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RECONNAISSANCE STUDY OF THE NATURAL PERIOD OF RC BUILDINGS FOR IRANIAN SEISMIC CODE REVISION

Mahmood RAHIMIAN[1], Ali MAZROI[2], Ayatollah MOMAYEZ[3] and Nader JOKAR[3]

SUMMARY

Seismic codes, are proposing empirical formula based on the common design and construction practice in their corresponding country. This is not the case in Iran, where the construction techniques are far different, from the developed countries, which make the Iranian built buildings behave unpredictably different from other countries. Therefore, it is necessary to check the applicability of the previously adopted formulas for Iranian seismic resistant design code of practice and if necessary a new formula should be tailored for domestic construction system. A reconnaissance study performed to see whether any change in current code is required. 10 common-rise reinforced concrete (CRRC) buildings have been chosen from a total of 45 buildings. Natural periods were obtained by ambient vibration survey (AVS) and finite element method (FEM) eigen-vector analysis. The proposed formula in the "Iranian code of practice for seismic resistant design of buildings 1997", is not conservative for the common rise RC buildings, which are commonly built by private owners. This reconnaissance study introduces an empirical formula for use in the next revision of Iranian seismic code.

INTRODUCTION

Natural period of building is related to spatial distribution of masses and stiffness. Therefore, it is not a probabilistic phenomenon, which can be predicted by statistical means. However, it is possible to find an empirical formula for the common-rise buildings (3 to 7 stories) with regular plans. The way most of the seismic codes are proposing nowadays as reported in the world list [1].

The construction techniques in Iran are far different, from the common methods in developed countries. This make their behavior unpredictable by the empirical formula obtained from other countries. There are indeed different alternatives to solve such problem. The most difficult one is to change the low enforcement policy in order to control any step of construction works and the other is to check the applicability of the previously adopted formulas for Iranian code and if necessary a new formula should be tailored for domestic construction system.

[1] PhD Candidate, Tokyo Institute of Technology, Yokohama, Japan. Email: mrahimian@yahoo.com
[2] Assistant Professor, Azad University, Tehran, Iran. E-mail: e-mazroi@yahoo.com
[3] Former Research Staff, Building and Housing Research Center, Ministry of Housing and Urban Developments, Tehran, Iran.

For this reason primarily, 45 buildings have been tested by ambient vibration survey (AVS), and among them, 10 common rise reinforced concrete (CRRC) buildings, which have been built with popular construction methods and their lateral force resisting system were simple moment resisting frame (SMRF), have been chosen for this reconnaissance study. Ambient vibration survey has been used to provide the required information about the buildings natural periods in linear state.

AVS results have been compared with the analytical dynamic propertied calculated by three dimensional finite element models

The Height and Depth of the buildings were taken as main variables for regression analysis of the types of equations, which have been considered as possible proposals.

The proposed formula in the draft of the second edition "Iranian code of practice for seismic resistant design of buildings", is not conservative for the common rise RC buildings, which are commonly built by private owners. This reconnaissance study introduces an empirical formula for use in the next revision of Iranian seismic code.

NATURAL PERIOD ESTIMATIONS IN SEISMIC CODES

Building codes generally consider the natural period as a necessary parameter to estimate the structure response coefficient. Therefore empirical formula should be based on general properties of the buildings, which could be known before a preliminary analysis, such as building height H or dimensions D_L and D_T. A general form of an empirical formula along a certain axis could be introduced as follow:

$$T(H,D) = aH^{b}D^{c} \qquad \text{(Eq. 1)}$$

where a, b and c are the parameters that different seismic codes proposed values based on the buildings characteristics related to the corresponding country. The parameters proposed by some of the seismic codes are shown in table 1.

Table 1. Parameters proposed by the seismic codes of different countries

	Countries Name	Parameters		
		a	***b***	***c***
Group 1	Venezuela 1982, Ethiopia 1983, Indonesia 1983, India 1984, Egypt 1988, Albany 1989, El Salvador 1989 and NEHRP 1994.	0.09	1	-0.5
	Italy 1986	0.1	1	-0.5
Group2	Australia 1993	1/46, 1/58	1	0
	UBC 1997	0.049	0.75	0
	Japan 1981	$(0.02+0.01\alpha)$	1	0

The model formula introduced by seismic codes in the world
Although there are some codes, which require a primary structure model to calculate the natural period based on stiffness properties, most of the codes still using simple formula as the one in equation 1.

Building codes, which are proposing an empirical formula for preliminary estimation of natural period, could be classified in two major categories. First group are the codes from Venezuela 1982[2], Ethiopia 1983[3], Indonesia 1983[4], India 1984[5], Italy 1986[6], Egypt 1988[7], Albany 1989[8], El Salvador 1989[9] and NEHRP 1994[10], which are considering both height and the dimension of the building for the proposed formula. The second group that considers only the height of the structure, as an effective measure for the natural period consists of United Stats of America UBC 1997[11], Australia 1993 [12] and Japan 1981[13].

Buildings technology and seismic codes in Iran
Iranian architect for about three millenniums had influenced the world of the building art. The common construction practice for ancient Iranian buildings was to provide a monolithic harmony with adobe arcs and shells to provide less stress concentration at the corners when transferring the load from the roof toward the foundations. Such technique made Iranian building stand for centuries in seismic prone areas of the country.

The modern skeleton type structures are made of straight elements. The theoretical implementation of such structures was easy also the type of construction was suitable for standardization and mass production that are the most beneficial for multistory constructions. However these structures are suffering from high stress concentration at connections and are especially weak at corner joints.

The idea of the skeleton type structures imported from Europe to Iran. The first committee to provide the building code for Iran was established in 1960 they have provided the first building design load as the standard no. 519 [14]. This standard was based on a mixture of the regulations obtained from building codes of Germany, France, USSR, United Kingdom and USA. However it could never satisfy the needs of Iranian engineers since the seismic regulations were not comparable with Iran seismic activities.

After heavy casualties of 1962 Boien-zahra earthquake a committee was established to provide the first draft in 1964. It was titled “Buildings safety regulations against earthquake”. It was approved to be included into the revision of Iranian Standard 519 in 1969 by government.

The first edition of the current building code, the “Iranian code for seismic resistant design of buildings-the standard 2800” [15], was enforced by low in 1988. The proposed formula considered the building height H and the dimension along the desired axis D as variables for the formula:

$$T = 0.09H\big/\sqrt{D} \qquad \text{(Eq. 2)}$$

This formula belongs to the first group of table 1.

This study was conducted during 1997-1998 period to examine the empirical formula that was introduced in the draft of second edition. The second edition of the Iranian code, “Iranian code of practice for seismic resistant design of buildings-the standard 2800”, was approved by government in 1999 [16]. This code is in the second group and is different for frame structures and frame with infill panels.

The formula for reinforced concrete frame structures is:

$$T = 0.07H^{3/4} \quad \text{(Eq. 3)}$$

and for the code requires a 20 percent decrease if the structure frame has in-filled panels. Then equation 3 will become:

$$T = 0.056H^{3/4} \quad \text{(Eq. 4)}$$

SAMPLE BUILDINGS AND THEIR ANALYTICAL NATURAL PERIODS

In this study we chose 10 buildings among 45 surveyed since they had better construction grades than the others. Buildings were chosen from different cities around the capital city Tehran to sample different construction skills in the area.

Buildings have been modeled three dimensionally by frame elements and the eigen-values analyses have been conducted by FEM routines, commonly used among Iranian engineers. Eigen values have been calculated based on Wilson [17] method. In the modeling the effect of the in-filled walls was neglected, as it is common in design practice in Iran, however their extra masses were considered in the models.

Table 2 shows the general information of the buildings and their calculated natural periods. The calculated periods showed in this table for the structures of this height and sizes are seemed to be long. This maybe related to the excessive masses of the in-fill walls considered on the structures without considering their stiffening effect in the frames. This is good consideration since in case of large earthquake the infill walls will collapse and the frame should carry its dead weight. Figure 1 shows the wire-frame and the corresponding mode shapes of the sample buildings.

Table 2. general information of sample buildings used for this study and their calculated natural periods using a popular FEM routine. Subscripts L and T refer to longitudinal and Transversal directions respectively.

Code Name	The City of Building Location	Building properties				FEM results	
		N	H (m)	D_L (m)	D_T (m)	T_L (s)	T_T (s)
C-01	Arak City	4	13.0	21.0	12.5	1.06	0.99
C-02	Arak City	4	13.0	21.0	12.5	1.06	0.99
C-03	Arak City	5	17.0	19.0	12.0	0.99	1.10
C-04	Pardis new town	5	16.0	15.0	14.0	1.15	1.07
C-05	Pardis new town	6	18.0	20.0	20.0	1.16	1.11
C-06	Pardis new town	6	18.0	15.0	13.2	1.42	1.44
C-07	Pardis new town	6	18.0	15.0	15.0	0.80	0.82
C-08	Vavan town	5	16.0	18.0	11.8	0.84	0.86
C-09	Vavan town	4	13.0	17.0	13.7	0.84	0.86
C-10	Punak, Tehran	5	16.0	17.0	11.5	0.94	1.17

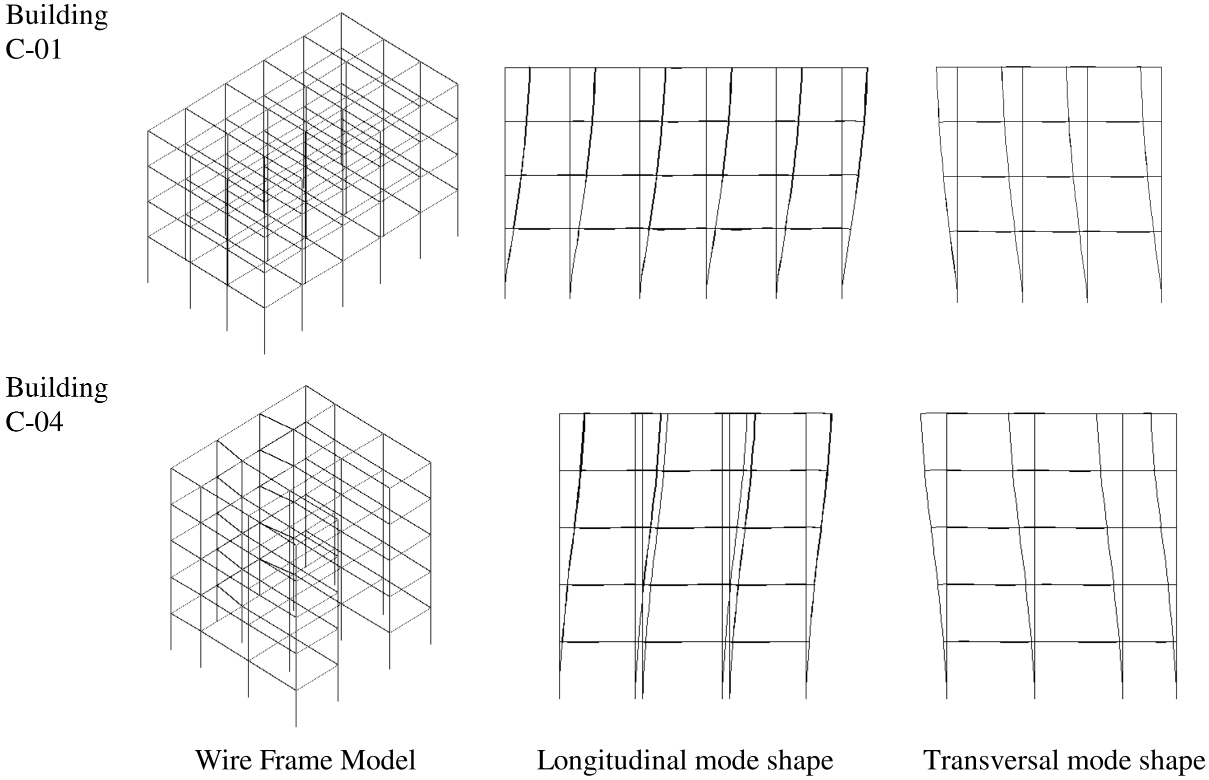


Figure 1. Samples of structure models and their longitudinal and transversal natural mode shapes calculated by finite element method.

AMBIENT VIBRATION SURVEY OF COMMON RISE RC BUILDINGS

Most of the published works on full-scale dynamic testing have used the ambient vibration testing method. This is due, among other factors; to the ease of measuring the vibration response while the structure is still in service. It also has the benefit of elimination of the bulky excitation devices and providing a test environment with normal service loads.

The literature on ambient vibration testing of buildings is extensive. Some of the reported tests are reported in this section. The list is by no means exhaustive but the papers reviewed are meant to illustrate the different test approaches employed and main results obtained.

The applicability of AVS has been approved by: Trifunac [18, 19, 20], Udwadia [21], Bouwkamp [22, 23, 24], Benuska [25] and Petrovski [26]. They compared the results of various types of methods (e.g. Earthquake response, forced vibration), with AVS and they suggest that the AVS is much easier than other methods and have save degree of accuracy in the results.

Other applications of AVS introduced by researchers. Hart [27] used AVS to provide a design response spectrum for torsion, Meyyapa [28], Torkamani [29] studied the dynamic properties of the buildings during different stages in construction and studied the effect of structural and nonstructural components on the dynamic characteristics of the buildings. Sparks [30] and Carydis [31], studied the differences in dynamic properties of buildings before and after a damage caused by earthquake.

Since the application of ambient vibration survey is comparatively simple, it is a very good method for mass measurements and provide the information in database form. Oliveira [32], Midorikawa [33, 34], Kobayashi [35, 36], Maeda [37] Komuro [38], Enomoto [39], Suzuki [40], Abeki [41], made measurements on several buildings and each provided empirical formula for natural periods and damping of existing buildings. Since the damping factor have no application in current seismic codes of practice we focus on the natural period of the Iranian reinforced concrete buildings.

Ambient vibration test instruments

The ambient vibration survey conducted by a set of instruments consists of three sensors and a solid state recorder SSR-1 all made by Kinemetrics INC. The model we used is shortly described here

Sensors

The SS-1 Ranger Seismometer is a short-period field seismometer. An important feature of the Ranger is that it can be adapted as either a vertical or horizontal seismometer by simple adjustment of the mass centering spring. The SS-1 is frequently used as a sensor for ambient vibration measurements of buildings, bridges, foundations and offshore platforms. The SS-1 Ranger Seismometer is a "moving coil" style (velocity) transducer. The natural period of our sensors was 1 second.

Recorder

The Kinemetrics Solid - State Recorder (SSR-1), which used for this study is a highly flexible digital seismographic event recorder. It has amplifier, filter, digitizer and recorder all in one. We used only three channels of its six available recording channels. SSR-1 has a 16-bit A/D converter with a dynamic range of 96 dB. The sensitivity can be increased by a 60 dB front-end preamp (the gain is software selectable in steps of 20 dB).

Test layout

This study was focused only on the first natural period of the building along its main axis. Therefore a general layout of the test was in two parts as follow

Field measurements

Three sensors where placed on the roof or on upper most floor of the buildings. Two of the sensors placed along the axis of the symmetry to avoid the effect of the torsion modes. The other one was placed in a distance about 10 to 15m far from the center of mass in a direction, parallel to the transversal sensor in order to check upon the possible torsion modes for future studies. A hi-cut filter applied while recording to avoid frequency components higher than 20Hz. SSR-1 recorder has recorded ambient vibrations for at least five minutes. The sampling frequency was 200Hz and the gain factor was adjusted accordingly, to avoid any instrumental noise.

Data processing

Sample data sets of 2048 points selected from stable stationary parts of a total five minutes recording. Hanning window applied to the data and the spectra was calculated by fast Fourier transform routine. Figure 2 shows a sample record at the roof of Building C-01. Sample spectra calculated for some of the buildings are shown in figure 3.

The Fourier spectra have clear peaks at natural frequencies. The periods observed from AVS are shown in table 3. A comparison made between the analytical and AVS results in figure 4. The periods calculated by FEM are about 2.44 times longer than those observed by AVS. This is due to the neglecting the effect of infill walls in FEM modeling and also considering their mass for eigen-value calculations.

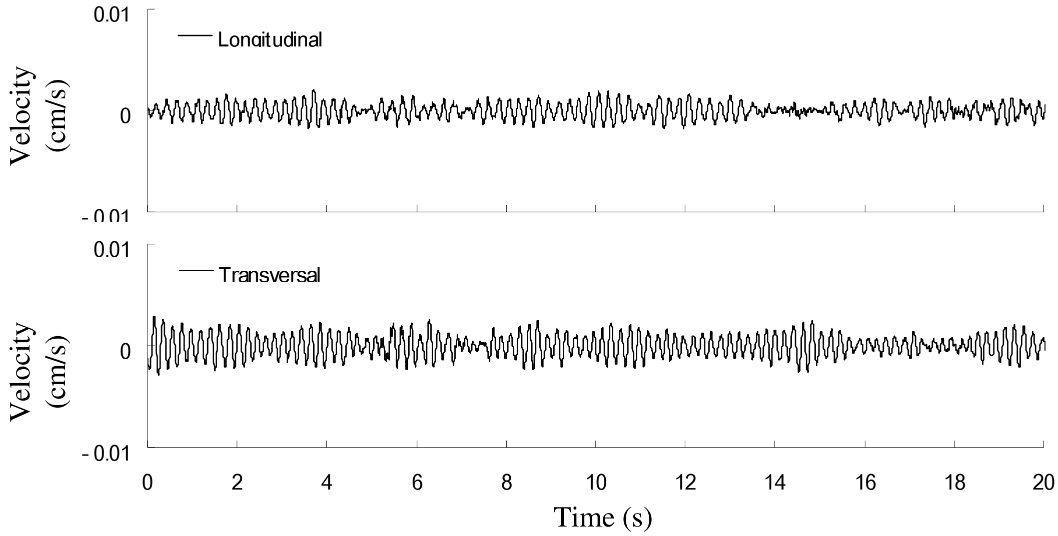
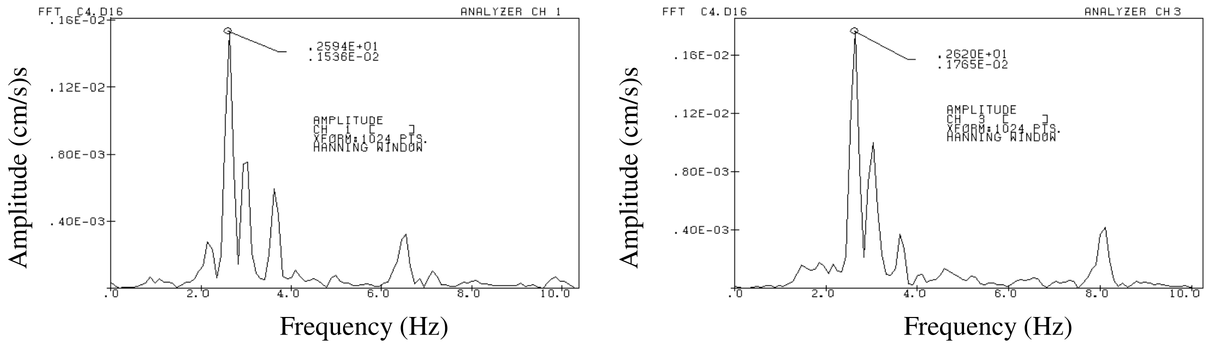


Figure 2. Sample of the recorded ambient vibrations at roof top of the building

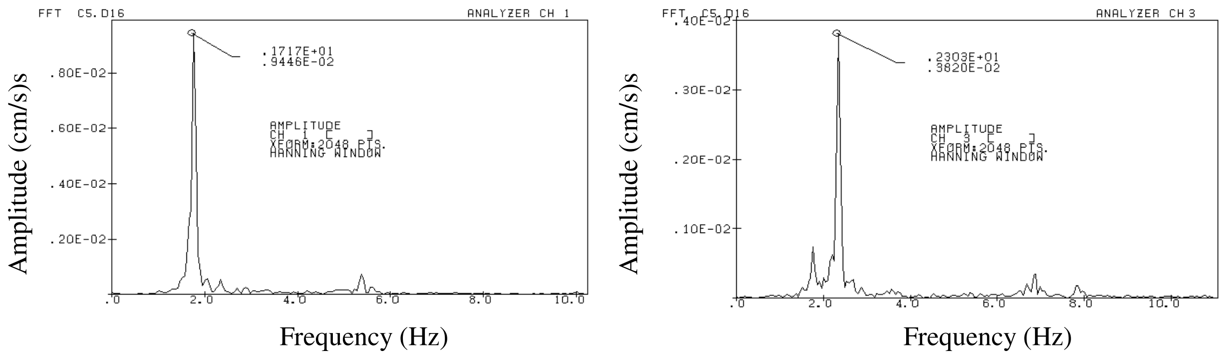
Table 3. The natural periods observed by ambient vibration tests. The results are compared with the their analytical natural periods from FEM. Subscripts L and T refer to longitudinal and Transversal directions respectively.

Code Name	Building properties				AVS results		FEM results	
	N	H (m)	D_L (m)	D_T (m)	$(T_{AVS})_L$ (s)	$(T_{AVS})_T$ (s)	$(T_{FEM})_L$ (s)	$(T_{FEM})_T$ (s)
C-01	4	13.0	21.0	12.5	0.23	0.21	1.06	0.99
C-02	4	13.0	21.0	12.5	0.24	0.21	1.06	0.99
C-03	5	17.0	19.0	12.0	0.47	0.48	0.99	1.10
C-04	5	16.0	15.0	14.0	0.39	0.38	1.15	1.07
C-05	6	18.0	20.0	20.0	0.56	0.43	1.16	1.11
C-06	6	18.0	15.0	13.2	0.35	0.54	1.42	1.44
C-07	6	18.0	15.0	15.0	0.43	0.36	0.80	0.82
C-08	5	16.0	18.0	11.8	0.47	0.43	0.84	0.86
C-09	4	13.0	17.0	13.7	0.37	0.57	0.84	0.86
C-10	5	16.0	17.0	11.5	0.43	0.49	0.94	1.17

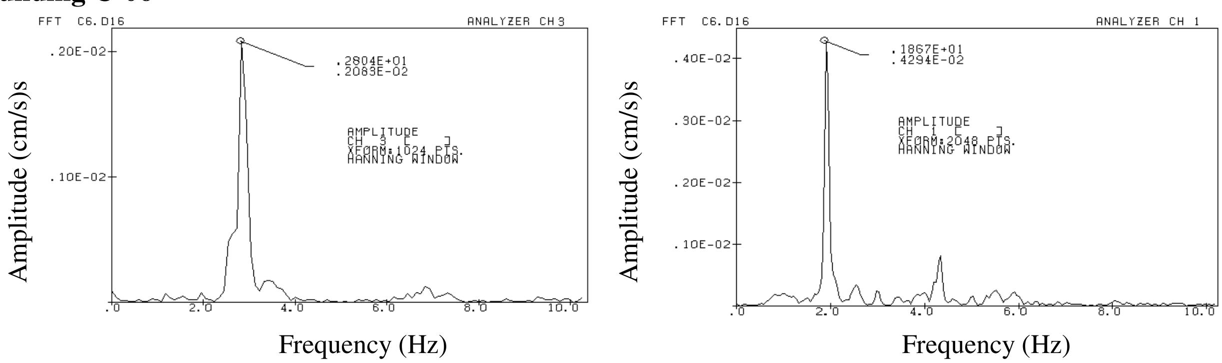
Building C-04



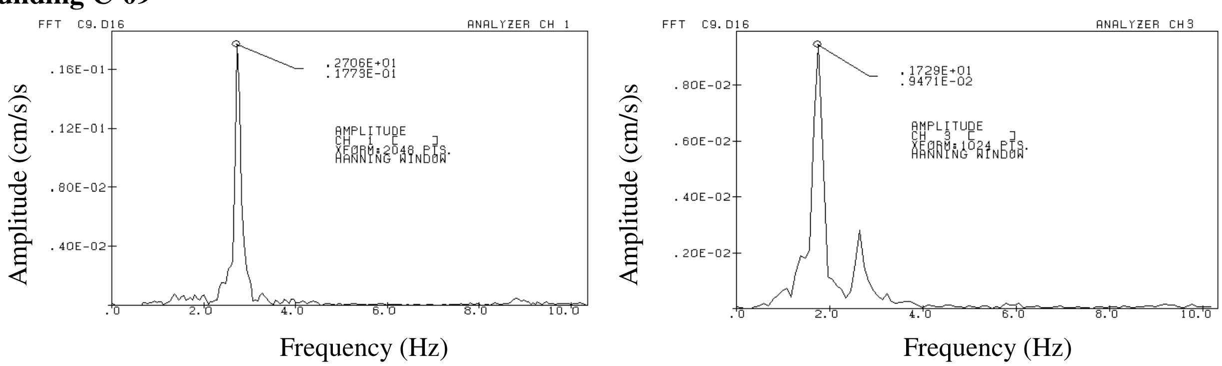
Building C-05



Building C-06



Building C-09



Longitudinal direction **Transversal Direction**

Figure 3. Sample spectra from ambient vibration records at the roof of the buildings. The spectra show clear peaks at natural frequencies.

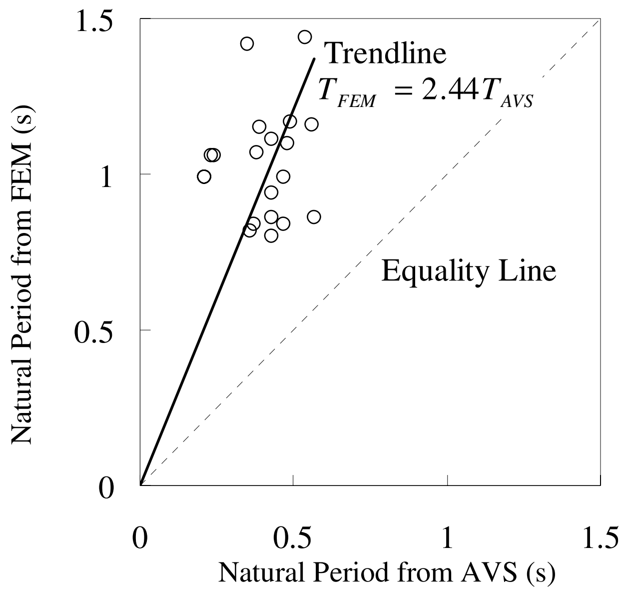


Figure 4. Comparison between the natural periods observed by Ambient Vibration Survey and those calculated with Finite Element Method. Results show the AVS periods are considerably shorter than those calculated by FEM.

REGRESSION ANALYSIS RESULTS

Taking logarithmic form both side of the equation 1 we can provide a linear polynomial model as:

$$\ln T(H, D) = \ln a + b \ln H + c \ln D \qquad \text{(Eq. 5)}$$

which is a very basic model for an empirical formula. For a set of sample data the parameters could be calculated by least square method and value as explained by Lapin [42]. This method calculates the statistics for a straight line that best fits the AVS data.

Other type of formula like those that using only height H as a variable can also be obtained by constraining the parameters in the regression process.

The results should be checked with statistical method to confirm the reliability of the estimation.
Standard error (SE), R-squared (r^2), F-test and T-test are the statistical checks we applied for this study. Standard error and r^2, are indicator of how well the equation resulting from the regression analysis explains the relationship among the variables. F statistic can determine whether the results occurred by chance or not. Finally T-test will determine whether each variable used in the regression equation is useful in predicting the natural period or not.

Parameters of the model formula were calculated for different variable sets. Table 4 shows the parameters a, b and c that calculated with different constraint on the equation 1. We made four different types of regressions. At first regression (Reg-1) no constraints were applied to the formula. The results converged to a power value more than one for the height (*b*>1.0). This is physically unacceptable, however this could happen when the height and Dimension range has a narrow band. The SE and r^2 statistics shows high scattering in the data, however the F-observed (4.295) is slightly higher than F-critical (3.359) therefore there are no chances involved for the regressed formula.

Table 4. Regeression parameters and their statistics. Four types of regression were made for different sets of variables.

Set No	*a*	*b* (*T-test*)	*c* (*T-test*)	*SE*	R^2	*F* ($F_{0.05}$)	$T_{0.05}$	Condition
Reg-1	0.010	1.451 (2.908)	-0.141 (-0.447)	0.272	0.336	4.295 (3.359)	1.740	Not good
Reg-2	0.007	1.444 (2.963)	{0.0} (-)	0.266	0.32	8.780 (4.414)	1.734	Not good
Reg-3	0.051	{0.75} 18.484	{0.0} (-)	0.098	0.229	5.638 (4.381)	1.729	Better
Reg-4	0.099	{1}	{-0.5}	0.1	0.19	4.542 (4.381)	1.729	Good
		Joint *T-test* 18.045						

The T-test for Variable *D* in reg-1, shows that it the variable *D* has none or little influence in the model. Therefore in regression no 2 we constrained the parameter *c*, to zero. In this way the formula will be independent from *D* and take the form of:

in this case (Reg-2) also the power of H is greater than one, therefore the formula has no physical meaning. However in statistical point of view the control values of standard error F and T had slight improvements due to the elimination of D.

Since an unconstraint formula could not provide a physically valid equation, we constrained the parameter b (reg-3). Since many different codes are using a power of 3/4 for height in meters we also constrained the parameters to this value in regression attempt no 3. The statistics shows an improvement on standard Error, F-test and T-test. The parameter a=0.051 is about 11 percent different with the one which have been proposed for the second revision of the Iranian seismic code for reinforced concrete moment resisting frame structures with in-filled panels (Eq. 4).

$$T(H) = 0.051H^{3/4} \qquad \text{(Eq. 6)}$$

A combine constrain on *b=1* and *c=-0.5*, (reg-4) will provide a formula as like as those proposed by group 1 of the codes in table 1. In regression 4 we tried to see how different would be the results of the regression and those proposed by the codes. The calculated formula have estimated the natural periods about 10 percent longer than Iranian code:

$$T(H) = 0.099H\big/\sqrt{D} \qquad \text{(Eq. 7)}$$

The statistics for equations 6 and 7 in table 4 shows that the equation 6 has better statistical representation than equation 7. Therefore we chose the Equation 6 as a basis for further discussions.

DISCUSSIONS

The proposed formula of the natural period of buildings in NEHRP recommendation 1994 [10] is based on the observed seismic responses of 40 tall buildings to 1971 San Fernando earthquake. This recommendation suggests that the base shear is proportional to $1/T^{2/3}$, therefore the design period should be taken less than the observed natural period to be conservative. NEHRP considers a 30 percent reduction in Natural period will provide a conservative estimation.

The response to the earthquake includes the inelastic behavior of the buildings, though the observed natural periods are longer than those of elastic behaviors (e.g. response to ambient vibrations). Therefore equation 6 is not conservative enough to be taken as the code representing formula.

Since in Iran we could not find buildings with seismographs at the time of this research we do not have any reduction factor to relate ambient response of buildings to their seismic response. However, a wise decision would be to reduce the parameter *a*, at least to cover 80 percent of the observed data points, which in this case is related to 20 percent reduction. Figure 5 shows the regressed formula along with the current proposed formula by Iranian standard 2800. As compared with other equations in Figure 5, our recommendation for the revision of the Iranian seismic code would be:

$$T(H) = 0.04H^{3/4} \qquad \text{(Eq. 8)}$$

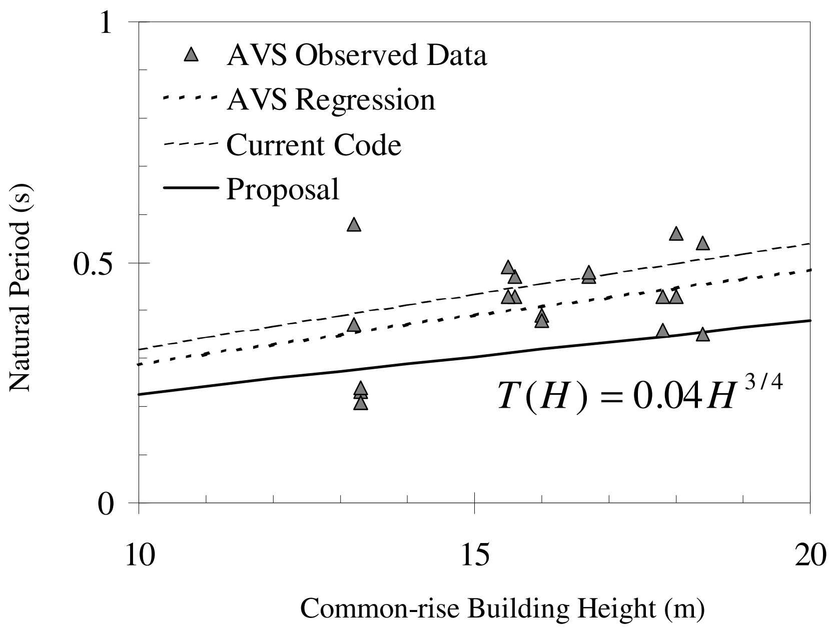


Figure 5. The proposal of this study for the next revision of the Iranian seismic code compared with the Observed Natural period from Ambient vibration survey, the Regressed formula and Current Iranian seismic code.

CONCLUSIONS

An empirical formula for preliminary estimation of natural period of building is introduced in this study. Among the buildings, which are commonly built by private owners and with popular construction methods, we studied on 10 buildings by ambient vibration survey (AVS).

Ambient vibration survey is very successful and accurate in producing the natural period of buildings.

AVS results have been compared with the analytical dynamic propertied calculated by three dimensional finite element models. The analytical natural periods are about 2.44 times longer than those of AVS results.

The Height and Depth of the buildings were taken as main variables in regression analysis for empirical formulation of ambient vibration data. Four types of equations have been considered as possible proposals. The successful regressed formula is only about 11 percent different from the proposed formula in the "Iranian code of practice for seismic resistant design of buildings 1999".

Since the regressed formula has no safety margin despite giving a shorter period than the current formula it is not conservative yet for the common rise RC buildings. We do not have any reduction factor to relate ambient response of buildings to their seismic response. However, a wise decision would be to reduce the period, to cover at least 80 percent of the observed data points, which in this case is related to 20 percent reduction of the empirical formula for use in Iranian seismic code.

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