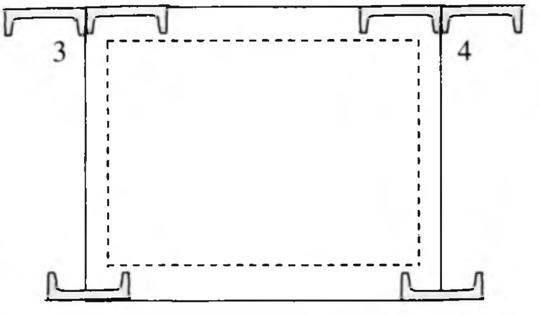


Fig. 4. Plan of steel frame, showing the alignment of channels and the dotted lines indicating the mass (slabs).

Front view of the frame

The figure below depicts a front view of the steel frame, where 1 and 2 represent the columns. These columns are channels extending through out its height of 1.52m. The dimensions of the channel are:

Depth of section	=	75mm
Width of flange	=	40mm
Thickness of flange	=	6mm
Thickness of web	=	3.7mm

Hence from the steel table, steel channel is designated as ISLC 75. And hence the width of columns 1 and 2 is 7.5cms. Also there exist a rolled steel angle at the top connecting the columns and upon which the load will be acting. The dimensions of the steel angle are :

Size of the angle = (60X60) mm.

Thickness = 5mm.

Hence from the steel table, this steel angle is designated to be ISA 6060. Also there exist two angles (a and b as shown in figure (5)) connecting from the top angle and the channel. The dimensions of this steel are:

Size of the angle = (40X40) mm.

Thickness = 4mm.

Hence from the steel table, this steel angle is designated to be ISA 4040.

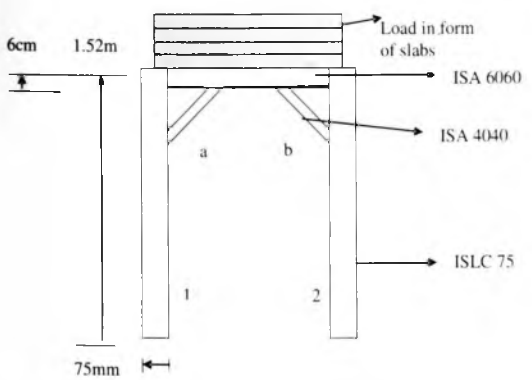


Fig. 5

The angles 'a' and 'b' are situated at a horizontal distance of 26cm and a vertical distance of 33cm from column '1' and '2' respectively.

Right view of the frame

The figure below depicts the right view of the frame, having columns 2 and 3. Here column is observed to be designated as ISLC 75 from its dimensions. Here the width of column becomes the width of flange of steel channel, and hence it is 40mm. Here there exist two long cylindrical steel rods (each having a diameter of 15mm), one extending from the centre of column '2' at the top to centre of column '3' at the base, and the other from the centre of column '3' at the top to centre of column '2' at the base as shown in figure (6).

Back view of the frame

Figure (7) below depicts the back view of the frame, having columns '3' and '4'.

Actually columns '3' and '4' are individually a combination of two ISLC 75 channels, whose individual centre line forms at the combination of these two channels. Hence in the figure the width of column becomes the depth of section (which is a combination of two ISLC 75 channels) and hence it is 15cm.

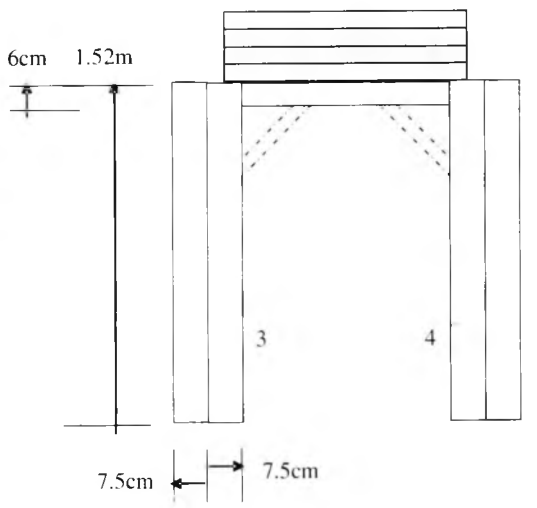


Fig. 6

Left view of the frame

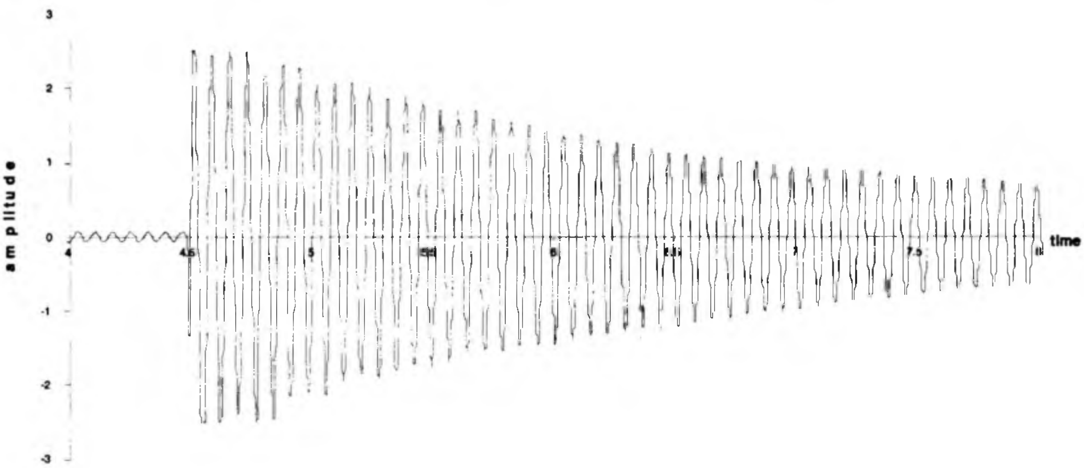
Here also the width of column becomes the width of flange, and hence it is 40mm. Even here there exist two long cylindrical steel rods having diameter of 15mm, similar as the case shown in figure(6).

Determination of time period experimentally

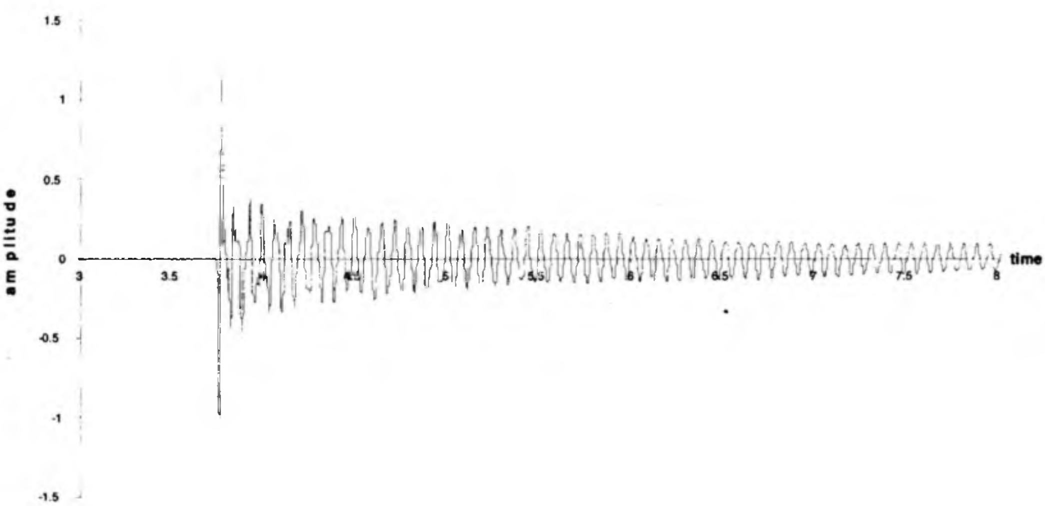
Initially the steel frame is rigidly fixed to the ground. Later the axis is defined. The axis passing from the centre of columns '4' and '1' to centre of columns '2' and '3' is considered as X axis. The axis passing from the centre of columns '1' and '2' to centre of columns '3' and '4' is considered as Y axis. Two sensors are placed over the slabs (load) each along different axis. This arrangement is so done that the response are read more accurately in the direction in which hit is given. The frame is allowed to undergo free vibration by just applying two varying hits (namely hit1 and hit2) at different locations on or around the frame and also on ground with the help of a hammer.

Case A: The responses are taken and observed in form of 'amplitude vs. time' graphs when load acting on the frame is 200kgs (i.e., 2slabs).

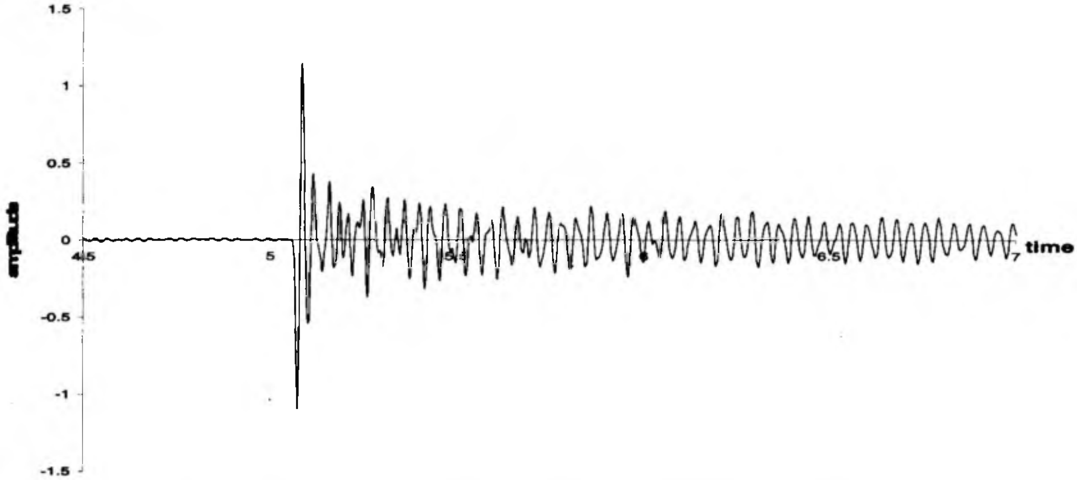
- Free vibration record of the frame along X axis when hit1 is applied-



- Free vibration record of the frame along X axis when hit2 is applied-



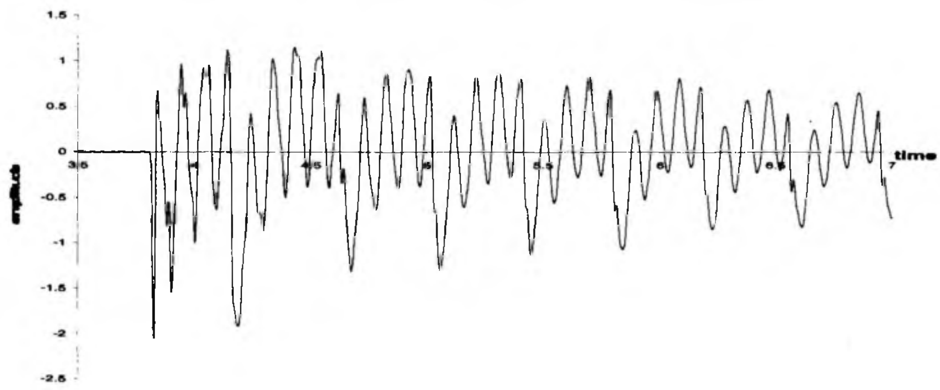
- Free vibration record of the frame along Y axis when hit1 is applied-



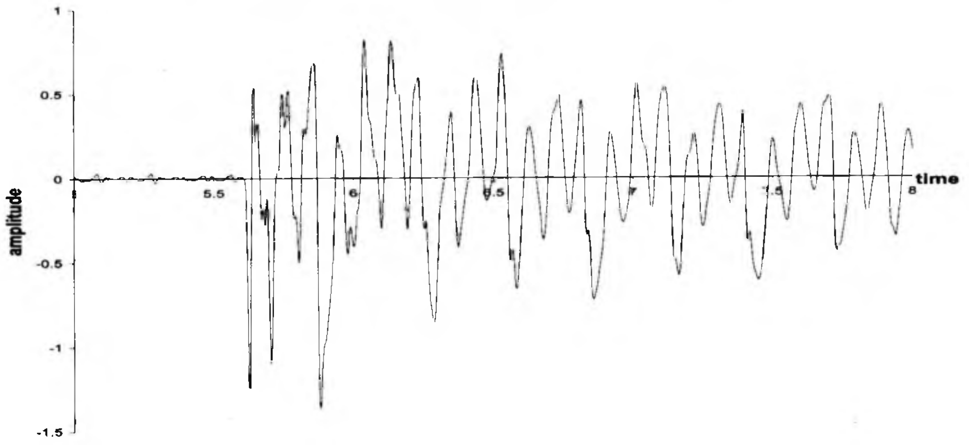
- Free vibration record of the frame along Y axis when hit2 is applied-

Case B: The responses are taken and observed in form of 'amplitude vs. time' graphs when load acting on the frame is 400kgs (i.e., 4slabs).

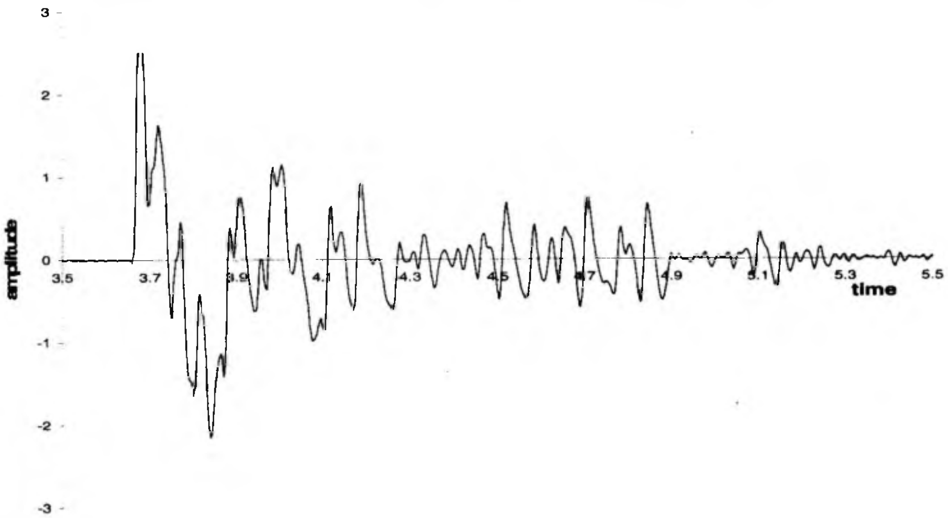
- Free vibration record of the frame along X axis when hit1 is applied-



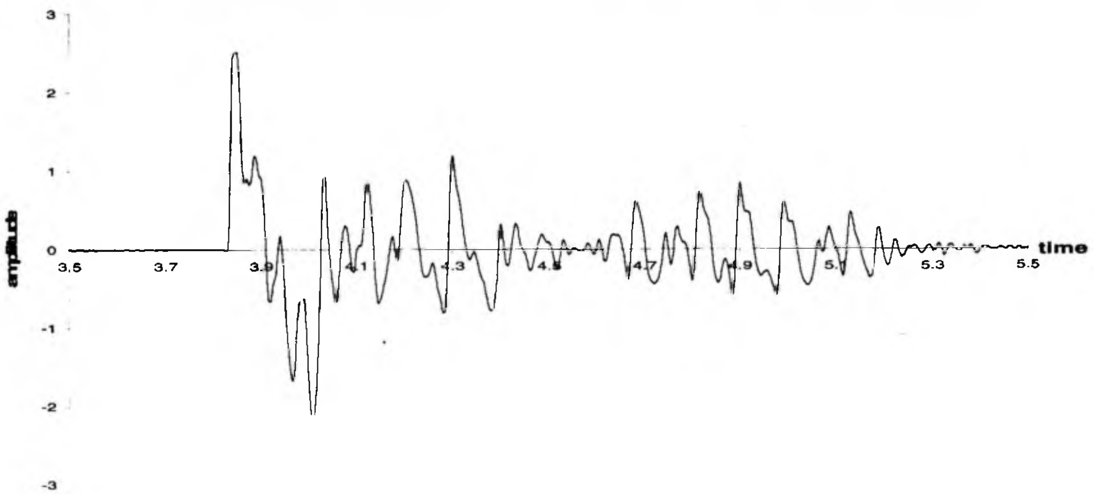
- Free vibration record of the frame along X axis when hit2 is applied-



- Free vibration record of the frame along Y axis when hit1 is applied-



- Free vibration record of the frame along Y axis when hit2 is applied- K.S. Krishna Murthy



The uncertainty in some graphs of case 'B' is due to lack of rigidity between the slabs as they are loosely held on each other.

The gap between the zero (0) of time to the first cycle in the graphs above is due to the reason that, the sensors display the readings from a while just before the hit. Thus creating a gap between them.

We have the damping ratio as 'æ; which is given by [ln(u1/u2)/2δj];

where u1 and u2 represent the peaks in the amplitude axis of 'amplitude vs time' graph and 'j' represents the number of cycles in between these considered peaks.

Hence for the frame, the damping ratio for different cases of mass and axis of vibration are calculated as follows-

1) Considering a graph in case A, vibrating along X axis, whose first peak is at 2.499(u1) and another is considered after 10(j) cycles which is at 2.005(u2) is given as :

= ln(2.499/2.005)/2δ(10) = ln(1.24)/20δ = 0.2202/20δ =0.0035

Thus the damping ratio of the frame in case A and vibrating along X axis is 0.0035 i.e., a damping percentage of '0.35%'

2) Considering a graph in case A, vibrating along Y axis, whose first peak is at 0.339(u1) and another is considered after 10(j) cycles which is at 0.145(u2) is given as :

= ln(0.339/0.145)/2δ(10) = ln(2.3379)/20δ = 0.849 /20δ =0.0135

Thus the damping ratio of the frame in case A and vibrating along Y axis is 0.0135 i.e., a damping percentage of '1.35%'

3) Considering a graph in case B, vibrating along X axis, whose first peak is at 1.113(u1) and another is considered after 10(j) cycles which are at 0.392(u2) is given as:

= ln(1.113/0.392)/2δ(10) = ln(2.839)/20δ = 1.043/20δ = 0.0166

Thus the damping ratio of the frame in case B and vibrating along X axis is 0.0166 i.e., a damping percentage of '1.66%'

4) Considering a graph in case B, vibrating along Y axis, whose first peak is at 0.593(u1) and another is considered after 10(j) cycles which is at 0.233(u2)] is given as :

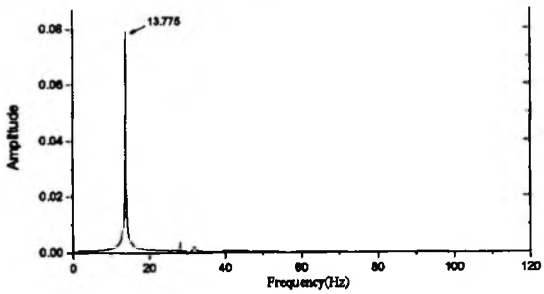
= ln(0.593/0.233)/2δ(10) = ln(4.29)/20δ = 1.46/20δ =0.023

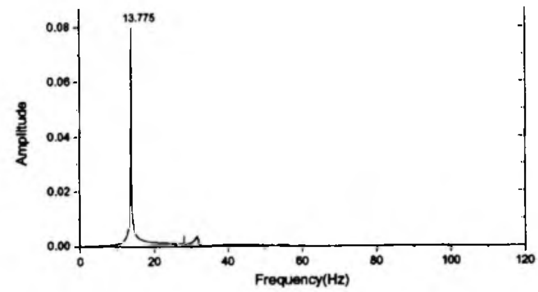
Thus the damping ratio of the frame in case B and vibrating along Y axis is 0.023 i.e., a damping percentage of '2.3%'

Fast Fourier Transform (FFT)

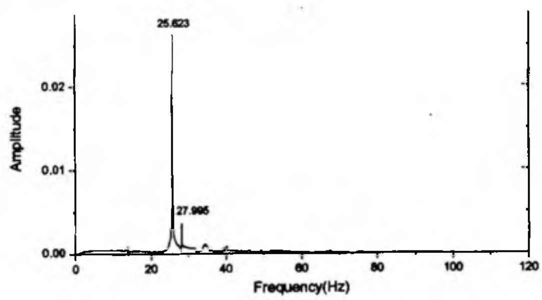
This transform is performed to the free vibration records and following are some of the FFTs which are observed.

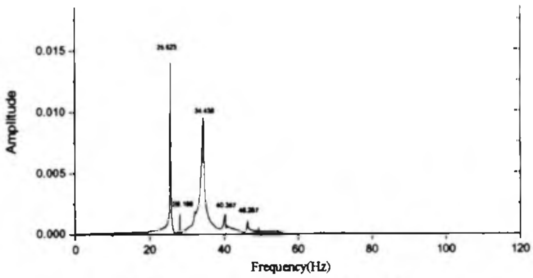
In case 'A' (2slabs), for vibration along X axis-



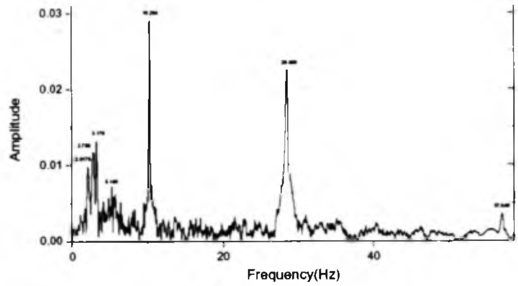


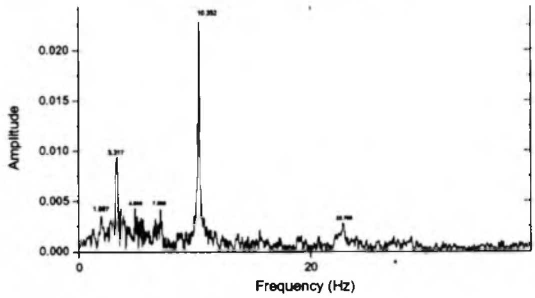
In case 'A' (2 slabs), for vibration along Y axis-



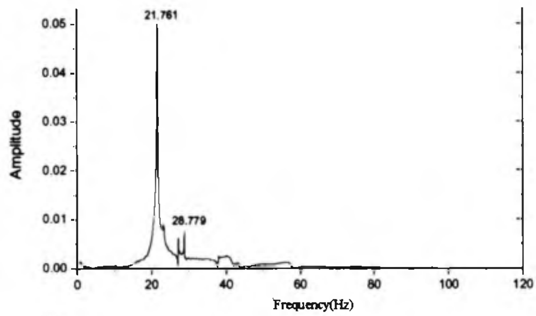


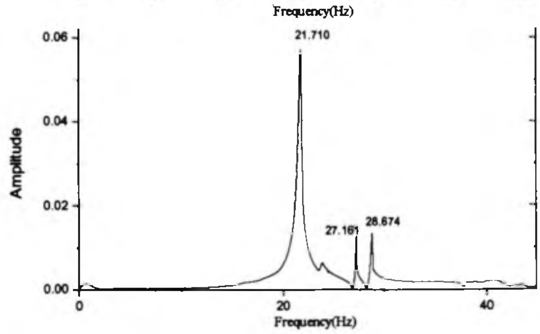
In case 'B' (4 slabs), for vibration along X axis-





In case 'B' (4 slabs), for vibration along Y axis





Results of experiment (from Graphs and FFTS):

Modeling and evaluation of time period in Staad Pro 2005:

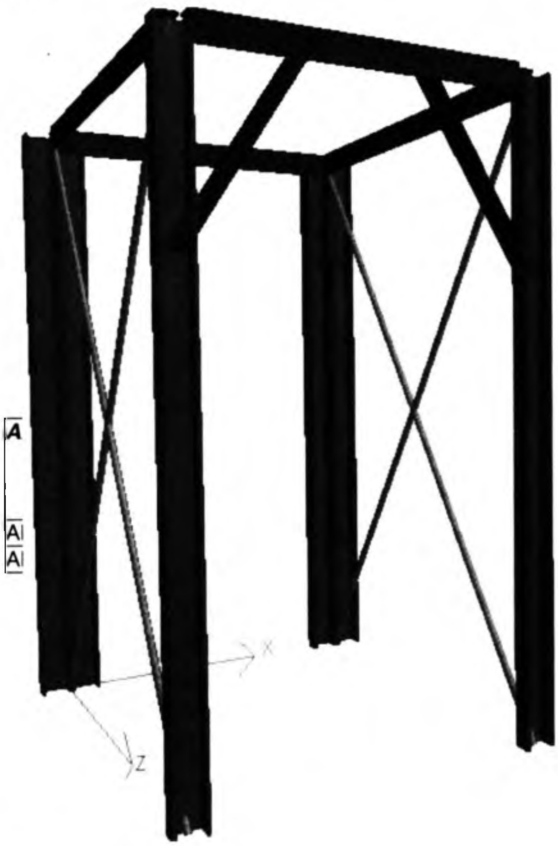
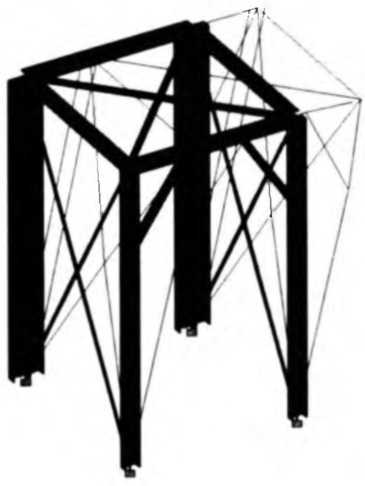


Fig. 8. Shows the modeling picture of the steel frame in STAADPRO 2005 with alignment of bracings, channels, angles.

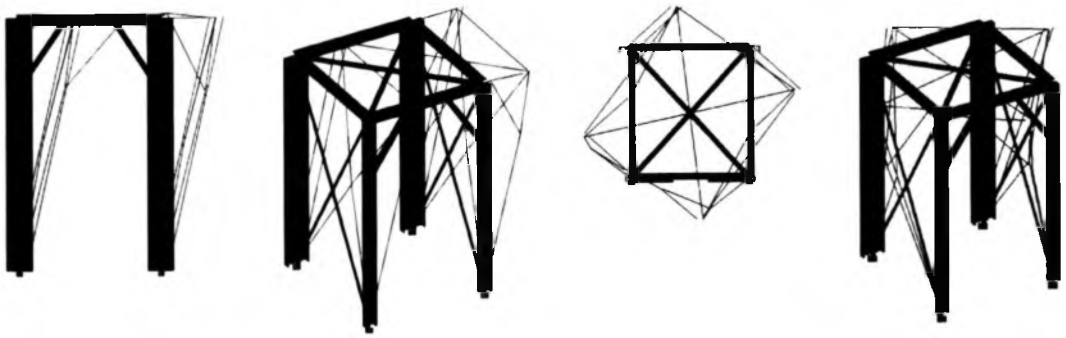
Due to asymmetry, irregularity and lack of rigidity, there also exist torsion along with normal vibration. And hence this mode of torsion is represented as 'Mode2', and that of normal vibration as 'Mode1'.One of the images of mode shapes working in STAADPRO 2005 is given below-



Modeling:-

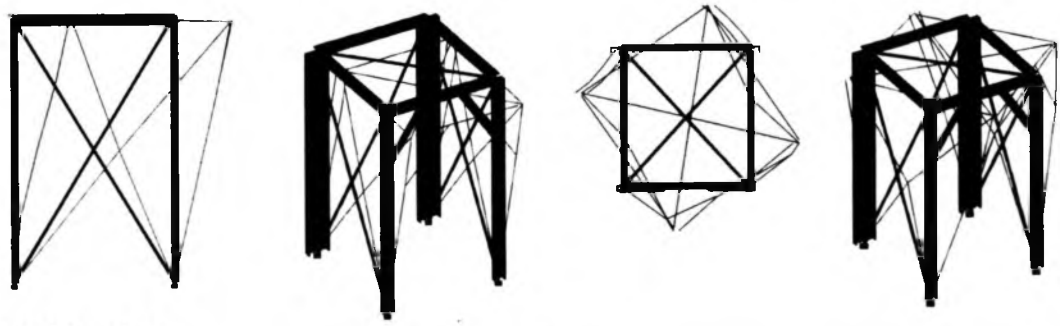
Case A: 2 SLABS (i.e., 200kgs)

1) Modeling in STAAD when the frame is hit along X axis-
   a. Mode1
   b. Mode2



Mode1(Elevation) Mode1(Isometric) Mode2(Top View) Mode2(Isometric)

2) Modeling in STAAD when the frame is hit along Y axis-
   a. Mode1
   b. Mode2



Mode1(Elevation) Mode1(Isometric) Mode2(Top View) Mode2(Isometric)

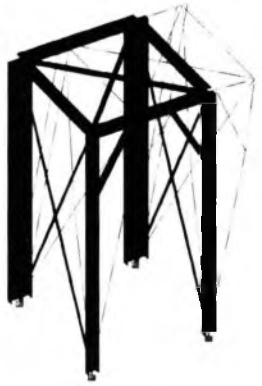
Case B: 4 SLABS (i.e., 400kgs)

3) Modeling in STAAD when the frame is hit along X axis-

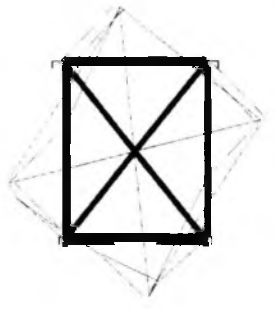
   a. Mode1

   b. Mode2

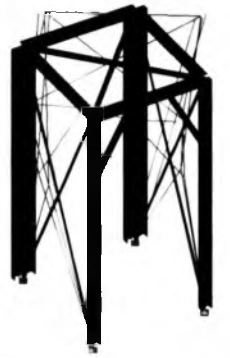
Mode1(Elevation)



Mode1(Isometric)



Mode2(Top View)

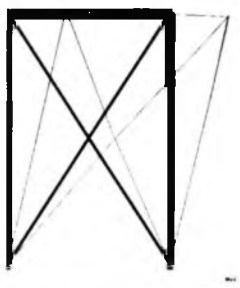


Mode2(Isometric)

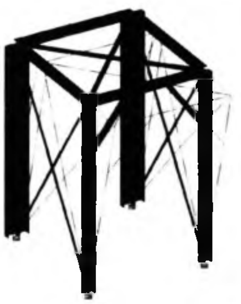
4) Modeling in STAAD when the frame is hit along Y axis-

   a. Mode1

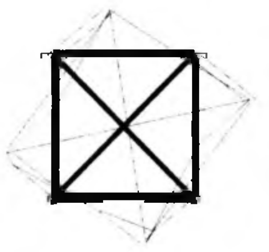
   b. Mode2



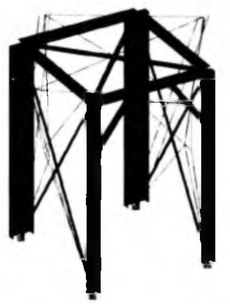
Mode1(Elevation)



Mode1(Isometric)



Mode2(Top View)



Mode2(Isometric)

Results from STAAD PRO 2005:

Axis and Mode	*Time-period of steei frame in case A (2 siabs)*	*Time-period of steel frame in Case B (4 slabs)*
Along X-axis, due to vibration only i.e., Mode 1.	0.0701 seconds	0.0842 seconds
Along X-axis, due to torsion only i.e., Mode 2.	0.0477 seconds	0.0525 seconds
Along Y-axis, due to vibration only i.e., Mode 1.	0.02097 seconds	0.02966 seconds
Along Y-axis, due to vibration only i.e., Mode 2.	0.01938 seconds	0.02775 seconds

However the results due to torsion are neglected because it comes into the picture due to the presence of some irregularity in the frame which is unavoidable.

Tabulating the results of experimental, manual, and STAADPRO 2005 observations:

METHOD OF CALCULATIONS	*Time-period for a load of 2 slabs(200kgs) and vibrating along X- axis(sec)*	*Time-period for a load of 2 slabs(200kgs) and vibrating along Y-axis(sec)*	*Time-period for a load of 4 slabs(400kgs) and vibrating along X- axis(sec)*	*Time-period for a load of 4 slabs(400kgs) and vibrating along Y-axis(sec)*
Experimental	0.0725	0.029	0.0962	0.046
STAADPRO 2005	0.0701	0.02097	0.0842	0.02966

METHOD OF CALCULATIONS	*Time-period for a load of 2 slabs(200kgs) and vibrating along X- axis(sec)*	*Time-period for a load of 2 slabs(200kgs) and vibrating along Y-axis(sec)*	*Time-period for a load of 4 slabs(400kgs) and vibrating along X- axis(sec)*	*Time-period for a load of 4 slabs(400kgs) and vibrating along Y-axis(sec)*
Experimental	0.0725	0.029	0.0962	0.046
STAADPRO 2005	0.0701	0.02097	0.0842	0.02966

	In case of 2slabs(200kgs) and vibrating along X- axis	*In case of 2slabs(200kgs) and vibrating along Y-axis*	*In case of 4slabs(400kgs) and vibrating along X- axis*	*In case of 4slabs(400kgs) and vibrating along Y-axis*
Damping ratio	0.0035	0.0135	0.0166	0.023

Conclusions

The asymmetry of steel frame, its irregular structure at some parts, and also due to lack of rigidity between the slabs are the key unavoidable reasons due to which the time-period calculated manually is in variation with that of experimental or STAADPRO 2005. Thus the time-period of steel frame is determined experimentally, and in designing software STAADPRO 2005, along with its damping ratio. The same can be correlated with complex structures, and their reflexes during seismic events can be monitored thus designing earthquake resistant structures.

Acknowledgements

I am grateful to Prof. Dr. R. Anbalagan, I.I.T., Roorkee for his help and guidance without which I could not have completed the research project. I am also thankful to Dr. Pankaj Agarwal, Asst. Professor, I.I.T., Roorkee who helped me to complete the project and guided me in the laboratory. I also thank Dr. S. Bhattacharya, Head of Civil Engineering Department, National Institute of Technology, Durgapur for helping me to attain this opportunity and to perform the research project.

References

Anil K.Chopra (1996): Dynamics of structures: Theory and applications to earthquake engineering, India.

C.E.Crede (1951): Vibration and shock Isolation, New York.

R.B.Randall (1977): Frequency Analysis, Denmark.