DYNAMIC CHARACTERISTICS OF RURAL ADOBE HOUSES IN IRAN USING AMBIENT VIBRATION MEASUREMENTS

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ABSTRACT :

In Iran most of the rural houses are made of mud and adobe. Various reasons have caused adobe construction to be the first choice for a long time, among them: low-cost materials, environmental compatibility, good insulation, simple construction methods, and limited financial resources. This type of buildings generally has one or two stories. On the other hand, experiences of past earthquakes indicate that these houses are among the most vulnerable types of building and may not resist even moderate earthquakes because of their high weight and low seismic strength and ductility.
Presented in this paper are the results obtained by experimental in situ testing of adobe houses from several earthquake-prone provinces in Iran. Three types of single-story houses are considered for investigation, including adobe walls with wooden flat roofs, adobe walls with arched roofs, and adobe walls with vaulted roofs using three SS-1 seismograghs and SSR-1 DAQ system. The results indicate that fundamental frequency and damping ratio of these adobe houses are at the range of 4.8 to 16.2 Hz and 1.5 to 3.5 per cent, respectively. Furthermore, dynamic characteristics of the tested houses have been used to calibrate numerical FEM models for low amplitude excitation at the range of elastic behavior.

KEYWORDS: Dynamic characteristics, Rural adobe houses, Ambient vibration measurements.

1. INTRODUCTION

About 97 percent of more than 4 million rural houses of Iran, housing more than 20 million people, have no lateral load bearing elements and are vulnerable to earthquake. On the other hand Iran is located on Alpine-Himalayan earthquake belt and has experienced many catastrophic earthquakes in the past, i.e.Tabas earthquake 1978 (18,000 deaths), Manjil earthquake 1990 (40,000 deaths), Bam earthquake 2003 (40,000 deaths) and Dahoeieh-Zarand earthquake 2005 (650 deaths). In fact most of the casualties took place in the rural regions showing the necessity of investigation of vulnerability assessment and retrofitting methods. In response to this need a project was defined at Sharif University of Technology under the title “Seismic vulnerability study of rural houses in Iran”. The first phase of this research dealt with gathering structural information and classification of rural houses based on their seismic behavior [1-3].
An extensive investigation has been done based on the results of full-scale dynamic tests performed on buildings, bridges, dams and masonry structures utilizing forced or ambient vibration tests [4-6]. Investigation of the dynamic characteristics of an existing structure system based on field tests is necessary and important task in the course of checking the construction quality and retrofitting the

structure against strong vibrations such as earthquake, therefore in the second phase, ambient vibration test has been applied to accomplish dynamic characteristics of typical rural adobe houses and its results have been used to calibrate numerical FEM models for low amplitude excitation at the range of elastic behavior.
Ambient vibrations are random phenomena which can be assumed stationary and/or ergodic under special circumstances. The spectral density function of such process will be enlarged at natural frequencies of the structure. Measurement of the response of the structure caused by random vibrations enables researchers to calculate dynamic characteristics of the structure [7-8]
In this paper, 11 houses from 3 types of masonry houses have been tested experimentally applying the ambient vibration testing method to obtain their dynamic characteristics. These houses have been located in 4 earthquake-prone zones, i.e., Eastern Azerbaijan, Southern Khorasan, Kordestan and Kerman provinces. Almost 5 tests have been performed for each house and results have been obtained from statistical average of these tests.

2. RURAL HOUSES CHOSEN FOR DYNAMIC TESTING

According to the experimental program, for dynamic in-situ testing selected were eleven representative adobe houses. For all houses, very common characteristic is that the structural system consists of massive facade walls (thickness up to 90 cm), constructed of adobe in lime mortar in both directions. These houses can be categorized in 3 types:

a. Adobe walls with wooden flat roofs
b. Adobe walls with arched roofs
c. Adobe walls with Vaulted roofs

2.1. Adobe walls with wooden flat roofs


Figure 1. Building No 1


Figure 2. Building No 2


Figure 3. Building No 3


Figure 4. Building No 4

Figure 5. Building No 5

Table 1. Geometric characteristics of houses with Adobe walls and wooden flat roofs

Building	Length (m)	Width (m)	Height (m)	Wall Thickness (m)	Roof Thickness (m)	(P.A.W.L)[1]	(P.A.W.D)[2]
No 1	5.10	4.70	2.90	0.50	0.30	21	20
No 2	6.80	6.70	4.40	0.40	0.30	12	12
No 3	19.70	3.30	3.20	0.40	0.40	24	7
No 4	13.00	4.10	3.45	0.60	0.40	27	19
No 5	10.10	5.10	3.30	0.65	0.45	25	26

2.2. Adobe walls with arched roofs

Figure 6. Building No 6

Figure 7. Building No 7

[1] Percentage area which covered by walls divided by total area of house in 1-1 direction (P.A.W.L)

[2] Percentage area which covered by walls divided by total area of house in 2-2 direction (P.A.W.D)

Figure 8. Building No 8

Figure 9. Building No 9

Table 2. Geometric characteristics of houses with Adobe walls and arched roofs

Building	Length (m)	Width (m)	Height (m)	Wall Thickness (m)	Roof Thickness (m)	(P.A.W.L)	(P.A.W.D)
No 6	4.70	4.40	2.85	0.80	0.30	39	28
No 7	9.80	5.20	3.10	0.80	0.30	31	24
No 8	10.65	4.50	2.85	0.65	0.20	29	18
No 9	5.05	5.00	2.45	0.55	0.20	22	21

2.3. Adobe walls with vaulted roofs

Figure 10. Building No 10

Figure 11. Building No 11

Table 3. Geometric characteristics of houses with Adobe walls and vaulted roofs

Building	Length (m)	Width (m)	Height (m)	Wall Thickness (m)	Roof Thickness (m)	(P.A.W.L)	(P.A.W.D)
No 10	11.50	5.50	4.45	0.80	0.35	29	21
No 11	11.00	4.70	3.75	0.70	0.30	30	25

3. TEST PROGRAM

The in-situ experimental testing of the houses was performed applying the ambient vibration testing method. This method used for definition of the dynamic characteristics of structures is a relatively simple method, which requires equipment easy to be transported and such a test can be conducted even if the structure is in use. The experimental and theoretical procedure starts from an assumption that the exciting forces are a stationary stochastic process with a relatively flat frequency spectrum. These theoretical needs could be successfully fulfilled if the wind is assumed as an exciting force. The response of the structure in time domain was recorded by highly sensitive sensors, accommodated with a three channel data acquisition system. The first tests were meant for calibration of the system: all sensors were placed at the same point and the same direction for simultaneous recording to find out their calibration factor. Resonant frequencies are defined as clearly selected peaks on the spectra. To obtain the mode shapes of vibration, the sensors were placed at different points along the height of the structure, while one of them kept unchanged as reference point during the test. The damping coefficients were obtained from the spectra by the so called half power method. The records were processed by program package in Matlab software. This program processes the signals in real time and allows a complete frequency analysis of the signal obtaining both amplitude and phase spectra. Some of data records and their corresponding spectral density functions are shown in Figures 12 to 22. To measure exciting vibrations, three 'Ranger' type seismometers, SS-1 model, manufactured by Kinematrics, USA were used. The signal conditioner model SSR-1, also manufactured by Kinemetrics was used for simultaneous control of the seismometers.

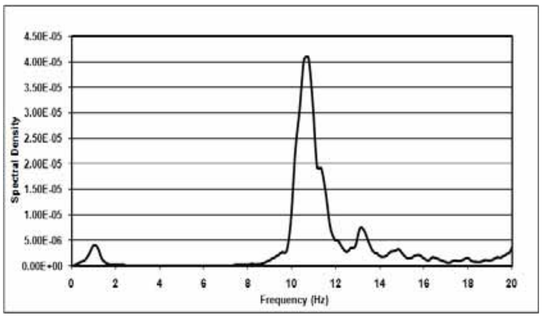

Figure 12. spectral density function for 1-1 direction – Building No 1

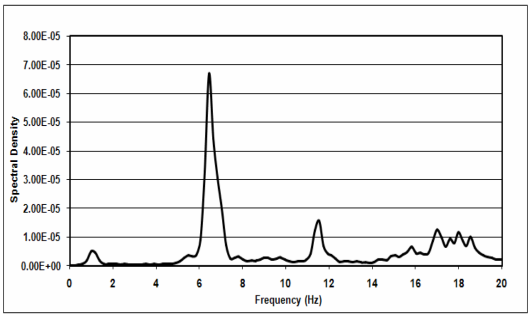

Figure 13. spectral density function for 2-2 direction – Building No 2

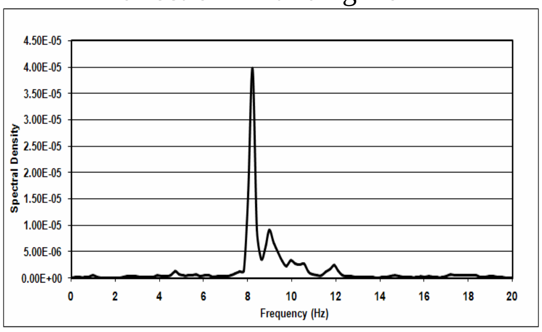

Figure 14. spectral density function for 1-1 direction – Building No 3

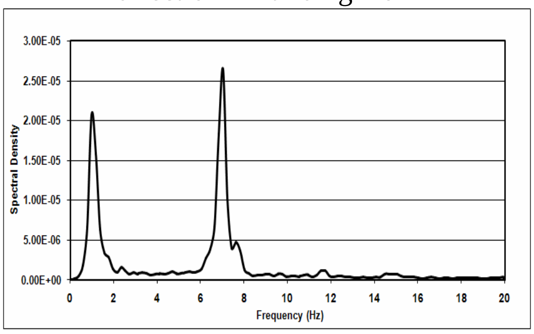

Figure 15. spectral density function for 2-2 direction – Building No 4

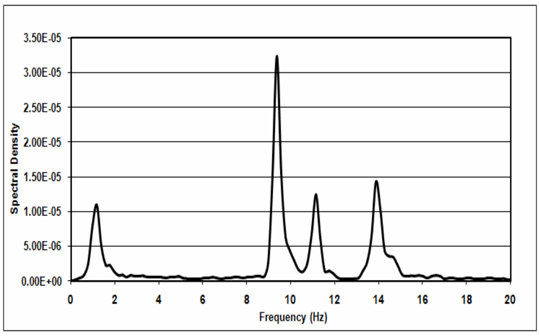

Figure 16. spectral density function for 1-1 direction – Building No 5

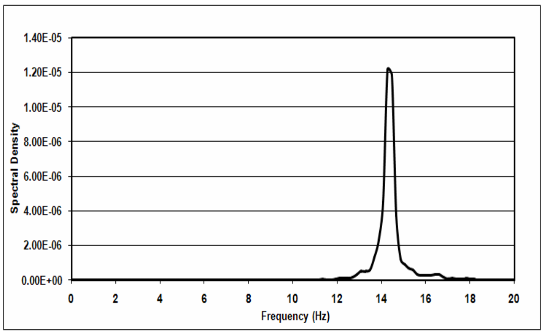

Figure 17. spectral density function for 2-2 direction – Building No 6

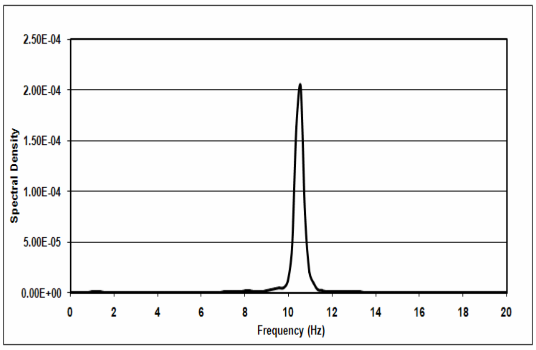

Figure 18. spectral density function for 2-2 direction – Building No 7

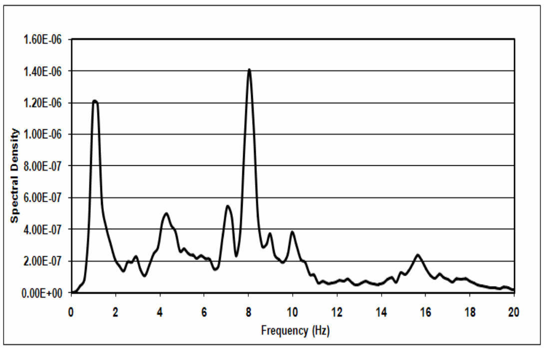

Figure 19. spectral density function for 1-1 direction – Building No 8

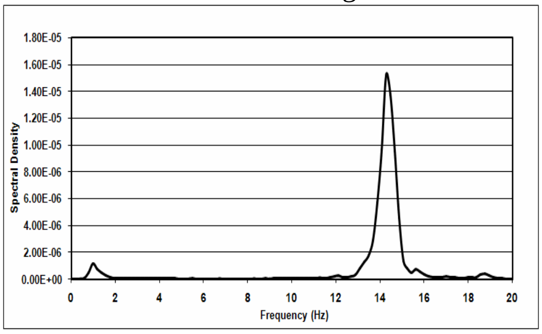

Figure 20. spectral density function for 2-2 direction – Building No 9

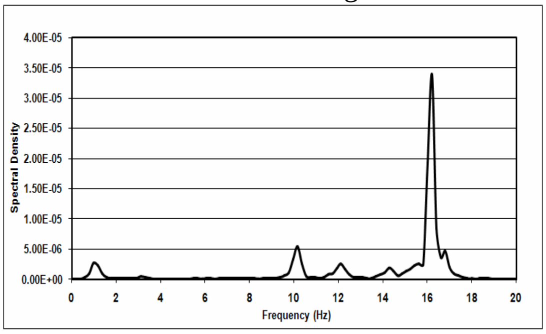

Figure 21. spectral density function for 1-1 direction – Building No 10

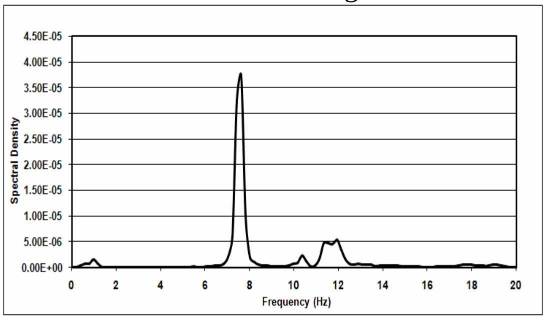

Figure 22. spectral density function for 2-2 direction – Building No 11

4. EXPERIMENTAL RESULTS

In order to define the dynamic behavior of the buildings, the following dynamic properties were measured: natural frequencies, mode shapes and damping coefficients. The natural frequencies were evaluated from the Fourier amplitude spectra for both horizontal directions (1-1 and 2-2) and for torsion in vertical axis.

Table 4. Dynamic characteristics of houses with Adobe walls and wooden flat roofs

Building	Natural frequency (Hz)		Torsion (Hz)		Damping ratio	
	1-1 Direction	2-2 Direction	1-1 Direction	2-2 Direction	1-1 Direction	2-2 Direction
No 1	10.67	9.26	13.09	14.45	2.83	2.18
No 2	6.45	5.47	10.94	9.18	2.25	2.65
No 3	8.20	4.79	8.98	5.47	1.04	2.47
No 4	10.47	7.03	11.13	10.16	1.83	2.18
No 5	9.65	9.38	14.65	11.13	1.23	1.52

Table 5. Dynamic characteristics of houses with Adobe walls and arched roofs

Building	Natural frequency (Hz)		Torsion (Hz)		Damping ratio	
	1-1 Direction	2-2 Direction	1-1 Direction	2-2 Direction	1-1 Direction	2-2 Direction
No 6	13.20	14.36	13.09	16.02	1.33	1.34
No 7	12.11	10.55	14.45	14.65	1.35	1.44
No 8	9.01	7.39	10.55	9.77	2.66	3.24
No 9	14.45	14.29	18.55	18.75	1.18	1.91

Table 6. Dynamic characteristics of houses with Adobe walls and vaulted roofs

Building	Natural frequency (Hz)		Torsion (Hz)		Damping ratio	
	1-1 Direction	2-2 Direction	1-1 Direction	2-2 Direction	1-1 Direction	2-2 Direction
No 10	9.66	7.62	11.33	11.33	1.51	1.76
No 11	16.21	11.52	17.58	14.26	0.93	0.88

The measurements identified two laterals and one torsional frequency in each house, in the frequency range of 4.8 Hz to 18.8 Hz. These frequencies were determined for small amplitude vibrations and, hence, indicate the structural behavior in the range of linear response. The natural frequencies are clearly selected for all houses. For the measured building no 1 and 9, which are almost with same dimensions for both orthogonal directions, the values of the natural frequencies are very close for direction 1-1 and 2-2. Frequently, For the buildings, natural frequencies for direction 1-1 is higher than the frequency in direction 2-2, which is result of the larger dimension of the houses in that direction (1-1). Although building No 1 has the same dimensions but torsional frequencies in 1-1 and 2-2 directions are different; because roof of house is covered by wooden beams in one direction. Torsional frequencies were achieved by subtracting signal records. The torsional rigidity of the buildings is higher than translational ones, which results in higher frequencies for torsion.
It was not possible to determine precisely damping values adequately by use of half power method due to closely peaks and to spectral overlap which resulted in widening of the Fourier spectrum peak; however, a rough estimation of the damping ratio was presented.

5. CONCLUSION

Eleven representative adobe houses have been tested in-situ applying the ambient vibration testing method for obtaining their dynamic characteristics – natural frequencies, mode shapes of vibration and damping coefficients. Natural frequencies for the translational vibrations are ranging between 4.8-16.2 Hz, while the torsion frequencies are higher, i.e. in the range of 9.0-18.7 Hz.
Because of lack of confinement in wooden flat roofs, torsional frequencies were found to be different in 1-1 and 2-2 directions.
Despite of the same dimensions in some of buildings, they had different frequencies. It was consistent with the fact that increase in percentage of covering wall area, increases the stiffness of building.

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