SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

FIELD EXPERIMENT ON STEEL INDUSTRIAL BUILDING WITH AMBIENT VIBRATION

Elif AĞCAKOCA[1], H. Serdar KUYUK[2], Muharrem AKTAŞ[3], Elif O. BORU[4], Erkan ÇELEBİ[5]

ABSTRACT

Understanding the dynamic behavior of the structures is very important. Finding dynamic characteristic of structures by testing techniques give crucial information for safe and economical design. Experiments on scaled structures in laboratory cannot address all complexities involved, thus full-scale structures need to be tested on the field although conducting field tests involve many challenges. Structural characteristics such as natural frequencies, mode shapes and damping must be determined prior to occurrence of an earthquake to estimate the response of the structure. Operational modal analysis (OMA) is a promising method for calculating modal parameters of existing structures. This study explores OMA approach to detect natural frequencies of one story steel frame structure and to compare those obtained from finite element analysis. A model steel frame structure is used to conduct ambient excitation tests. The steel structure consist of three different steel frames; a truss, a castellated beam and a plate girder. Tested structure is modeled with finite element software; SAP 2000 to obtain modal parameters such as natural frequencies and mode shapes numerically. Verification of numerical modeling is made my using FEMtools in which test results are directly used. Moreover, structural damping and modal shapes are determined. Results obtained from numerical models agrees well with those obtained from tests.

INTRODUCTION

Dynamic behavior of structures depends on many unknown parameters. Modal natural frequencies mode shapes are the most important parameters that need to be identified prior to design. Numerical methods can be used for the purpose however, once the structures are constructed their stiffness can be changed under fatigue loads. Thus, experimental approach is necessary to identify the mode shapes and related natural frequencies of existing structures. These data obtained from the test can provide very important information about the performance of the structure under next possible earthquake.

Dynamic characteristics of a structure such as damping ratio, natural frequency and mod shape are directly related to mass and stiffness. These parameters will be crucial to identify the damage level of a structure under dynamic loads (Bayraktar et al., 2010). In recent studies, experimental modal analysis method is employed to identify the modal characteristics of a structure, to verify and to

[1] Assist. Prof. Dr., Sakarya University, Sakarya, elifd@sakarya.edu.tr
[2] Assist. Prof. Dr., Sakarya University, Sakarya, serdarkuyuk@gmail.com
[3] Assist. Prof. Dr., Sakarya University, Sakarya, muharrema@sakarya.edu.tr
[4] Research Assist. MSc., Sakarya University, Sakarya, eorak@sakarya.edu.tr
[5] Prof. Dr., Sakarya University, Sakarya, ecelebi@sakarya.edu.tr

update the existing analytical models. Natural frequencies and modes of vibrations of many civil structures are already determined experimentally and analytically in literature. However, these methods that are used to determine modal properties supplement each other. Ventura et al, (2000) investigated heritage tower building and proved that the natural frequencies of a structure can be measured satisfactorily and can be used to correlate numerical models by experiment. Dynamic characteristics of a 48-storey reinforced concrete shear core building with tuned mass system were determined experimentally and analytically (Lord et al., 2002). A steel model bridge was constructed at lab and dynamic characteristics are determined for possible deterioration of steel (Ozcelik et al., 2013). Another steel model bridge was tested by Dönmez et al., 2009 to update finite element model with the results obtained from lab test.

In this study, dynamic characteristics of a single story steel structure with three different frame systems are investigated experimentally and analytically. Frames are constructed as a truss, a castellated beam and a plate girder to cover mostly used frame types for steel structures. Ambient vibrations are recorded with two accelerometers mounted at the structure. Once the tests are completed then finite element model of the same structure is created by commercial software package, SAP2000. FEMtools that directly uses the data obtained from field tests is used to verify the numerical modeling. Verification of modeling technique is completed by comparing natural frequencies. Modal shapes and structural damping of the structure are also obtained by using FEM tools software package.

FINITE ELEMENT MODELING

Structural engineers use finite element analysis to obtain natural frequencies of structure. However, assumptions made for modeling material properties, connection types and analysis type can give different results from actual structure. To verify the modeling techniques scaled or real test for similar structure can be done prior or after the design. Verified model then give the designer opportunity to check any safety levels he/she desires. In this study commercial software package SAP2000 that is widely used in structural community is employed. Material properties and element cross-sections that are used to model the structure is given in Figure 1 and Table 1. Structure is simply supported and purlins are simply supported beams. Linear modal analysis is conducted to determine the natural frequencies of the structure. Natural frequencies are found as 9.09 Hz for transversal direction, 12.04 Hz for torsional mode and 21.36 Hz for longitudinal direction.

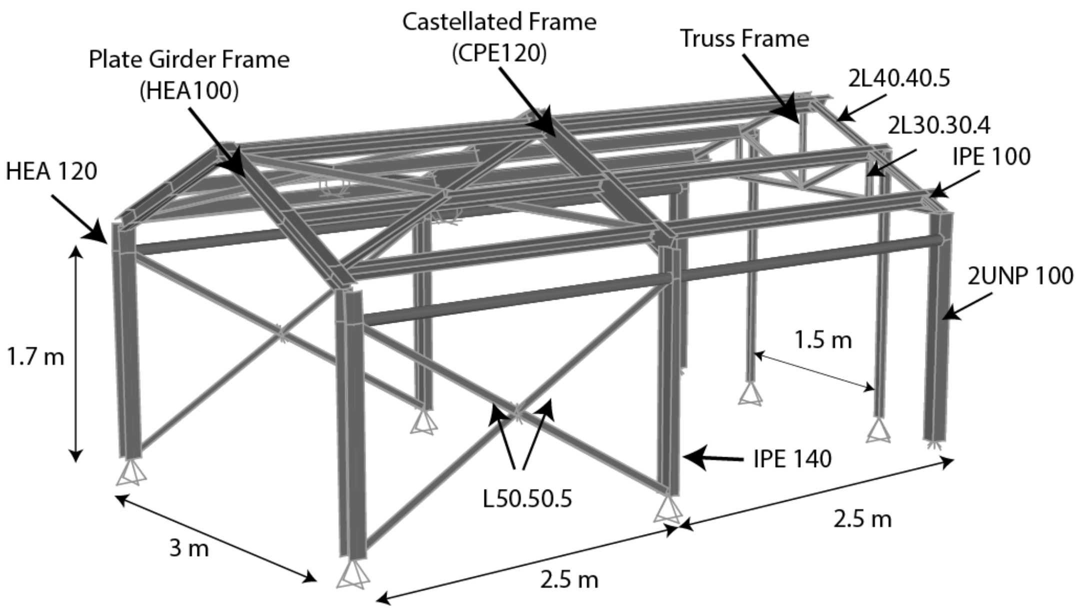

Figure 1. Finite element model of test structure with dimensions and sections.

Table1. Section properties for considered structure

Member	Section	Elasticity Modulus (kN/m^2)	Poison Ratio	Length(m)	Quantity
Column	2UNP 100 IPE 140 HEA 120	2.1E8	0.3	1.7	6
First Frame Beam(upper chord and bottom chord, diagonals)	2L40.40.5 2L30.30.4			1.36	2 5
Second Frame Beam	CPE120			1.36	1
Three Frame Beam	HEA100			1.36	1
Purlin	IPE 100			2.5	12
Bracing	L50.50.5			2.9	8

EXPERIMENTAL STUDY

Structure is instrumented with accelerometers mounted at the top of the structure. Ambient vibrations are recorded with high quality Capacitive Force Micromachined accelerometers, which have 32-bit high resolution and have 120 dB dynamic range, located at top of the structure (Figure 2). Accelerations are recorded for x, y and z direction for a sample rate of 100. During the test vehicle traffic near the structure was stopped.

Figure 2. Dimensions of cross section and structure tested

General layout of the frame is given in Figure 3a. Plate girder frame, castellated frame and truss frame are given in Figure 3b, 3c, 3d, respectively. All six columns are simply supported to the reinforced concrete foundation (Figure 3e). The truss is connected to the column with a pin support as shown in Figure 3f. Finally close picture of accelerometer, GPS anttenna and its power unit is given in Figure 3g.

Figure 3. a) General layout b) Plate girder frame c) Castellated frame d) Truss frame e) Simple support f) Pin connection for truss frame g) Accelerometer GPS antenna and its power unit

Since lateral characteristics are used to design structures for lateral loading, accelerations records for only lateral directions are investigated. Thus, vertical acceleration records are ignored. 30 seconds of ambient vibration record obtained from two accelerometers are plotted in Figure 4 for longitudinal and transversal direction. Maximum acceleration of 0.007 g is measured during the test.

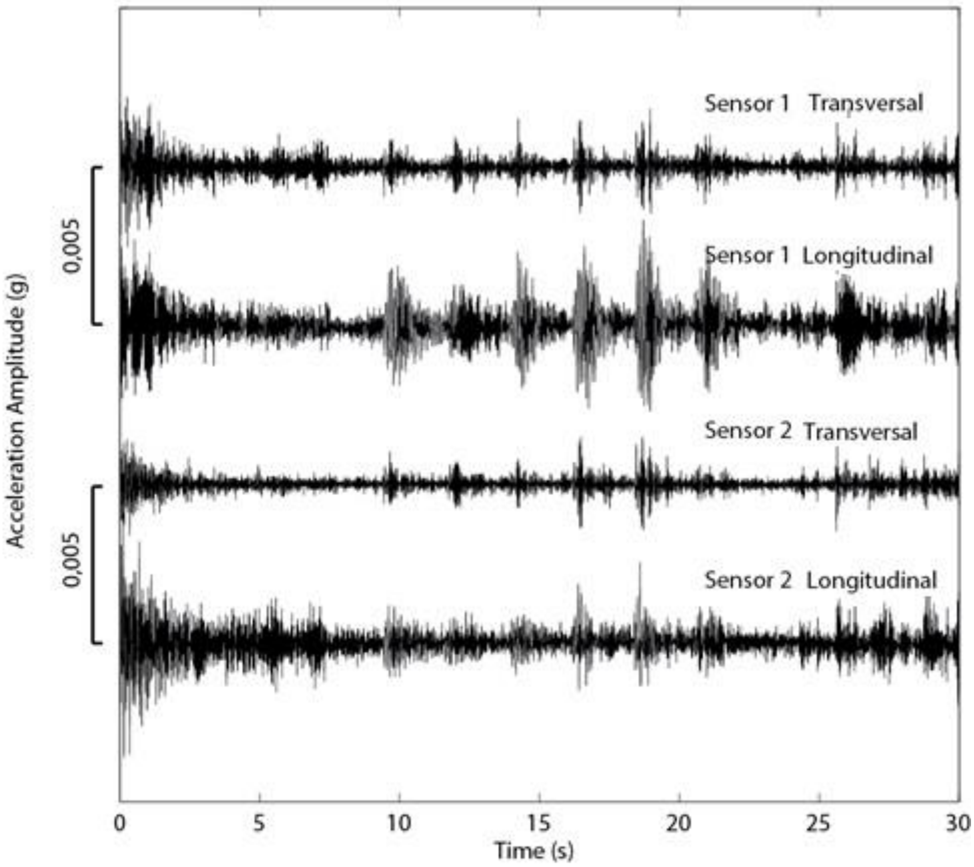

Figure 4. Measured acceleration record of ambient vibration

Fast Fourier Transform (FFT) is applied with Matlab to determine frequency content of the record (Matlab, 2013). FFT results are plotted in Figure 5 both for longitudinal and transverse direction. Fundamental frequency observed for transversal axis from sensor 1 and sensor 2 is 15.83 Hz 9.19 Hz, respectively. However, fundamental frequency for longitudinal direction is determined 18.91 from both sensors.

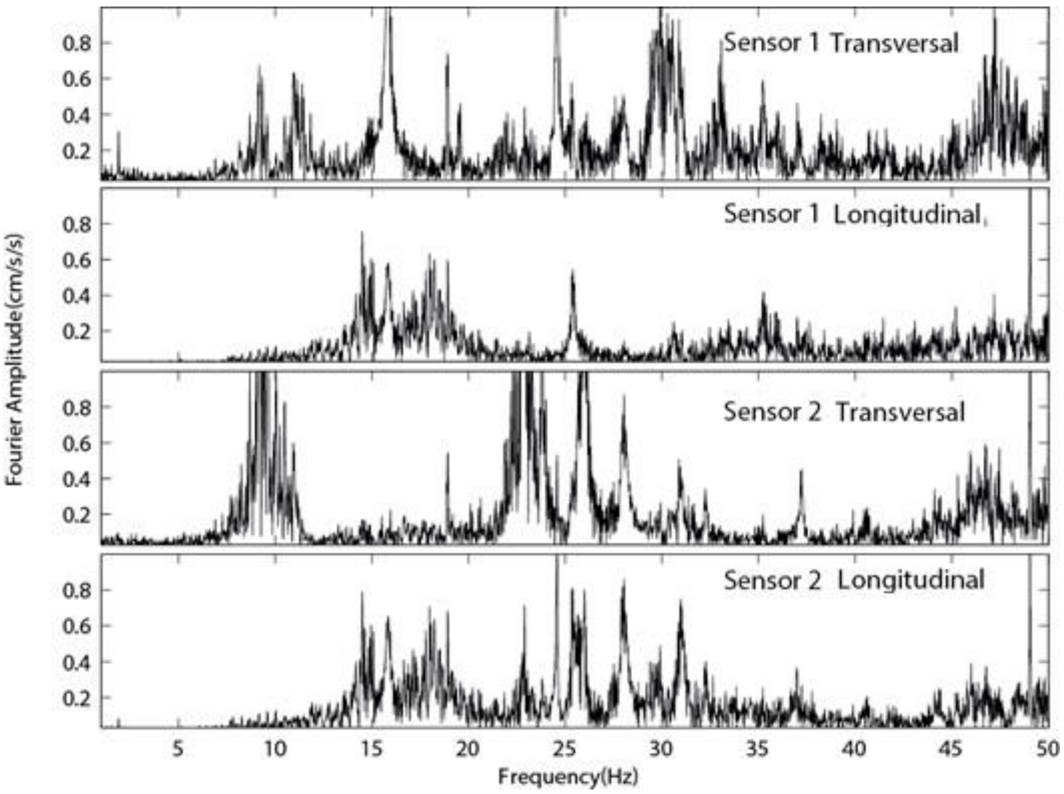

Figure 5. FFT results for longitudinal and transverse direction

OPERATIONAL MODAL ANALYSIS

Operational modal analysis (OMA) is also known as ambient modal analysis and natural input modal analysis. OMA uses ambient vibration measurements to identify the dynamic characteristics of a structure. OMA employs Multiple Input Multiple Output (MIMO), technique in which closely space modes and even repeated modes are determined with high accuracy. Ambient vibration is very attractive since there is no need for shaker or impact hammer to create vibration. Some random tapping on the structure would give satisfactory records to obtain dynamic characteristics. However, the tapping must be applied in three different directions and in random order. More randomness will provide better modal results. Another important feature of OMA is that the estimated modes are based on true boundary conditions, and the actual ambient excitation sources.

Since the input force is not known in an ambient vibration test, vibration data recorded through the test are not suitable for frequency response function (FRFs) or impulse response function (IRFs) calculations (Altunışık et, al,.2012). Thus, a modal identification procedure is needed to base itself on ambient vibration data. In this study, poly-reference Least Squares Complex Frequency (pLSCF) method for identification procedure is used.

FEMtools software is employed for OMA. First ambient vibrations recorded with accelerometers are filtered to reduce the unwanted noises in the records. Then stabilization chart in which relation of frequency content and amplitude is obtained (Figure 6). Each peak value of the diagram shows the possible natural frequencies of the structure. OMA also provides damping ratio of the structure which is found as 1.15%, 0.91% and 0.4% for, mode 1, mode 2 and mode 3, respectively.

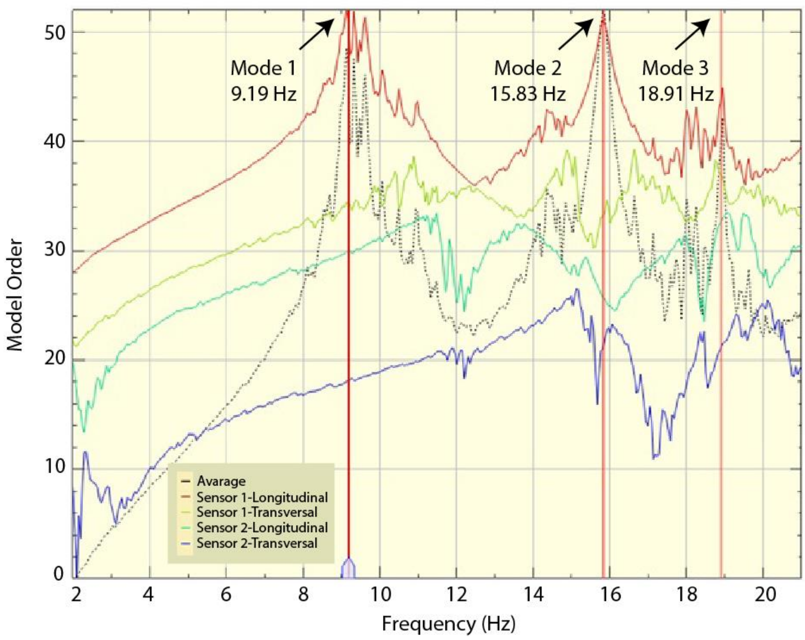

Figure 6. Stabilization chart of steel frame

DISCUSSION

All the frequencies obtained from finite element analysis and experiments are tabulated in Table 2 for the first three modes. The maximum difference is found as 31% between numeric and test results for second mode. However for the fundamental modes the difference between results dramatically reduced to 1%.

Table 2. Comparison of frequencies for each mode

Mode	Frequency (Hz)		Difference (%)
	Finite Element Analysis	Operational Modal Analysis	
1	9.09	9.19	1
2	12.04	15.83	31
3	21.36	18.91	12

First three mode shapes are obtained for the tested structure (Figure 7). First mode is in transversal direction for which stiffness is less than the longitudinal direction. This is due to the existing three rigid frames in this direction. Second mode is found torsional mode and finally third mode is in longitudinal direction. Mod shapes of analysis from experimental and numerical modelling are compared with FEMtools software. Similarity of modes are 98%, 70% and 25% for first, second and third modes, respectively.

Both natural frequencies and mode shapes are sufficiently close to each other. The similarity of first two modes are acceptable, however third mode is considered unlike and is not adequate. Since OMA directly uses ambient records, results obtained from this method are more reliable. Considering the results obtained from this study, it is decided that finite element model analysis represents actual model in great similarity. Furthermore, authors think that a detailed finite element model updating (model calibration) would increase the consistency of the third mode.

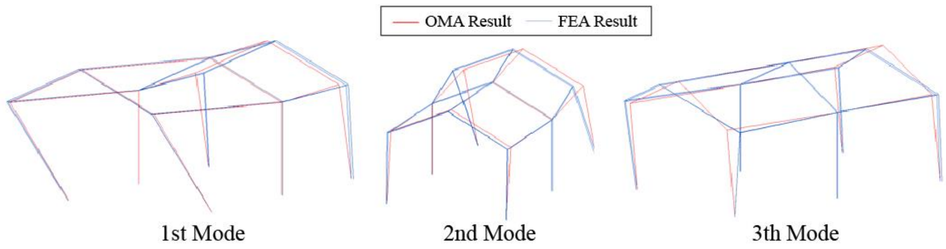

Figure 7. First three mode shapes of steel frame structure determined by OMA and FEA

CONCLUSIONS

Using ambient vibration with OMA to determine the dynamic characteristic of an existing structure is an easy method to implement when compared with Forced Vibration Test. With this approach assessment of existing structures can be made. In this study OMA is applied to a steel structure with three different frame types and results obtained are satisfactory. This proves that OMA can also be used for unsymmetrical structures. A designer can employ OMA to existing similar structures prior to design a new structure. Thus, the new design should be modeled in finite element analysis with the closest dynamic characteristic values.

REFERENCES

Altunisik, A. C., Bayraktar, A., & Sevim, B. (2012). “Operational modal analysis of a scaled bridge model using EFDD and SSI methods” *Indian Journal of Engineering and Materials Sciences*, 19(5), 320-330.

Bayraktar A, Türker T, Altunışık AC, Sevim B, Şahin A, Özcan M (2010) “Binalarda Dinamik Parametrelerin Operasyonal Modal analiz Yöntemiyle Belirlenmesi” *İMO Teknik Dergi*, 337(1):5185-5205.

Dönmez, C, Karakan E (2009) “Köprülerde Deneysel Modal Analiz Uygulamaları” *İMO Teknik Dergi*, 4851-4863.

FEMtools 3.7. Dynamic Design Solutions.

Lord, J-F and Ventura, C.E (2002) “Measured and Calculated Modal Characteristics of a 48-Story Tuned Mass System Building in Vancouver”, *International Modal Analysis Conference-XX: A Conference on Structural Dynamics, Society for Experimental Mechanics*, Los Angeles, CA, USA, 2, 1210-1215.

Matlab (2013a) The MathWorks, Inc. Natick, Massachusetts, United States.

Özçelik, Ö, Gündoğan M, Kahraman S, (2013) “Çelik Model Köprünün Sistem Tanımlama Yöntemleri ile Modal Parametrelerinin Tahmini” *İMO Teknik Dergi,* 6471-6478.

SAP2000 15.1 Version, Integrated Structural Analysis & Design Software, Computers and Structures, Inc., Berkeley, California, 1997.

Ventura CE, Horyna T (2000) ‘‘Measured and calculated modal characteristics of heritage court tower in Vancouver, B.C.’’ *Proceedings of the: A Conference on Structural Dynamic* (6):1070-1074