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Comparative Study on Seismic Performance of Bamboo and Steel using Shake Table

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***Abstract:** Recent research has shown that structures made with Bamboo offer an enhanced seismic performance over conventional materials by providing an additional elastic capability. In the present investigation seismic performance of the bamboo structure is considered. The bamboo is chosen because it is a very flexible material (this property makes it to use in seismic areas), growth rate is too high, easily available, bio-degradable and mainly it is carbon sequestrate and it is cost effective. The model will be designed for stringent similitude requirements and a series of dynamic tests. Once the model is prepared using Bamboo, it is tested in a shake table against various frequency ranges. And the respective drift values, displacement values and accelerations are noted down for different frequency ranges, and the model behavior is analyzed. The design similarity is the key to obtain the good test results. The careful design and construction of a scaled model of a Bamboo structure is going to report herein. In India in the Himalayan regions (which are highly seismic prone areas) the Bamboo is provided at lintel level, plinth level as bands, to provide resistance to seismicity. The experimental results are taken and represented in this project. This test program was composed of two three-story single-bay Bamboo frames.*

***Keyword:** Seismic Performance, Shake Table, Bamboo, Displacement, Stiffness.*

I. INTRODUCTION

Bamboo, is an very important agricultural as well as forest plant. It is used by many communities in Asian and Pacific region for economic and environmental needs. Bamboo is used for centuries to build mud houses and huts. It is a durable and flexible material and also environment friendly.
Bamboo is a natural raw material and it is one of the fastest growing plant in the world, it n complete its growth cycle in 120 to 150 days. The collection of bamboo for 3 to 5 years is equal to the 10 to 30 year collection of other trees.
The carbon storage and carbon sequestration rate in the bamboo range from 30 to 121 Mg/ha. As it is having high biomass accumulation and does carbon (CO_2) fixation in effective manner, it has high carbon sequestration capacity. It has good productivity and even after harvesting it stands as a carbon sequestrate and continues to grow.

1.1. Bamboo: Characteristics, Properties and Uses

The stems of bamboo are called as 'shoots', when it is young and when it is mature they are called as 'culms'. Bamboo plant is mainly consisting of two parts

1. Culm or stem - It grows above ground level.
2. Rhizome - It grows underground and it bears roots.
3. Each bamboo can produce a usable pole of upto 15 km (30 cm in India) during its lifetime.

1.2. Structure

Its culms have hollow shape and each and every culms are innerly divided into many diaphragms and they looks alike rings from outside. In between every two rings the inter-node is present from where the branches will grow. The microscopic structure of the culms has many number of vascular bundles. They are embedded in inside the parenchyma tissue and distributed along wall thickness.

1.3. Characteristics

- It is a fastest growing plant in the world
- It has around 70 genera and more than 1000 species
- It has a very short development cycle and can grow upto 70 mm per day and can also reach up to 350 to 450 mm per day.
- They are generally cylindrical in shape with diameter of 29 to 300 mm.
- The bamboo comprises 60% to 70% of fibre in it.

1.4. Properties

- Tensile and Compressive strength
  Bamboo has good tensile and compressive strength. In bamboo the fibres run axially, hence the outer zone is having tensile strength. Along with the height its tensile strength varies. And as the height of the bamboo increases the compressive strength of it increases and it is vice-versa in case of bending strength.
- Elasticity
  Bamboo is a environmental friendly and possess a very good elastic property and that makes it a good construction material
- Shrinkage
  When bamboo looses water it shrinks more than that of wood.
- Resistibility
  Bamboo is having a high amount of silica acid and due the presence of which it has a very good flame resistibility.

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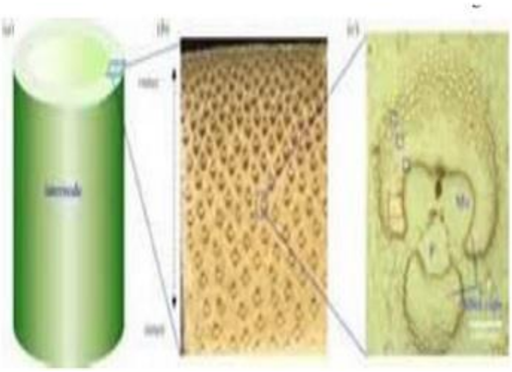

Fig.1: Bamboo in Electron Microscope Study

1.5. Uses of Bamboo

- It can be used as a construction or building material
- It is used in furniture production
- Used in paper making industry
- Used in textile industry
- For pharmaceutical usage
- To make household items

II. EXPERIMENTAL PROGRAMME

2.1. Analysis and Design of a Model

The design of a bamboo scale model is a highly delicate work by theoretical as well as practical consideration. Here, the test model includes 3 storey single bay bamboo structures. The prototype of this model is very large. In this the horizontal members like beams and vertical members like columns are scaled and modelled.

1. The structure includes columns, beams, attaching bolts and rivets for connection.

2 . The rigidity and mass are pre-fixed.

First and foremost for the preparation of model the fresh bamboo is collected from the nearby place. Once the bamboo is collected the dimension fixed by the scaling factor is noted down. Then the bamboo is cleaned and it is cut into desired shapes and dimensions to create a required model. The rivets are provided wherever the connection is needed.

On this simplified and scaled model, the seismic analysis is done and the results of model and prototype are compared. The result obtained includes acceleration, velocity, and displacement with respect to time period.

Table-1: Model Material Properties

Material	Elastic modulus (MPa)	Compressive strength (MPa)
Bamboo	5000-25000	40-80
Steel	2000-2500	160-200

2.2 Scaling

The prototype building taken here is 3 storey and single bay building. The model is designed on the basis of parameters of prototype.

Here in the prototype building is a residential building of 3 storeys. In a shake table test the scaling factor of dimension, elastic modulus, acceleration, and density is very important. Here two models are tested against the vibrations and values of acceleration, displacement, etc., are tabulated below.

Table 2: Scaling Factors

Parameter	Scaling Factor
1.Dimension	10
2.Elastic Modulus	1
3.Acceleration	1
4.Density	1

The scaling is achieved by setting the scaling factors of length as

$S_L = L_{prototype}/L_{model}$

And the Elasticity scale factor as

$S_E = E_{prototype}/E_{model}$

2.3 Model Preparation

After deciding the scaling factor the preparation of the scaled model is done. The model is prepared as follows,

At first the prototype building is considered.

The scaling of prototype building is done then the model with precise and required sizes is obtained.

Once the model size is been decided we moved to the preparation of model using bamboo.

The main components of model are columns, base and storey plates, steel nails, bamboo (in case of bamboo model) and steel (in case of steel model).

We searched for the bamboo's and collected required amount of bamboo and cleaned it.

Then the bamboo is cut into desired shape and size

The columns prepared using bamboos are of height-400 mm (each storey height), thickness-3mm, and width-25mm, are formed using bamboo.

The plates of length-300 mm, width-150 mm, and thickness-12.5 mm, are made.

Here as the thickness and width of plate is more we attached two bamboo strips to achieve the thickness and 5 bamboo strips of 30 mm width to achieve width of 150 mm. To attach the bamboo strips we used glue and steel wires.

In the base plate the holes of 12mm diameter are made to fit the model safely on to the shake table (here 12mm diameter bolts are used).

Once the individual elements of model are prepared they are joined and made into a 3 storey single bay replica of a building. Here the steel nails are used to join the individual elements.

Fig.2: Shake Table with Bamboo Model

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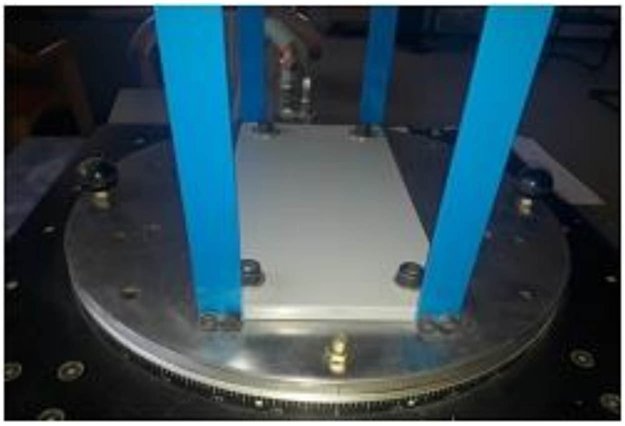


Fig.3: Shake Table with Steel Model

Once the modelling is done the model is fitted onto the shake table safely for experimental analysis.

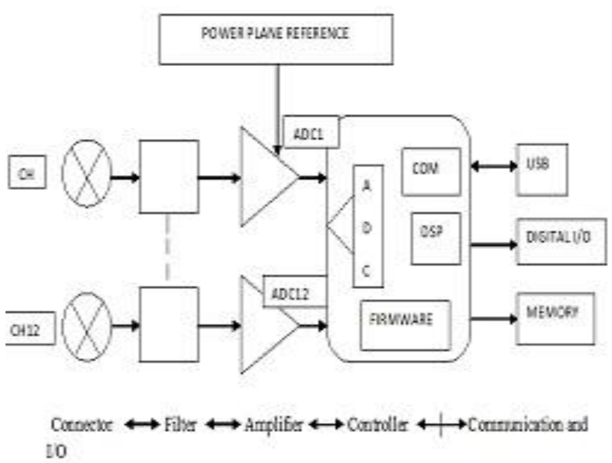
2.4 Testing using shake table About shake table

This is a portable Vibration analyser designed for examining structural model vibrations and performing various experiments for analysing experimental Civil and Mechanical structures. It has multiple unique arrays of functions for the mentioned purpose. Except for analog filtering, all processing functions are carried out in the digital domain. The built-in flash memory allows easy storage and export of data to a computer. The unit has a time domain display mode and an analyser mode for FFT analysis. In time domain display mode, simultaneous measurement of acceleration, velocity, and displacement is carried out frequency can also be displayed simultaneously. In analyser mode, FFT analysis is used to determine the power spectrum and vibration waveform. The capability to limit the bandwidth using digital filters before FFT analysis gives a higher signal to noise ratio.

Salient features

High performance DSP chip performs acquisition Simultaneous display of acceleration, velocity, displacement. Real-time display of parameter. Digital filtering achieves higher signal to noise ratio. FFT analysis Simple operation with only minimal controls. Internal buffer for data flow management. Automatic storing of data. Capability to record and analyse data in offline mode. High-speed serial data transfer using USB2.0. User friendly GUI allows easy operation and fast learning. Compact and portable unit.

Block diagram of MILDAQ Vibration Analyzer (Shake table)



2.5 Testing by Shake Table

The testing procedure using shake table is as follows. It works on two soft-wares.

Launch the Kampana Vibration Analyser Software by clicking the Icon on the on the Desktop.

After the application launches, click on setting and select the appr opriate port in the com port tab, also select the channels and grid settings.

Press the start button and let the time domain data get plotted.

Verify the frequency value. (Any change in frequency should have a minimum of 20 second off-time margin, half a minute could be taken as reference).

Use the keys to scale the time and voltage scale for the display windows.

Click Filter ON, then filter settings to select the filter parameters, edit the values as required and click apply.

You can see the change in the time domain waveform.

Similarly corresponding change will be visible in frequency domain.

Check the vibration parameters displayed on the control window.

Click on the Log mm/Hz tab and check whether the data saved is as expected.

Change the frequency to a different value and follow the steps from step 4 to step 10.

Repeat the procedure from step 4 to step 11 for further experiment.

Stop the experiment by clicking on the stop button.

Browse the files that are saved by default, verify the date and time of file creation.

Read the data and plot the data in offline mode for verification.

Export the acceleration data and verify the generated file by checking the time histories of acceleration, velocity and displacement.

2.6 STAAD.pro Analysis

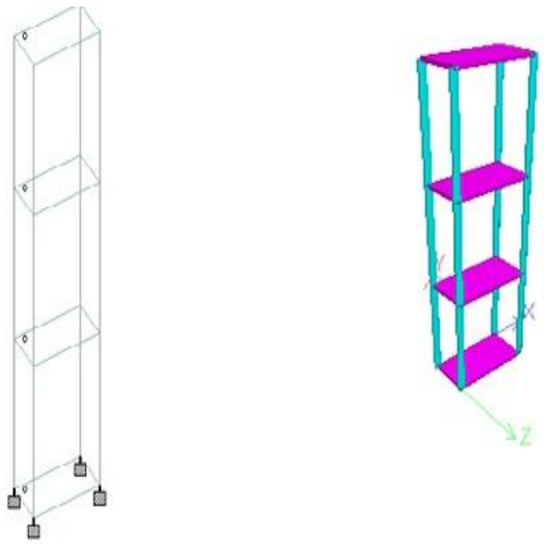


Figure 4: STAAD Model

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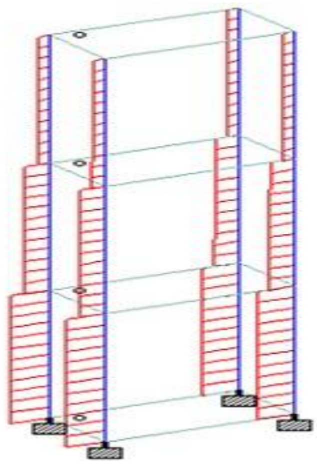

Figure 5: Beam-Column Stresses

The analysis is been done for the prototype using STAAD.pro and the results are observed. Here the displacements for lower levels (CH1-X,Y,Z) and as we move upwards it increases along above levels (CH2-X,Y,Z) and (CH3-X,Y,Z).

III. EXPERIMENTAL RESULTS

3.1 Experimental Results for Bamboo

The figure: 6 show the Displacement vs. Frequency variation graph for bamboo. The below graph is drawn using the values of displacement obtained for varying frequencies for channel 1-X to channel 4-X in table 3.Here the variation of frequency is between 2.5Hz to 9.0Hz. While doing the test using shake table till 2.5Hz frequency the displacement will be less, and after reaching 2.5Hz we observed the more displacement in model and after that again the displacement became less till it reaches 4.5Hz frequency. Likewise there is continuous variation in the displacement. The bamboo can sustain the frequency till 9.0Hz.

Table3: For Bamboo: Frequency vs Displacement in X Direction

Frequency	CH1-X Disp	CH2-X Disp	CH3-X Disp	CH4-X Disp
2.5	11.008	5.161	9.502	17.349
4.5	7.703	4.569	1.012	5.04
6.5	3.957	3.014	1.045	2.8
7	3.252	4.222	1.008	2.399
8.25	1.315	2.758	1.615	2.494
9	1.204	3.572	3.25	3.083

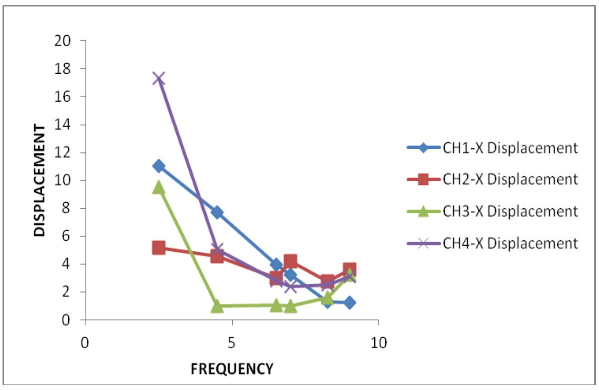

Fig.6: Frequency vs. Displacement for Baboo

The figure 7 shows the Displacement vs Frequency variation graph for bamboo. The below graph is drawn using the values of displacement obtained for varying frequencies for channel 1-Y to channel 4-Y. Here the variation of frequency is between 2.5Hz to 9.0Hz. While doing the test using shake table till 2.5Hz frequency the displacement will be less, and after reaching 2.5Hz we observed the more displacement in model and after that again the displacement became less till it reaches 4.5Hz frequency. Likewise there is continuous variation in the displacement. The bamboo can sustain the frequency till 9.0Hz.

Table4: For Bamboo: Frequency vs. Displacement in Y Direction

Frequency	CH1-Y Disp	CH2-Y Disp	CH3-Y Disp	CH4-Y Disp
2.5	0.109	0.938	2.114	0.94
4.5	0.123	1.028	1.815	3.76
6.5	5.225	0.225	0.31	0.641
7	23.11	0.515	0.207	0.518
8.25	99.194	0.296	8.854	0.387
9	106.527	0.725	43.997	62.769

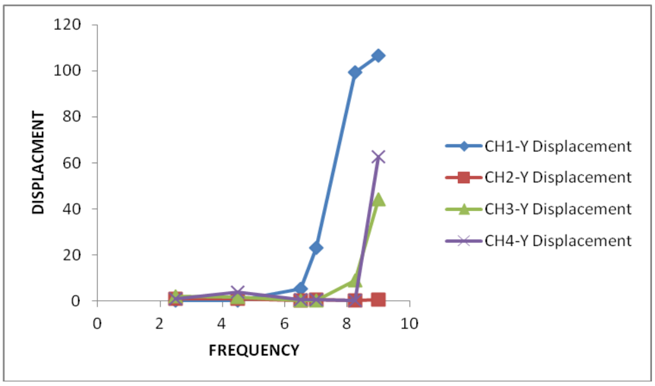

Fig.7

3.2 Experimental Results for Steel

The figure 8 shows the Displacement vs. Frequency variation graph foe steel. The below graph is drawn using the values of displacement obtained for varying frequencies for channel 1-X to channel 4-X. Here the variation of frequency is between 2.5Hz to 8.25Hz. While doing the test using shake table till 2.5Hz frequency the displacement will be less, and after reaching 2.5Hz we observed the more displacement in model and after that again the displacement became less till it reaches 6.5Hz frequency. Likewise there is continuous variation in the displacement. The steel can sustain the frequency till 8.25Hz.

Table5: For Steel: Frequency vs. Displacement in X Direction

Frequency	CH1-X Disp	CH2-X Disp	CH3-X Disp	CH4-X Disp
2.5	12.623	74.578	11.839	132.31
6.5	4.133	10.532	114.252	18.679
7	3.249	8.228	5.645	8.488
8.25	2.399	13.973	3.041	14.373

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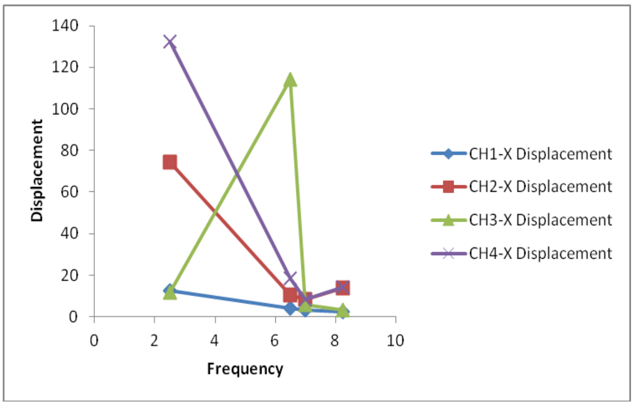

Fig. 8: CH 1-4X for Steel

The figure 9 shows the Displacement vs. Frequency variation graph for steel. The below graph is drawn using the values of displacement obtained for varying frequencies for channel 1-Y to channel 4-Y. Here the variation of frequency is between 2.5Hz to 8.25Hz. While doing the test using shake table till 2.5Hz frequency the displacement will be less, and after reaching 2.5Hz we observed the more displacement in model and after that again the displacement became less till it reaches 6.5Hz frequency. Likewise there is continuous variation in the displacement. The steel can sustain the frequency till 8.25Hz.

Table6: For Steel: Frequency vs Displacement in Y Direction

Frequency	CH1-Y Disp	CH2-Y Disp	CH3-Y Disp	CH4-Y Disp
2.5	10.519	1.523	7.214	10.113
6.5	1.058	0.32	1.085	1.463
7	11.524	0.751	0.598	0.72
8.25	15.356	0.978	0.798	1.088

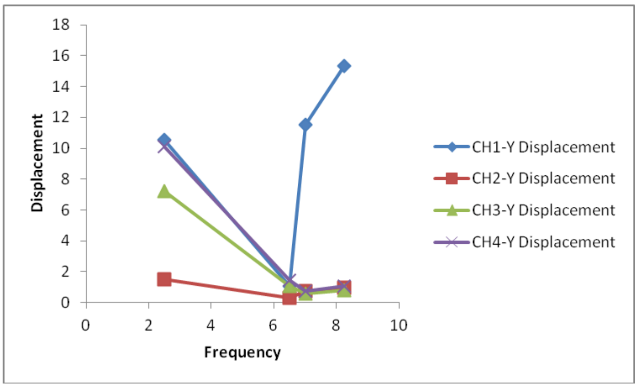

Fig. 9: CH 1-4X for Bamboo

3.3 Comparison of Results

By observing all the above displacement values and displacement vs. frequency graphs at varying frequency for both bamboo and steel, we observed the max displacement values for bamboo at 2.5Hz and 9.0Hz frequency and that of steel at 2.5Hz and 8.25Hz frequency ranges.

Table 7: CH 1X

Frequency	Displacement of Bamboo	Displacement of Steel
2.5	11.008	12.623
8.25	1.315	2.399
9	1.204	

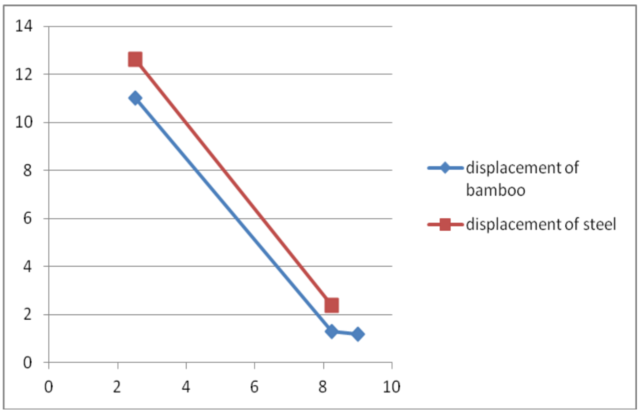

Fig. 10: CH 1X

Table 8: CH 2X

Frequency	Displacement of Bamboo	Displacement of Steel
2.5	5.161	74.578
8.25	2.758	13.973
9	3.572	

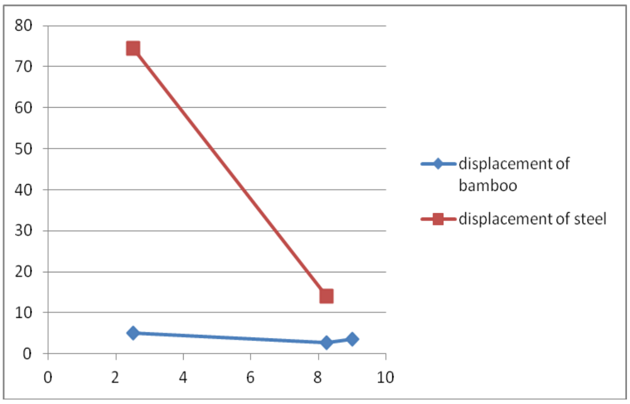

Fig.11: CH 2X

Table 9: CH 3X

Frequency	Displacement of Bamboo	Displacement of Steel
2.5	9.02	111.839
8.25	1.615	3.041
9	3.25	

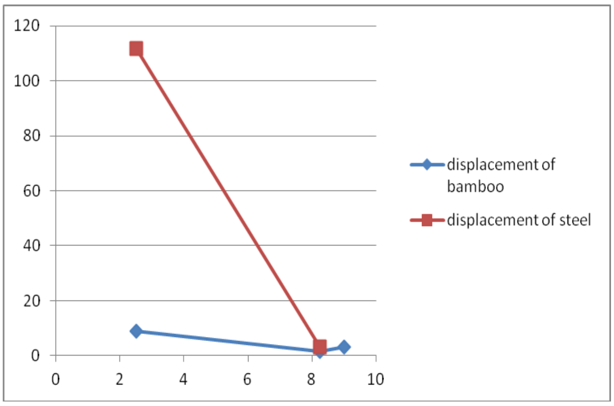

Fig.12: CH 3X

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Table 10: CH 4X

Frequency	Displacement of Bamboo	Displacement of Steel
2.5	17.349	132.31
8.25	2.494	14.373
9	3.083	

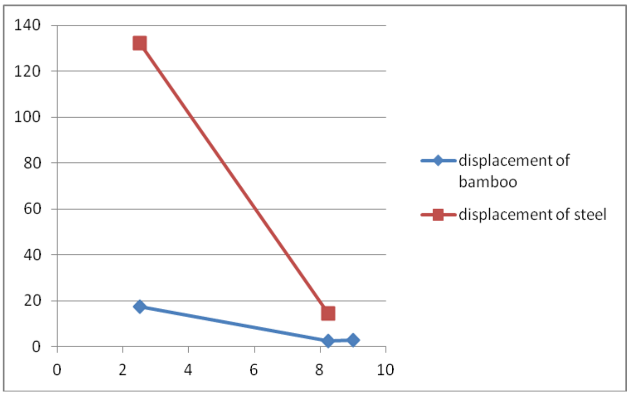

Fig.13: CH 4X

By observing all the above comparative graphs we can easily say that the displacement observed in case of bamboo is lesser than that of steel for all the critical sections such as CH-1X,CH-2X,CH-3X,CH-4X. The steel shows mare displacement for same frequency ranges that of the bamboo.

IV. CONCLUSIONS

By observing all the above investigations, graphs and results the below conclusions can be made.

- After studying all the basic properties of the steel and bamboo it is concluded that bamboo has the more flexibility than that of steel.
- By seeing the less displacement values of bamboo in comparation with steel we can say that bamboo possesa very good elastic property.
- By all above studies we can say that the bamboo has a good tensile and compressive strength.
- After observing that graphs drawn to the displacement values of steel and bamboo at critical sections (comparative graphs) we can conclude that in all the graphs for 2.5Hz,8.25Hz,and 9.0Hz the displacement curve foe bamboo is showing lesser values and that of steel shows more amount of displacement. So the bamboo can sustain large amount of seismic force.
- As mentioned earlier the growth rate of bamboo is very high i.e. it can grow up to 70mm per day and can also reach up to 350 to 450mm per day. Bamboo can grow in almost all climatic conditions, an economical material and the structures constructed using it can be easily moulded and de-mounded.

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