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Experimental and Numerical Study of a Steel Bridge Model through Vibration Testing Using Sensor Networks

Patel S G[1], Vesmawala G R[2]
[1]*Applied Mechanics Department, Sardar Vallabhbhai National Institute of Technology, Surat - 395007*
[2]*Applied Mechanics Department, Sardar Vallabhbhai National Institute of Technology, Surat - 395007*

Abstract: *In recent years, vibration signatures are used to investigate modal parameters (i.e. modal frequencies, mode shapes and damping etc.) from vibration response of the structures under the external excitations. These identified parameters gives valuable information on the behaviour and performance of the structures. In this paper, experimental study on a steel bridge model was carried out by using ambient excitation method (i.e. remote car model). Mode shapes and its respective modal frequencies are extracted with the use of sensor technology, signal communication and data acquisition technology. Along with the experimental study, numerical, study is also carried out to evaluate the vibration properties of a steel bridge model with the help of FEA software package (ANSYS) and the results are compared.*
Keywords: *Vibration test; Steel bridge model; Ambient vibration; Data acquisition; Finite element analysis.*

I. Introduction

Vibration measurement of structure is a relatively new technique within civil engineering and other engineering disciplines. Vibration measurement used to identify the vibration parameter which helps to understand the real behaviour and condition of structure. The study is to evaluate the vibrational properties or characteristic such as natural frequencies; Mode shape, Damping of the bridge structure with the help of the vibration signature produced by the external excitation forces i.e. force or ambient excitation [1,2,3]. The frequencies of vibration of the structure are directly depends on stiffness and mass of the structure, while the mode shapes are related to the deflection of structures. Therefore vibration testing is good approach among all other methods to obtain the data of the dynamic properties for structural monitoring and evaluation [4].

In this study, vibration testing on steel bridge model was carried out to study the interference between sensing technology, data acquisition systems and computer. Therefore, the experimental set up is established to study, how to measure the vibration signal, acquiring vibration signal, and evaluating vibration properties from data obtained from vibration study. Hence, the steel bridge model is not prepared by considering the actual bridge blueprints or prototype of the actual bridge. The force excitation method is used in this study with moving car model for excitation of steel bridge model to perform the laboratory experiment

A complete vibration signal measurement system consists of Sensory system composed of sensors; Data acquisition system; Data Communication system; Data processing system; Data Storage system and Evaluation and verification system.[5] Following Fig. 1 shows flowchart of complete monitoring system.

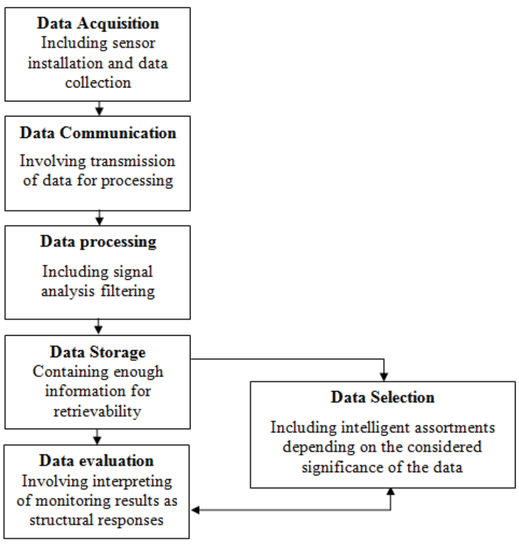


Fig. 1 Flowchart of an effective complete monitoring system

II. Test Instrumentation

1.1 THE STEEL BRIDGE MODEL

The steel bridge model is prepared with mild steel plate to study the vibration measurement system to evaluate vibration properties from acquired data from experiments. The mild steel plate having a thickness of 8 mm is selected to prepared bridge model and experiments are performed. The steel bridge models are of the size 1250 mm x 350 mm. A railing on steel plate is made with the help of the mild steel bar section of size 10 mm x 10 mm. The steel bridge model geometry and manufacturing is shown in following Fig. 2

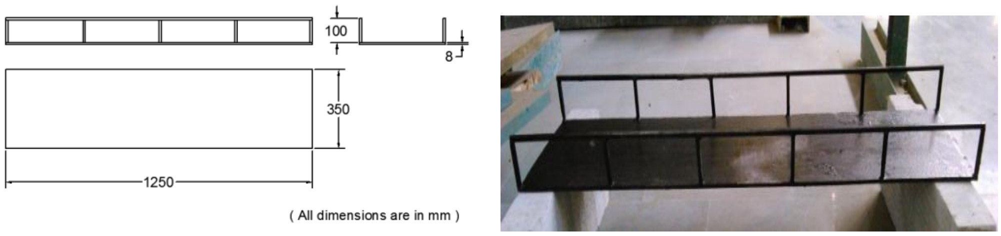


Fig. 2 Geometry of the Steel Bridge Model adopted for study

1.2 MOVING CAR MODEL

The ambient excitation method is used to excite the steel bridge model by moving car model. A remote control car having wheel spacing is considered for the study i.e. 150mm c/c. which is used to decide path of moving car model over a steel bridge model as shown in figure. Weight of car model is not considered for the study as excitation inputs are not measured in operational modal analysis.

1.3 SENSORS

Sensors are used in experimental study are uniaxial accelerometers. It measures acceleration in one direction. As per the acceleration measurement in particular direction we have to use the accelerometer accordingly. Sensitivity of sensor is 100mV/g. it’s having dynamic range ± 50g and frequency range is 0.5 to 10000 Hz. Curved surface magnet mounting pads were used for fixing the accelerometers at its predefine location for experimental study.

1.4 DATA ACQUISITION SYSTEM

In experimental study, we have use NI compact DAQ i.e. NI cDAQ – 9174 and NI Data acquisition (DAQ) Modules i.e NI 9234 module for acceleration measurement from National Instruments, USA. The NI Compact DAQ system consists of a chassis of 4 - Slot, NI C Series I/O modules, and software. Chassis can connect to a host computer over USB, Ethernet, or 802.11 Wi-Fi or operate stand-alone with a built-in controller. With over 50 measurement-specific modules and 4-slot chassis, NI cDAQ provides a flexible, expandable platform for sensor measurement system. The NI 9234 is a four-channel C Series dynamic signal acquisition module for making high-accuracy sound and vibration measurements from sensors with NI cDAQ systems. The NI 9234 delivers 102 dB of dynamic range and incorporates software-selectable AC/DC coupling and IEPE signal conditioning for accelerometers. The four input channels simultaneously digitize signals at rates up to 51.2 kHz per channel with built-in anti- aliasing filters that automatically adjust to our sampling rate. The computer provides a processor (2.40 GHz), a system clock, a bus to transfer data into disk space to store data. The processor controls how fast data is accepted by the converter. The system clock provides time information about the acquired data.

1.5 LABVIEW SOFTWARE

The vibration data acquisition system software is designed in modularization using Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW), which is a platform and development environment for a visual language from National Instruments. The programming language used in LabVIEW, referred to as graphical language, is a dataflow programming one. LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms. The designed software based on LabVIEW can finish such the functions as data collection, data display, data transform, data memory, Time record, FFT etc.[6]

III. Experimental Setup And Test Procedure

The steel bridge model is simply supported over a concrete block. The grid marking is done on the steel bridge model to specify the coordinate & location for path of moving car model and the location of the accelerometers as shown in Fig. 3. The Data Acquisition System is established with NI cDAQ – 9174 Chassis and Two Module NI – 9234. The head of the accelerometers are fixed with magnetic mounting pads and signaling cables are connected at its output end. All accelerometers are attached on the edges of steel bridge model at specified grid points. Accelerometers are attached with the second and third module NI – 9234 at each BNC input slots. The computer system is attached with the NI cDAQ – 9174 with a USB connector. After configuration of all instruments test were perform and data was recorded for the post analysis processes to estimate the modal parameters of the model.

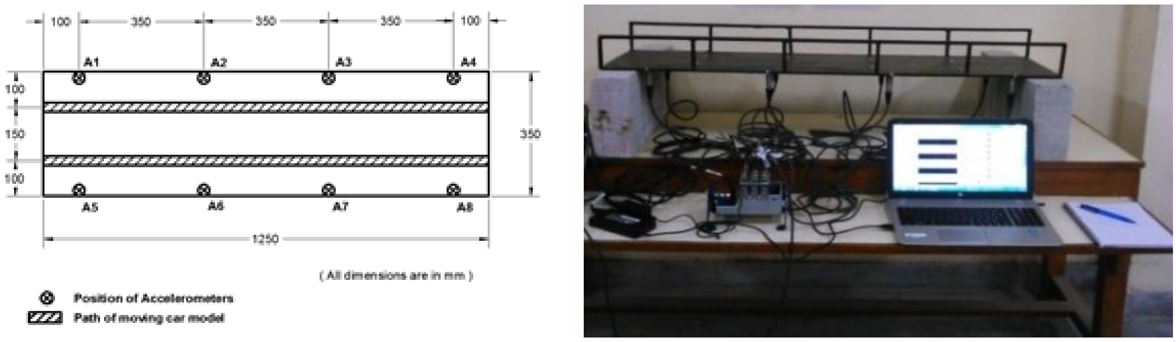


Fig. 3 Experimental setup for vibration measurement of the steel bridge model

Establish connection between accelerometers, data acquisition chassis (DAC) and modules with computer. In LabVIEW, the graphical programming has to develop to create interface between data acquisition system and computer. Vibration testing involves the steel bridge model with moving car at predefines location path on the model. Moving car model generates motion waves, which are capture by accelerometers and measures the resultant motion. Actual signals captures from accelerometers are recorded and analyzed in LabVIEW to get the results. These results are used to get the natural frequencies, mode shape of the model.

IV. FE Modelling of Steel Bridge Model

The Steel bridge model geometry is generated in ANSYS as per dimensions of model adopted for the experimental work. Model of 8 mm plate thickness are generated with properties were assigned as Density = 7850 Kg/m^3, Young's modules (E) = 200000 MPa, Poisson's ratio (υ) = 0.3. The origin of axes is shown in figure, where the z- and x- axes are located in the plane of the bottom surface of the plate along the longitudinal and transverse directions, respectively. The y-axis is perpendicular to the plate and positive upwards.

The steel bridge model is modelled using the SOLID 185 as model prepared from mild steel material in study. Solid 185 is used for the three-dimensional modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node i.e. translations in the nodal x, y, and z directions. The model of 8 mm thickness plate comprises 6281 elements. The total number of nodes included in the model is 4964 resulting in a system with 14892 degrees of freedom [7,8]. The model is illustrated in Fig.4

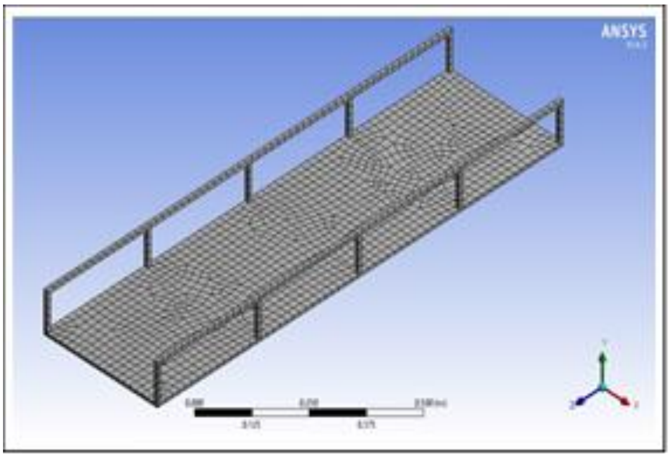


Fig. 4 Experimental setup FE modelling, meshing of the steel bridge model in ANSYS

All eight acceleration time histories obtain in experiment at specified location of sensors are taken into the consideration for analysis of the model in ANSYS. Support condition is provided to the geometry of model as simply support by imprint faces generated at bottom of the plate as per provided in experimental work. Analysis of the steel bridge model is carried out using modal analysis performs in ANSYS. The results obtain from analysis gives modal parameters such as mode shapes and modal frequencies.

V. Results & Discussion

In experimental results, spectrum graph shows different colour plot lines which represent the spectrum produce due to individual accelerometers. The natural frequencies of the steel bridge model were identified using spectrum graph, which is computed for the vertical signals obtained from car model during test. Thus, the individual spectrum graphs have peaks corresponding to all modes [9] Therefore, the frequency values obtained in all the graphs for all modes are varying. Exect prediction of the frequency value related to mode is not possible but it can give the approximate range. Typical acceleration time histories and Spectrum graph generated during experiment at each run in LabVIEW are shown in Fig. 5 and Fig.6 respectively.

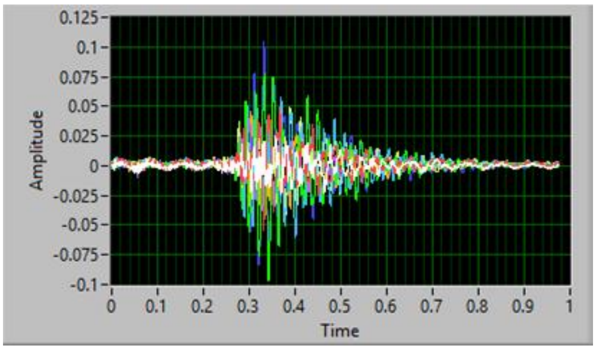


Fig. 5Typical acceleration time history generated at each run in LabVIEW program

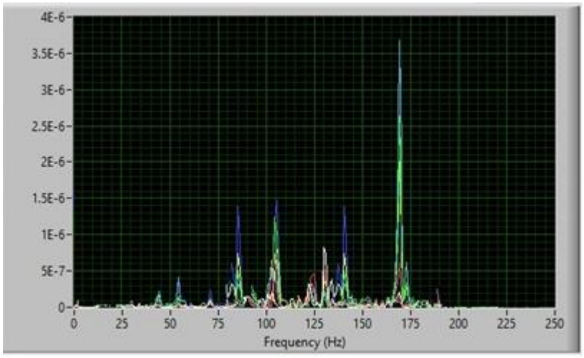


Fig. 6 Typical Spectrum graphs generated during experiment at each run in LabVIEW program

The very small first peak in all spectrum graphs corresponds to the fundamental mode with a natural frequency[9], which is 28.978 Hz for first vertical bending mode. The second peak and other corresponding peak at a frequency of near to 46.864 Hz ,64.109 Hz, 96.981 Hz, 104.064 Hz, 107.538 Hz, 134.651 Hz, 144.098 Hz, 148.078 Hz and 165.556 Hz respectively is more clearly find, indicating second and other correspond to predominantly different modes. In total, 10 modes with natural frequencies below 200 Hz were identified as shown in Fig. 7.

In analytical results, the first peak in spectrum graphs corresponds to the fundamental mode with a natural frequency of 29.468 Hz for first mode represents bending. The second and third peak in spectrum graphs at frequency 47.097 Hz and 64.305 Hz corresponds to torsional and bending mode respectively. The remaining peaks are clearly defined peaks represents the remaining eight modes with a frequencies 97.082 Hz, 103.94 Hz, 107.37 Hz, 134.85 Hz, 143.99 Hz, 148.17 Hz and 165.63 Hz. corresponds to bending, tortional or combination of both modes. Which is shown in Figure 8. The experimental and analytical results obtained are much closed as shown in Table 1.

Table 1 Comparison of experimental & numerical values of Model Frequencies

Modes	Modal Frequencies	
	Experiment Values	Numerical Values
1	28.978 Hz	29.468 Hz
2	46.864 Hz	47.097 Hz
3	64.109 Hz	64.305 Hz
4	96.981 Hz	97.082 Hz
5	104.064 Hz	103.94 Hz
6	107.538 Hz	107.37 Hz
7	134.651 Hz	134.85 Hz
8	144.098 Hz	143.99 Hz
9	148.078 Hz	148.17 Hz
10	165.556 Hz	165.63 Hz

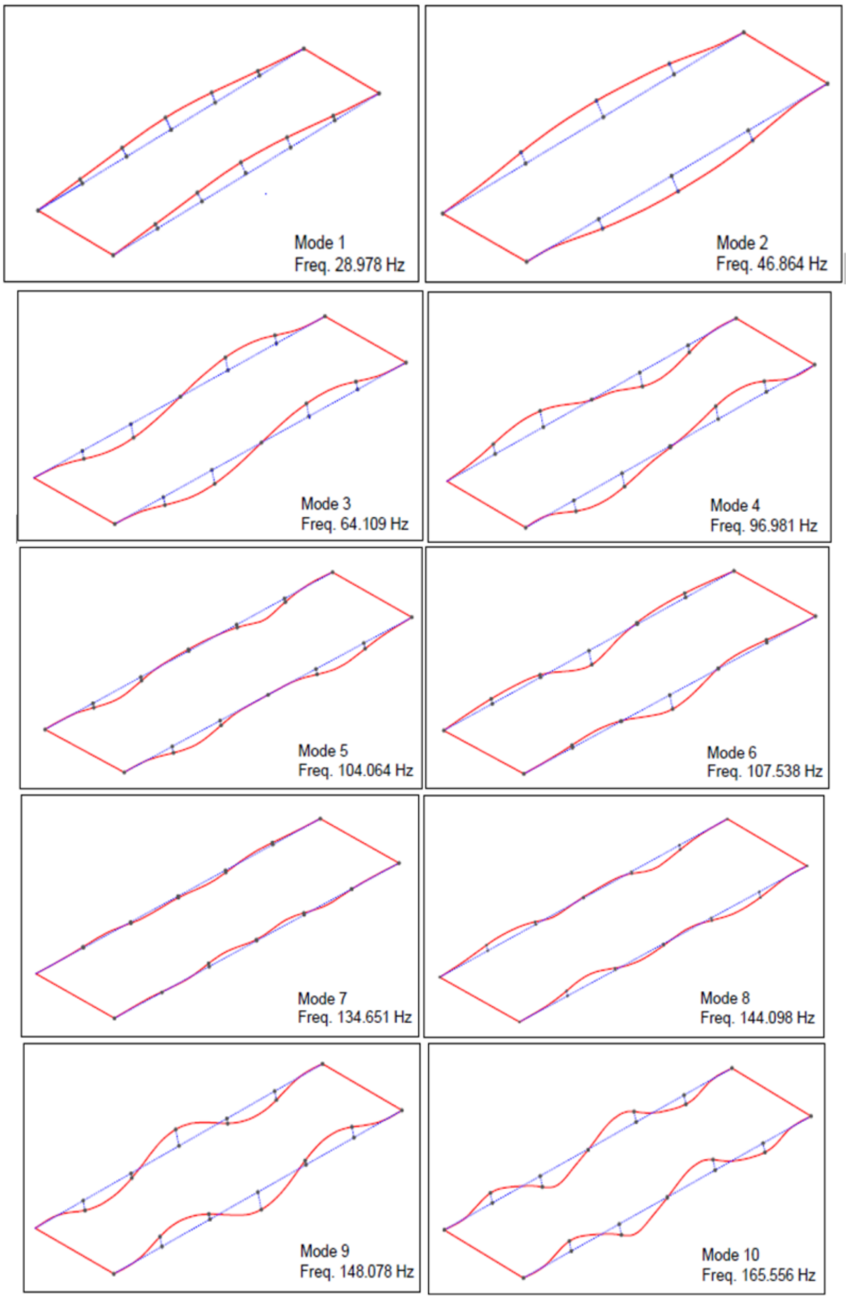
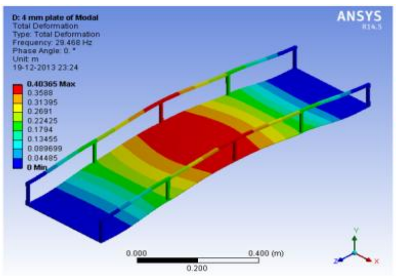
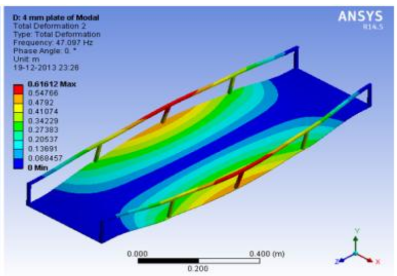


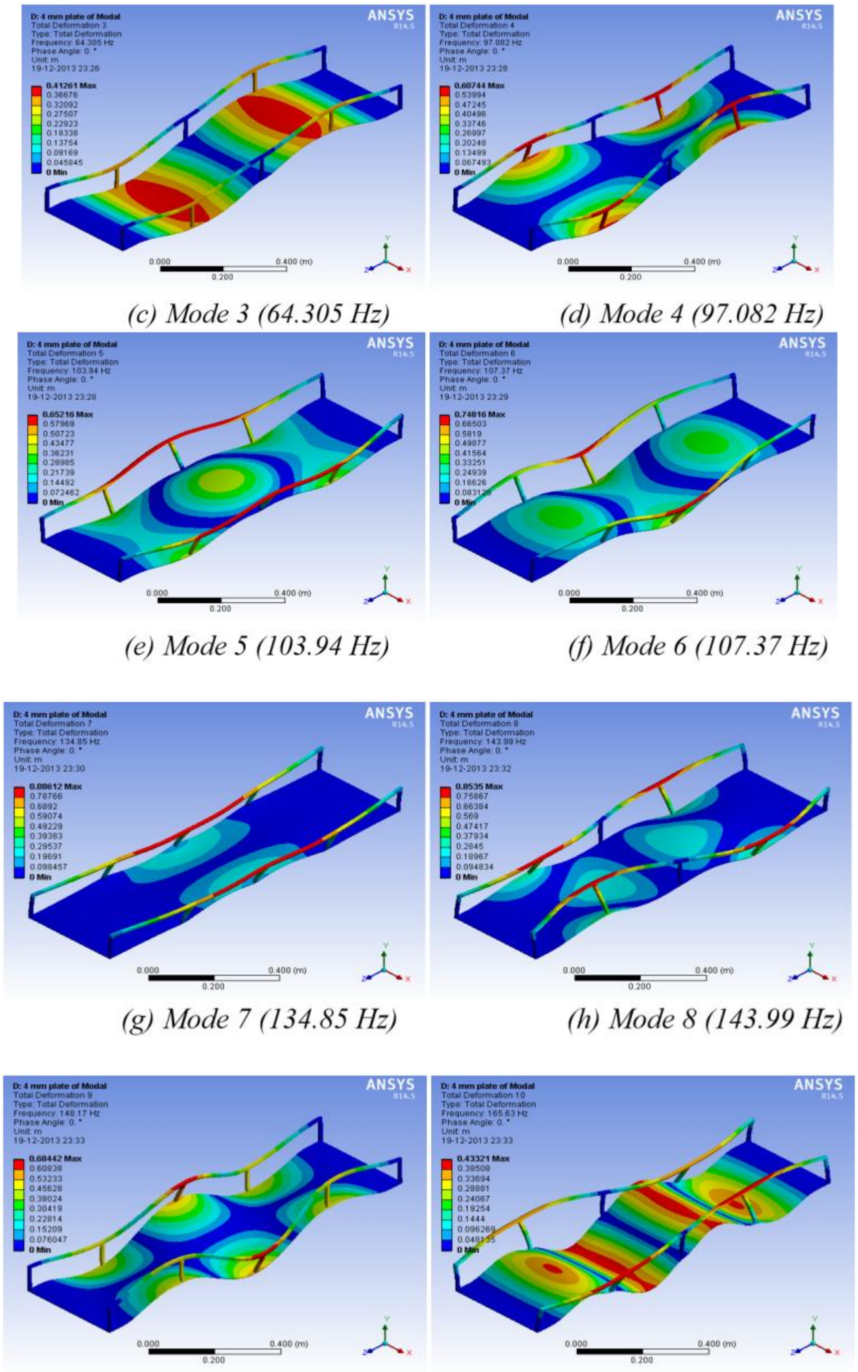
Fig. 7 Mode shapes and Modal Frequencies for 8 mm plate model (Experimental)



(a) Mode 1 (29.468 Hz)



(b) Mode 2 (47.097 Hz)



(c) Mode 3 (64.305 Hz) *(d) Mode 4 (97.082 Hz)*

(e) Mode 5 (103.94 Hz) *(f) Mode 6 (107.37 Hz)*

(g) Mode 7 (134.85 Hz) *(h) Mode 8 (143.99 Hz)*

(i) Mode 9 (148.17 Hz) *(j) Mode 10 (165.63 Hz)*

Fig. 8 Mode shapes and Modal Frequencies for 8 mm plate model (Numerical)

VI. Conclusion

From the presented study, vibration properties such as modes and modal frequencies are evaluated for steel bridge model under constant moving load without considering the ambient excitation (i.e. remote car). Experimental results are evaluated by the data store during test by using LabVIEW program. These data are in a form of time domain signals, after applying filters and single processing technique to reduce the disturbance in signals such as white noise etc. and time domain data were process with applying fast fourier transform technique to get spectrum graph in frequency domain. Each peak in spectrum graph represents corresponding modes and modal frequencies.

First modal frequency is 29.978 Hz corresponds to bending mode. Other corresponding modal frequencies are 46.864 Hz, 64.109 Hz, 96.981 Hz, 104.064 Hz, 107.538 Hz, 134.651 Hz, 144.098 Hz, 148.078 Hz and 165.556 Hz, which represents bending, torsional and combination of both were identified. Numerical study carried out in FEA commercial software (i.e.ANSYS) with same parameters of steel bridge model adopted for the experimental study. After performing numerical analysis, First modal frequency 29.468 were calculated with bending mode. Remaining modes and modal frequencies are 47.097 Hz, 64.305 Hz, 97.082 Hz, 103.94 Hz, 107.37 Hz, 134.85 Hz, 143.99 Hz, 148.17 Hz and 165.63 Hz. corresponds to bending, tortional or combination of both modes. It is found that results are having closed resemblance of modes and its modal frequencies calculated with experimental as well as numerical studies.

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