First Middle East Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures
8 – 10 February 2011, Dubai, UAE

SMAR 2011

A discussion for proposing modified design and construction procedure in a small town considering results of ambient vibration monitoring performed on a student dormitory

Mohammad Mahdi Amiri

Islamic Azad University, Firuzkooh Branch, Firouzkooh, Iran

ABSTRACT: Assessment of structural dynamic behavior and its comparison with design assumptions is one of the aims of structural monitoring. Some modification in structural design assumptions and even proposing modified construction procedures could be extracted from these kinds of comparison. In recent years, there has been an increasing interest in structural monitoring and generally lots of researches are based on special structures. By definition of a proper scope, we could get some benefits from results of structural monitoring for ordinary buildings.

Lack of sufficient information in basis of design and construction procedures of ordinary buildings in small towns and villages is probable. Building's wide destructions in Turkey and Iran's small towns after recent earthquakes could be shown this pretension.

Design and construction of buildings are more or less same in small towns and villages. Executing sets of structural ambient vibration monitoring (AVM) on a sample building and generalizing the findings to other buildings may lead to some modification in design and construction for such structures.

This paper will focused on ambient vibration monitoring (AVM) of Firuzkooh university dormitory located in Firuzkooh. Due to the significant number of habitants in the dormitory, this building is of high importance and could be a proper sample for performing structural monitoring tests and generalization of the results. Extraction of dynamic behavior of the dormitory (e.g. structural frequency response and damping ratio) and comparing with design assumptions and also some proposals for modification of design assumptions and construction procedures will be discussed in this paper.

1 INTRODUCTION

Lack of sufficient information during designing structures (e.g. concrete exact compression stress, steel exact yield stress, structural response during ambient vibration, earthquake exact loading characteristics etc.) necessitates consideration of some hypothesis in the design of structures according to common practices. In this way, some safety factors are taken into account during design of the structures to reduce the unreal effects of such hypothesis.

Also, some simplified hypothesis in modeling is considered during design of structures and all of the details of the structure are not considered in the FE modeling as per structural guidelines.

Therefore, one could conclude that based on the accuracy of the hypothesis, the behavior of a constructed structure might have some differences from the original design modeling.

In typical buildings, since these differences are minor and do not have major effects on structural response, normally, determining the exact structural behavior is not considered after construction of the building.

Monitoring of the structural response is one of the most common practices in the recent years. In this method, one could obtain the structural static/dynamic characteristics considering interaction between all important parameters. The unknown hypothesis during design stage could be determined and improved by designing a monitoring system for the constructed building. The results could help owners to strengthen the structure against random loading like earthquake, wind etc.

The study was conducted in the form of a survey, with data being gathered via structural monitoring for a dormitory as a sample structure and some discussions on generalization of the findings to other buildings in Firuzkooh city are presented.

2 MONITORING OF FIRUZKOOH UNIVERSITY DORMITORY

The dormitory of the islamic azad university is a five story steel building. The structure resists against lateral loads (e.g. earthquake) by X-bracing and flexural framings in two orthogonal directions. Cast beams were used in this structure align with the bracings direction. Fig. 1 shows this building during construction.

Figure 1. Firuzkooh university dormitory during construction.

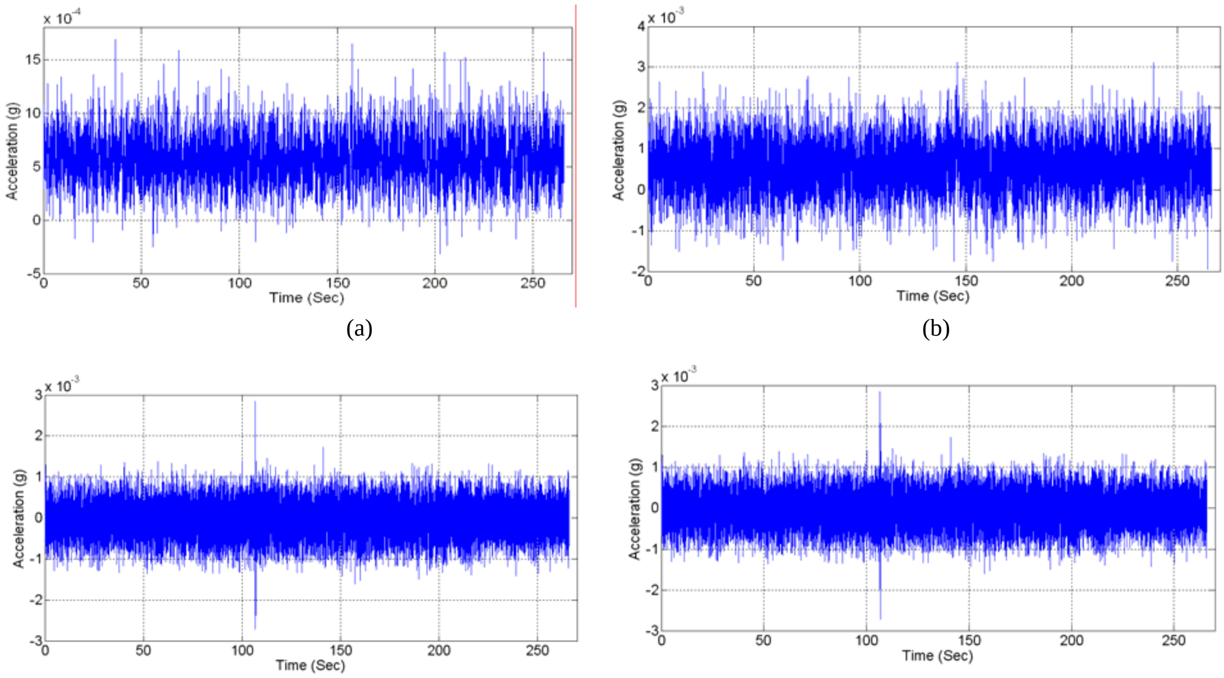
Ambient vibration monitoring (AVM) was selected for extraction of structural dynamic characteristics. Sensors used for these tests were servo accelerometers type ASQ-1CL. All data were logged with an OROS 35 data logger and analyzed by NVGate and MATLAB software.

Two types of field measurements were executed during AVM. In the first type, reference accelerometer was located at top elevation (5^{th} floor) and aligned to the flexural framing direction and the other accelerometer was located at the 3^{rd} floor. In the second type, all accelerometers were rotated and aligned with structural X-bracing direction. Wind speed was 30 km/h during monitoring. Fig. 2 shows the location of installed sensors.

Figure 2. Location of sensors during AVM

3 AMBIENT VIBRATION MONITORING RESULTS

Usually the records obtained from data acquisition have some noises. Effects of these noises should be reduced by proper selection of sampling frequency and filtering of the records. practical formulation, $T = 0.08H^{0.75}$,shows that time period of the dormitory is near 1 second and as per Nyquist law, at least 2Hz sampling frequency is required for data acquisition. To obtain proper results, 40.96 Hz sampling frequency was selected for AVM of this structure. Since response of the structure is in low frequency range, Low pass filtering was selected for analysis of the records. Fig. 3 presents some of the records obtained from AVM.



(a) (b) (c) (d)

Figure 3. AVM acceleration response,

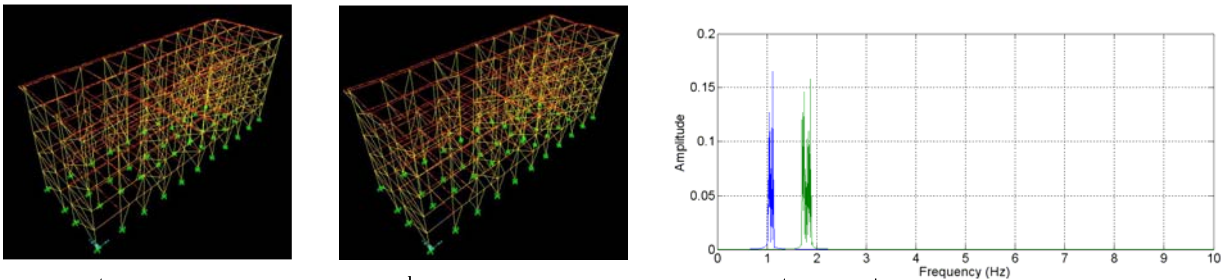
(a) Type 1,5th floor - (b) Type 1, 3rd floor – (c) Type 2,5th floor – (d) Type 2, 3rd floor

Structural natural time period could be obtained from FFT analysis. Table 1 shows field measurement results in comparison with computational model natural time period.

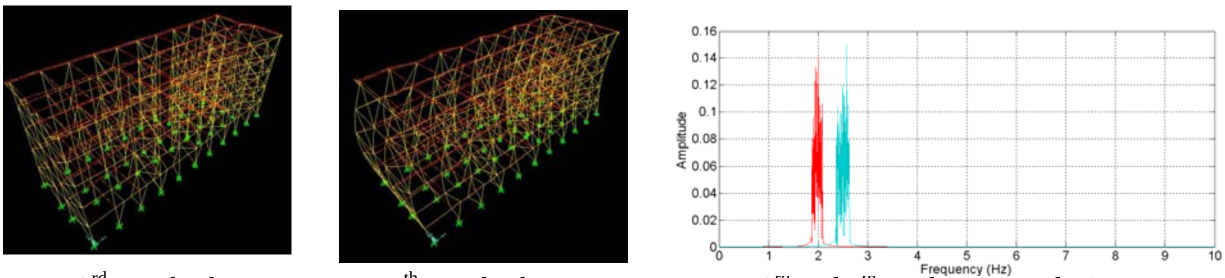
Table 1. Comparison of computational model and AVM results

Mode No.		1	2	3	4	5	6
Structural Time period (sec)	AVM	0.926	0.556	0.505	0.400	0.209	0.187
	Computational Model	0.983	0.591	0.535	0.386	0.223	0.196
Difference (%)		5.8	6.0	5.5	-3.7	6.1	4.4

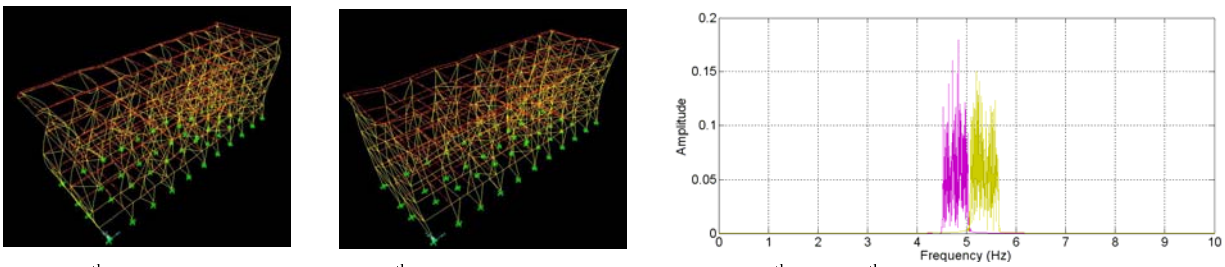
Fig. 4 shows the first six modes shape and FFT analysis results of the structure which is extracted from computational model and field measurement results.



1st Mode shape 2nd Mode shape 1st and 2nd mode FFT analysis



3rd Mode shape 4th Mode shape 3rd and 4th mode FFT analysis



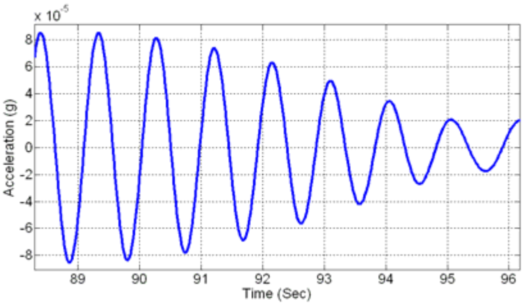
5th Mode shape 6th Mode shape 5th and 6th mode FFT analysis

Figure 4. First six structural mode shapes and FFT analysis results

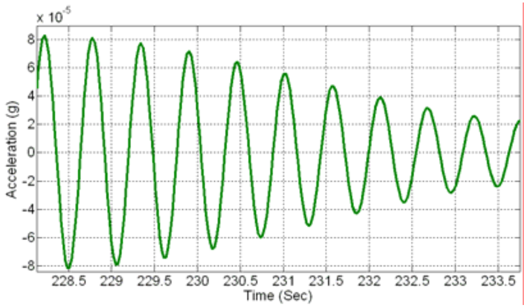
Since the construction of the structure was not finished during AVM, actual weight of the structure is slightly less than the weight considered in computational model and this is the reason for 6.1% difference between AVM and computational model. This small difference shows that results of the AVM are reliable and could be considered for further analysis on the records.

4 ESTIMATION OF STRUCTURAL DAMPING RATIO

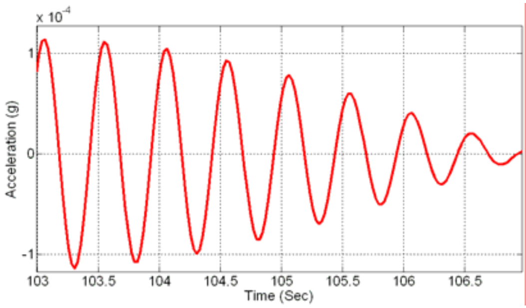
Damping ratio is one of the parameters assumed practically during design stage. In many cases the as-built condition of the structures are different from those considered in design drawings. These differences may due to changes in material characteristics, construction procedures, connection welding etc. Since construction of buildings are typical in small towns, executing AVM on a sample structure and extracting the damping ratio based on the as-built condition may help designers to modify their assumptions in the design stage. More exact damping ratio would help to have a better estimation of structural response during earthquakes and also might reduce the amount of structural damages.



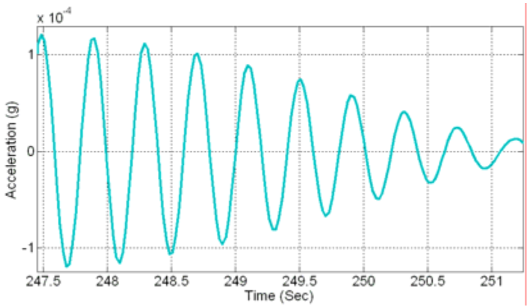
(a) 1st mode



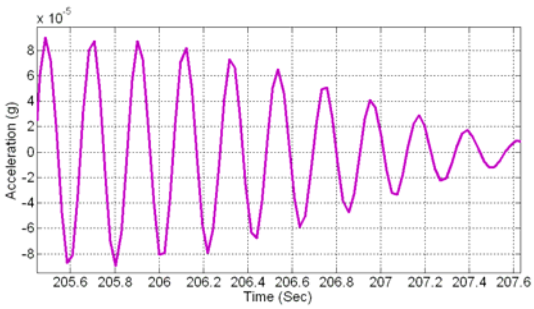
(b) 2nd mode



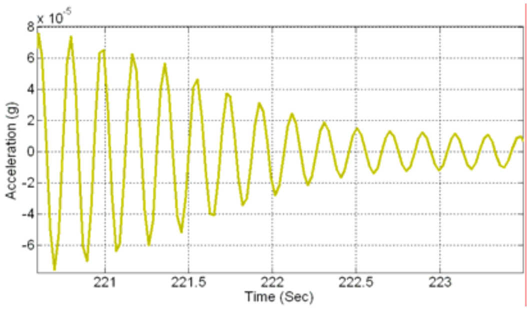
(c) 3nd mode



(d) 4th mode



(e) 5th mode



(f) 6th mode

Figure 5. Eliminating initial displacements and ambient vibration loads from records using RDT

The random decrement technique (RDT) which was suggested by Ibrahim for modal identification of structures in 1977, represents a quick and practical method for establishing the non-linear damping characteristics. [1]. Basis of this method was described by other researchers [2].

For estimation of eigen-modes damping ratio, it is necessary to extract relevant records of each eigen-mode from the acceleration response of the structure. This could be extracted using FFT analysis and calculating eigen-modes natural frequencies. Each eigen-mode relevant excitation record will be obtained by performing IFFT analysis on each eigen-modes natural frequency.

For estimation of eigen mode damping ratio, the initial displacements and ambient vibration loads on the structure were eliminated from the field measurement records of structural eigen-modes and consequently, the effect of initial displacements and ambient vibration loads were eliminated from the records. Fig. 5 shows the eigen-modes acceleration response in which initial loads and displacements are eliminated.

Structural damping ratio could be calculated using equation (1).

$$\frac{V_n}{V_{n+1}} = \exp\left(2\pi\xi\omega/\omega_D\right) \qquad (1)$$

Table 2 presents the damping ratio for the first six structural modes.

Table 2. Damping ratio for the first six structural modes

Mode No.	1	2	3	4	5	6
Damping Ratio (%)	6.4	3.2	7.5	7.6	6.8	6.1
Structural Time Period (sec)	0.926	0.556	0.505	0.400	0.209	0.187

Five percent damping ratio was considered in the original design of this structure. The results show that the damping ratio is more than what was considered in the design stage. Although structures with more damping ratio have better response during earthquake, but the damping did not increase by increasing the number of modes according to rayleigh formulation. This difference has two reasons. Firstly, partitions and walls were not constructed during AVM and secondly, structural connections had poor welding.

Obviously, absence of partitions and walls causes more damping ratio for the structure. 6.4% actual damping ratio compared with 5 %design damping ratio shows this fact. Also, it seems that welding of the connections has a considerable effect on this difference. Fig. 6 shows some of the welding of this structure.

Figure 6. Some typical welding in the dormitory

Results of AVM and the above figures shows that in addition to local weakness of structural connections, these kinds of welding have global effect in structural response and they are the major problem of this structure. Clients should have special consideration to the welding procedure of these kinds of buildings & other buildings in the Firuzkooh Region.

Considering transversal modes of the structure (e.g. first and forth mode), rayleigh damping ratio formula could be calibrated and proposed for design of new structures in Firuzkooh region.

$$\xi = \frac{\alpha}{2\omega_i} + \frac{\beta\omega_i}{2} \qquad \alpha = 52 \qquad \beta = 0.757 \tag{2}$$

5 CONCLUSION

Performing AVM on ordinary structures, discussion on the results and proposing some modifications on structural design and construction procedures was the aim of this research. A dormitory in a small town (Firuzkooh) was selected as the sample structure.

The most interesting finding was that there is a good agreement between the results of the computational model and the results of AVM in estimation of the structural damping ratio. Differences in structural damping ratio between the computational model and AVM have some reasons such as differences in material characteristics, structural interface with foundation and soil, poor welding of connections etc. In this paper, it was assumed that all other parameters was same in the Firuzkooh district and welding of connections was focused as one of the important reasons for difference between the assumed practical damping ratio in the design stage and those extracted by RDT. Rayleigh damping ratio formula was calibrated for this structure and it was proposed for design of new structures in Firuzkooh region.

6 ACKNOWLEDGEMENT

The author wish to record his thank to Mr. Mohammad Lesani for his contribution and assistance in this paper.

7 REFERENCE

[1] Ibrahim S.R ,1977. “Random Decrement Technique for Modal Identification of Structures”, Journal of spacecraft and rockets Vol. 14, Issue 11, 1977.

[2] Wenzel, PI, “Ambient Vibration Monitoring”. New York: John Wiley & Sons, Inc

[3] Amiri, MM, Yahyai, M. 2009. "Proposing the monitoring system of Milad Telecommunication Tower during construction and serviceability stages ", 4th International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-4), Zurich, Switzerland

[4] Kenneth .G . 1995. " Vibration testing, theory and practice", John Wiley & Sons INC,

[5] Sparks, PR., Jeary, AP, desouza, VCM. 1980. “A study of the use of ambient vibration measurements to detect changes in the structural characteristics of a building”, Hart G., ed., dynamic response of structures, experimental, observation prediction and control, prod. Of the 2nd specially conf. ASCE, New York,