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Research Article

Determination of Period of RC Buildings by the Ambient Vibration Method

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Determining the dynamic properties of structures is important for understanding their seismic behaviour. Ambient vibration signal measurement is one of the approaches used to determine the period of structures. Advantages of this method include the possibility of taking real-time records and presenting nondestructive and rapid solutions. In this study, natural vibration periods are calculated by taking ambient vibration signal records from 40 buildings. The height of the building, infill wall effect, presence of seismic retrofit, and presence of damage are taken into consideration, and their effects on natural vibration periods are investigated. Moreover, the results are compared with the analytical methods to reveal the differences. A significant correlation between the period and height of the building is observed. It is seen that the natural vibration periods of the buildings decrease by 7% to 30% (15% on average) due to infill wall contribution. However, the efficiency of infill walls decreases as the building height increases. Another significant result is that adding shear walls substantially decreases the vibration period values by 23% to 33% with respect to the shear wall ratio. When the analytical estimates and measured building period results are compared, it is seen that analytical models have closer period estimates before infill walls are implemented. The limited data in scope of the study suggest that significant differences may present in the analytical and measured periods of the buildings due to infill wall contributions.

1. Introduction

Determination of dynamic structural parameters is a basic and indispensable procedure for a proper engineering application. As a result of increasing importance of dynamic loads on structures, it was taken into account in theoretical base in 1920s. The early literature about it was available at 1950s [1, 2]. In the following decades, experimental research data and theoretical dynamics of structures promote numerical and analytical models which help to determine the amplitude of forced vibrations and shape/frequency of fundamental vibration modes of structures. Modelling a structure accommodates many difficulties because of some assumptions, and analytical models might not reflect the cases in practice. The majority of the assumptions in the models come from some dynamic characteristics of structures, and enlightening them in practice by using experimental methods provides a better understanding. A tentative model includes vibration tests and succeeding analysis on the measured data, and this process is called modal testing. Presently, the main testing techniques are single-point and multipoint excitation. The first method excites a structure at one coordinate and measures the response at all the coordinates while the latter implies it at many points at the same time. Both methods have some advantages and disadvantages inherently.

The ambient vibration measurement (AVM) is one of the dynamic analysis techniques that works as a single-point excitation method [3]. The advantage of the method is gaining real-time records and rapid nondestructive analysis [4]. Dominant natural vibration periods of structures can be effectively determined by AVM [5]. Since natural period is among the most effective parameters for seismic demand of structures, determination of the period of a structure in the most realistic way is very important.

Ambient vibration tests of structures have been conducted for some decades. The U.S. Coast and Geodetic Survey started using ambient vibration tests to measure the fundamental periods of buildings in the 1930s [6, 7]. Later, Crawford and Ward [8, 9] showed that AVM can be used to determine the highest period and fundamental modes of vibration of full-scale structures. Trifunac [10] compared the wind- and microtremor-induced vibration test and forced vibration experiment results on the same two buildings and observed that the outcomes are consistent and comparable. Additionally, the AVM method is validated by direct comparison with small-amplitude forced vibration tests [11, 12]. Most frequent use of AVM involves identification of natural modes, mode-shapes, and equivalent viscous damping parameters of vibration of various full-scale buildings [13–16]. Besides, AVM tests have been used to enhance the parameter approximations and the overall modelling of full-scale structures [4, 17, 18].

The ambient vibration measurements (AVM) are widely used in recent studies to determine dynamic properties of structures. Foti et al. used AVM to determine dynamic characteristics of a historical tower in Italy and for updating their 3D finite element model. The authors reported a very good match between theoretical and experimental modal parameters for the tower [19]. The method is also used for a field investigation on a damaged floor slab of a reinforced concrete frame building. It was observed that there was a 25–53% drop in natural frequencies of the damaged slab compared to the undamaged slab [20]. The dynamic characteristics of the masonry vault of a historical building have been identified by using the ambient vibration test [21]. Realistic estimation of RC building periods and effect of infill walls on the dynamic characteristics were also investigated using AVM [22–25]. Both ambient and forced vibration surveys were used to investigate the dynamic properties of a six-story residential building in Istanbul, and mode shapes, modal frequencies, and damping ratios were determined [26].

As aforementioned, there are many studies using AVM methods to evaluate building dynamic characteristics in the literature. However, as the regional construction practices affect the building properties, the reported values from different regions are important to enrich the current literature [27]. Additionally, it is stated in the literature that in situ measurement of full-scale partially damaged structures is of considerable interest [3].

This study aims to evaluate present natural vibration period measurements from ambient vibration signal records from 40 buildings with different characteristics. The height of the building, infill wall effect, presence of seismic retrofit, and presence of damage are taken into consideration and their effects on natural vibration periods are investigated. Considering that the measurements related to seismically damaged buildings before and after retrofit and values before and after construction of infill walls are limited in the literature, this study provides valuable contribution to the literature.

2. Materials and Methods

The tests in scope of the study have been carried out in western Turkey, namely, in Denizli, Simav, and Kutahya towns. All these towns are subjected to the same tectonic regime which is dominated by widespread active continental extension. These sites are formed by horst-graben systems which are bounded by active normal faults [28–30] (Figure 1). All the faults in three sites lie in the northwest-southeast direction.

The measurements were obtained on two orthogonal components at the same location (near the floor mass center) for minimum 30 minutes recorded by using a three-component CMG-6TD seismometer of Guralp Systems. The records were taken at the late nighttime as the noise magnitude was lesser and/or the buildings were not used so that the undesired interference was at the minimum. The measurements were repeated in each story to obtain consistent test data to calculate the vibration period of buildings properly. Required measurement duration of ambient vibrations is directly affected by environmental conditions. For example, the undesired environmental noise is much higher in studies related to determination of soil properties, so the measurement duration increases. Similarly, higher measurement durations may also be required to calculate higher mode periods with lower amplitude. However, since the study was limited to the measurement of the dominant-mode period in the long and short direction of the buildings, 30 minutes of measurement time is found to be sufficient. In a similar study by Gallipoli et al. [32], measurement duration was 10 minutes per building. Additionally, the measurements were repeated on each story and controlled to confirm the dominant-mode vibration period of the building across its height for possible inconvenience in measurements.

Geopsy software was used to evaluate the records [33]. To obtain natural vibration periods of structures, Fourier amplitude spectrum is calculated for each direction from measurement data. The highest amplitude frequency obtained from the spectrum corresponds to dominant vibration of the building in that direction.

Amplitude spectrums of the records with filtering of 0.1–20 Hz frequency were calculated by zeroing the start and the end points through a Cosine Taper Window. Attention was paid in the calculations to make sure that the measurement windows taken from records did not include the undesired peaks and noise.

The tested buildings were categorized into two groups (sets):

(1) Nondamaged buildings

(2) Lightly damaged and retrofitted buildings

The first group (Set 1) includes low-, medium-, and high-rise buildings that have reinforced concrete (RC) systems with infill walls. The vast majority of buildings have been constructed according to modern Turkish Earthquake Code [34]. The set includes 40 residential buildings with typical structural properties observed in the building stock of Turkey [35]. Concrete strength of examined buildings varies between 20 and 25 MPa. All buildings are constructed as RC frame without shear walls. Since the buildings are used as residential, the infill wall placement and ratios to story area have the similar trend. Construction stages of six buildings

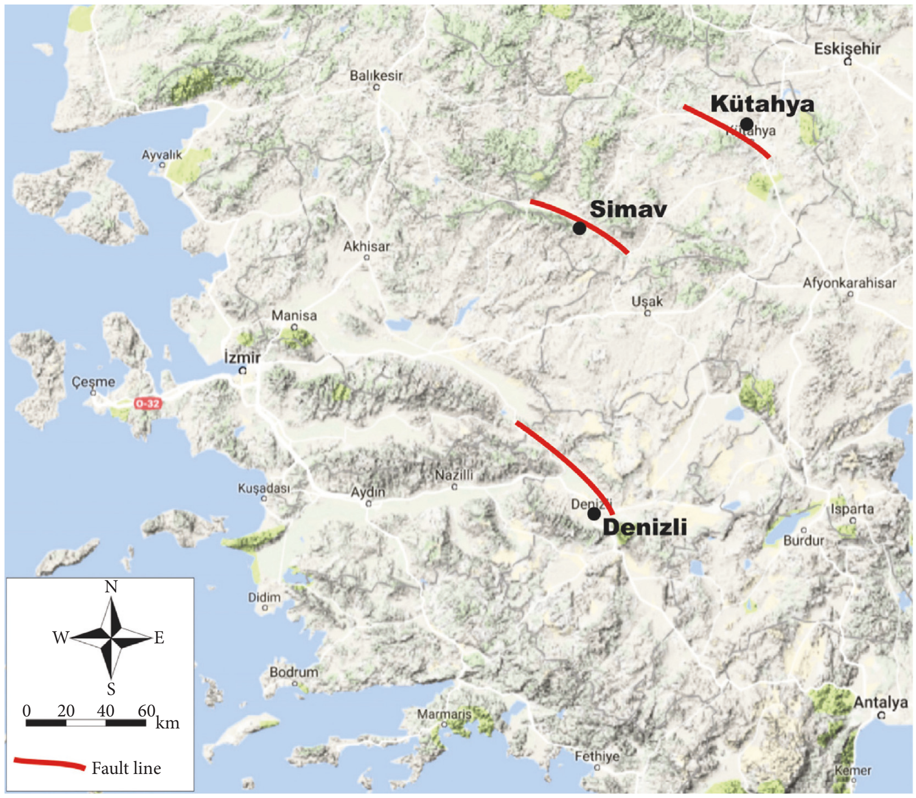

FIGURE 1: Location map of the tested buildings and major fault lines nearby (based on [31]).

in this group are monitored; AVM tests were taken before and after the construction of infill walls. The measurements were taken as bare frame and frame with plastered infill walls.

The second group (Set 2) has four residential buildings built before the Simav earthquake dated 2011, and they were lightly damaged and retrofitted ones [36, 37]. Although the dimensions, infill wall ratios, and purpose of construction are similar to those in Set 1, construction quality is poor. Concrete compressive strength of buildings in Set 2 was determined as 7 to 10 MPa in the field investigation. In scope of this paper, *lightly damage* is used for the buildings that have not any structural damage but common infill wall cracks. The microtremor records were taken in this set before and after the structural retrofitting. It made possible to visualize the retrofitting effects on the natural period of these existing buildings. The buildings in Set 2 have been designed according to premodern Turkish Earthquake Code [38]. The characteristics of the buildings used in the study are shown in Table 1.

3. Ambient Vibration Measurement Results

Amplitude spectrum graphs of a typical record are shown in Figure 2. Peaks observed in the frequency between 4 and 6 Hz for both directions define dominant-mode vibration frequency of the building. Short and long directions describe geometrically the shorter and longer side of measured buildings, respectively.

3.1. Building Height and Period Relationship. The distribution of natural vibration periods obtained for Set 1 with respect to the heights of the buildings is shown in Figure 3. As expected, building periods increase with respect to height. The height-period curve defined in many regulations [39–41] and ambient vibration signal measurements were compared to evaluate the consistency of obtained data with other results in the literature. Empirical equation derived by Euro Code 8 is given in equation (1). T defines the building period and H defines the building height in the following equation:

$$T = 0.075H^{0.75}. \tag{1}$$

Gallipoli et al. [32] derived equation (2) by using ambient vibration signal records taken from 244 buildings located in various regions in Europe:

$$T = 0.016H. \tag{2}$$

Chiauzzi et al. [42] defined the height-period relationship in equation (3) by using ambient vibration signal records taken from twelve buildings located in Canada:

$$T = 0.037H^{0.76}. \tag{3}$$

Based on the measurements in this study, a derivation of an empirical equation with respect to height-period parameters is given in

$$T = 0.01815H. \tag{4}$$

Table 1: Structural characteristics of the sets.

ID	No. of stories	Design code
S1-1	2	2007
S1-2	2	1975
S1-3	3	2007
S1-4	3	2007
S1-5	3	1975
S1-6	3	1975
S1-7	4	2007
S1-8	4	2007
S1-9	4	2007
S1-10	4	2007
S1-11	4	2007
S1-12	4	2007
S1-13	4	2007
S1-14	4	1975
S1-15	4	1975
S1-16	5	2007
S1-17	5	2007
S1-18	6	2007
S1-19	6	2007
S1-20	9	2007
S1-21	9	2007
S1-22	10	2007
S1-23	10	2007
S1-24	12	2007
S1-25	13	2007
S1-26	15	2007
S1-27	17	2007
S1-28	19	2007
S1-29	22	2007
S1-30	30	2007
S1-31*	4	2007
S1-32*	2	2007
S1-33*	5	2007
S1-34*	9	2007
S1-35*	8	2007
S1-36*	7	2007
S2-1	5	1975
S2-2	5	1975
S2-3	5	1975
S2-4	3	1975

*AVM taken before and after the construction of infill walls.

When results are compared, it is observed that the data obtained from Set 1 have similar tendency with the equation proposed by Gallipoli et al. [32]. The proposed equation by Chiauzzi et al. is successful to estimate the period of low- and mid-rise buildings. But the measured period values are higher for high-rise buildings. The code height-period curve resulted in estimations much higher than expected for all ranges possibly due to omitting the contribution of infill walls. Another significant point is that buildings used in data sets are residential buildings having similar characteristics. Therefore, it can be assumed that these buildings having reinforced concrete frame systems are constructed in accordance with design codes and do not have great differences. For buildings with high amount of shear walls, lack of such a high-level relationship between height and period can be expected depending on the amount of shear walls [43]. Natural vibration period of a building is affected by various parameters such as stiffness, mass, and their distribution in the structure, as well as height. Thus, equations derived from buildings of a certain region may not represent the properties of buildings in another region. But the obtained results clearly indicate that empirical equations obtained from ambient vibration signal records are useful tools for period estimates when typical residential buildings are considered.

3.2. Infill Wall and Period Relation. Although infill walls provide high stiffness to a structure under low amplitudes, they can be easily damaged under seismic loads because of their brittle characteristics [44]. Moreover, the strength of infill wall is influenced by numerous parameters such as material and mortar properties as well as production quality. Therefore, it is reasonable that under large displacements, building periods even in elastic regions can be higher than the period values determined based on ambient vibration records. Within the scope of the present study, in order to investigate the effect of the presence of infill walls on the stiffness of the building, six residential structures in Set 1 were monitored during their construction stages and ambient vibration measurements were taken before and after construction of the infill walls. Both periods obtained from the ambient vibration measurements were compared. Periods calculated before and after implementing infill walls, as well as their variations, are shown in Table 2. Comparison of the results shows that the building periods decreased by 6.6% to 30.3% after the construction of infill walls. The average change is approximately 15%. The change of building period decreases as the building height increases as shown in Figure 4. The obtained data indicate that there is a noticeable inverse correlation between the effectiveness of infill walls and the height of the building.

3.3. Effect of Retrofitting on Building Period. The damage evaluation has been carried out on 144 buildings in the Simav region after 2011 Simav Earthquake [45]. In the scope of the current study, AVM of four lightly damaged buildings was taken before and after retrofitting and the results were compared. There were hairline bending cracks in beams of reinforced concrete buildings and common infill wall damage. Thus, it can be said that infill wall stiffness contributions were at limited levels in Set 2 buildings compared to those in Set 1 and some of the reinforced concrete frame members reached to their cracked cross section stiffness. Table 3 shows period values measured before and after retrofitting, the added shear wall amounts (the area of shear walls divided by story area) for both directions. The comparison of period change with retrofitting shear wall ratio is shown in Figure 5. It can be said that retrofitting using shear walls decreases natural vibration periods by 22.7% to 32.6% with respect to the shear wall ratio. Figure 5 clearly indicates a significant correlation between the ratio of shear walls and the observed decrease in the period.

3.4. Evaluation of the Building Period/Building Height Ratio. The obtained data in the current study indicate that there is a significant correlation between period values and the

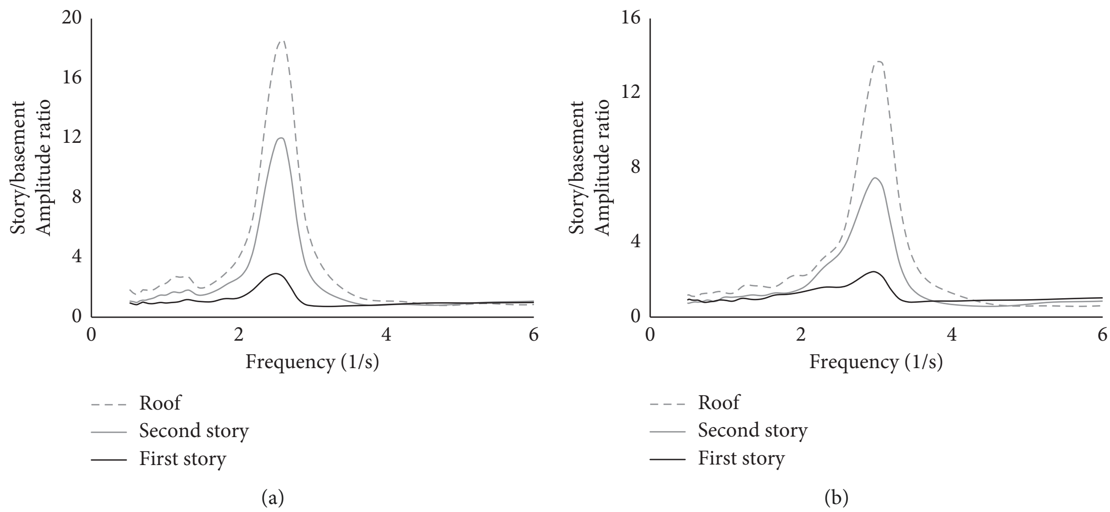

Figure 2: Amplitude spectrum graphs of a typical record. (a) Short direction. (b) Long direction.

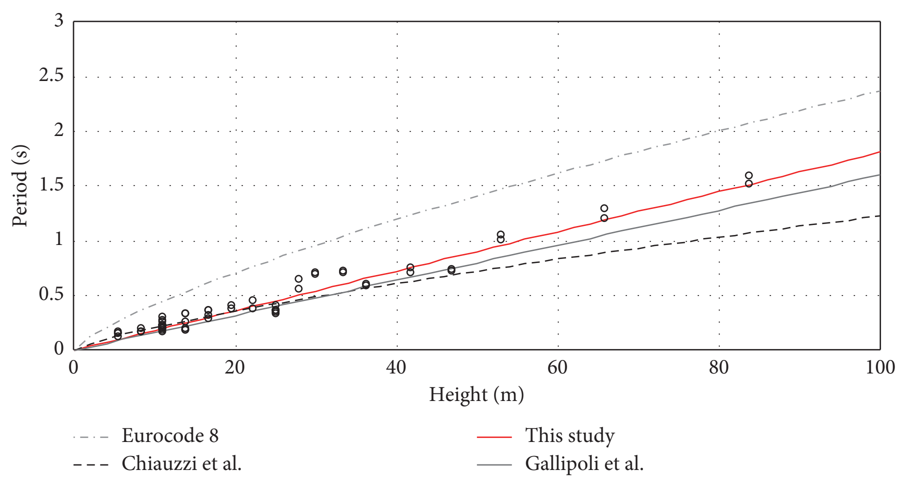

Figure 3: Distribution of natural vibration periods obtained from measurements with respect to the building heights.

Table 2: Effect of the infill walls on periods.

ID	Height (m)	Short direction			Long direction		
		Before	After	% change	Before	After	% change
S1-31*	11.20	0.28	0.26	8.53	0.25	0.21	15.97
S1-32*	5.60	0.21	0.15	30.30	0.18	0.15	18.38
S1-33*	14.00	0.39	0.32	16.83	0.39	0.32	17.78
S1-34*	25.20	0.40	0.34	14.63	0.37	0.34	6.55
S1-35*	22.40	0.47	0.44	6.28	0.38	0.37	3.70
S1-36*	19.60	0.46	0.40	12.75	0.45	0.36	20.58

building height for undamaged Set 1 structures. Although buildings in Set 1 were built based on different design codes, they show similar variations. Despite that, damaged buildings in Set 2 have higher scatter depending on the damage level of structural and nonstructural members. Similarly, measurements taken from buildings without infill walls have higher variation compared to the other sets.

It is hard to investigate the period of buildings with different heights. Thus, period/height ratios may better reflect the effect of different building properties such as damage level and retrofitting on stiffness capacity of buildings. Measured periods were divided by height of buildings and compared in Table 4 and Figure 6. The highest average (0.030) period/building height ratio was calculated for buildings of Set 2 before retrofitting as expected due to its damaged structural system and infill walls. This value decreased to 0.024 with 20% change, after retrofitting. The existence of infill walls decreases period/building height

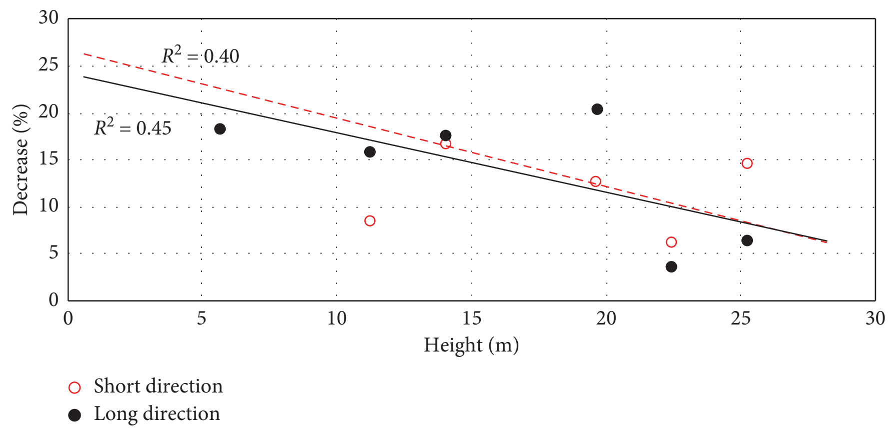

Figure 4: Change of building period with height due to contribution of infill walls.

Table 3: Period values measured before and after retrofitting.

ID	Height (m)	Short direction				Long direction			
		Period before (sec)	Period after (sec)	Shear wall (%)	Decrease in period (%)	Period before (sec)	Period after (sec)	Shear wall (%)	Decrease in period (%)
S2-1	11.20	0.43	0.35	0.86	22.73	0.24	0.19	1.32	24.87
S2-2	5.60	0.43	0.34	1.62	28.96	0.31	0.25	0.90	23.72
S2-3	14.00	0.43	0.33	1.31	27.84	0.34	0.26	1.65	28.52
S2-4	25.20	0.41	0.31	1.70	32.58	0.37	0.30	0.60	23.26

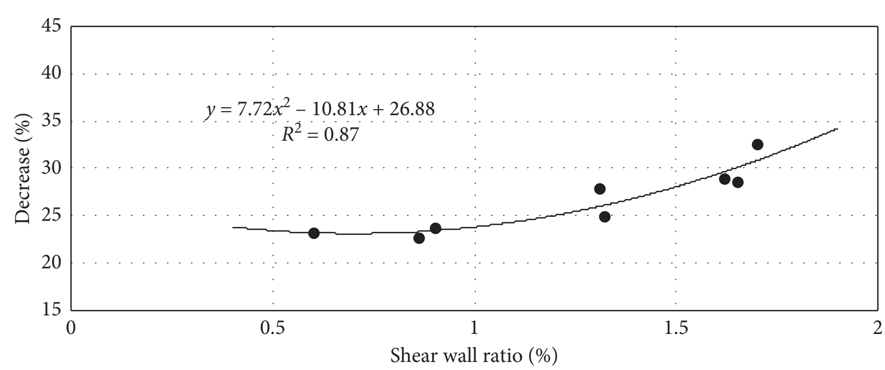

Figure 5: Effect of shear wall ratio on the period.

Table 4: Comparisons of period/height ratios in average.

	Set 1 before infill wall	Set 1 with infill wall	Set 2 before retrofit	Set 2 after retrofit
Average period/height ratio	0.0240	0.0190	0.0300	0.0240
Standard derivation	0.0115	0.00404	0.00843	0.00703
Decrease on period/height ratio (%)	21		20	

ratio by 21% (the ratio changes from 0.024 to 0.019). When average values of Set 1 and preretrofitting Set 2 buildings are compared with each other, a 37% difference is observed. This difference is attributable to the observed damages in infill walls and cracked structural members of Set 2 buildings.

The highest standard deviation was found for Set 1 buildings before infill walls were implemented (0.0115). The standard deviation was significantly lower for the buildings with infill walls (0.004). The observed difference clearly shows that the presence of infill walls is highly effective on the vibration period of buildings. The differences on structural members are more predominant for buildings without infill walls. Consequently, high ratio of scatter is observed.

Set 2 buildings exhibit relatively smaller ratio of scatter except for one measurement. Since the damage level of structural and nonstructural members and the influence on stiffness is not clearly predictable, the unexpectedly high ratio of vibration periods for some cases may be acceptable for Set 2.

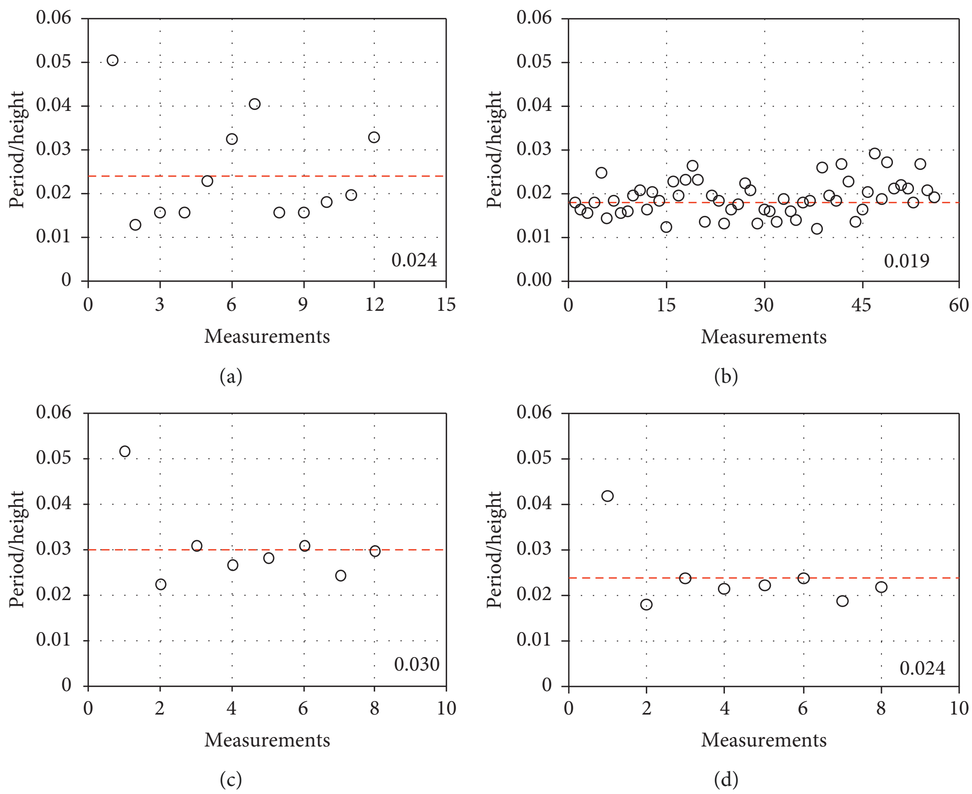

Figure 6: Comparison of period/height ratios of the buildings. (a) Set 1: without infill walls. (b) Set 1: with infill walls. (c) Set 2: before retrofit. (d) Set 2: after retrofit.

Table 5: Comparison of period values obtained from measurement and analytical analysis.

ID	Before infill				After infill			
	Analytical		Measurement		Analytical		Measurement	
	Short direction	Long direction	Short direction	Long direction	Short direction	Long direction	Short direction	Long direction
S1-31	0.30	0.24	0.28	0.23	0.27	0.23	0.26	0.21
S2-32	0.20	0.22	0.18	0.21	0.15	0.18	0.15	0.15
S2-33	0.39	0.42	0.39	0.39	0.46	0.40	0.32	0.32

3.5. Comparison of Test and Model Data. The vibration periods obtained from ambient vibration measurements were compared with the periods obtained by analytical models. Three buildings in Set 1 were modelled with and without infill walls as 3-D models using SAP 2000 software [46]. Concrete compressive strength, steel properties and size of structural members were taken from construction drawings.

The modelled buildings were reinforced concrete frame-type structures without shear walls. The stiffness contribution of the infill walls that meet the FEMA-356 [47] and TEC-2007 [34] criteria was modelled as diagonal struts. The other infill walls with openings that prevent diagonal strut formation were considered as dead loads, only. Aerated concrete block is used in the buildings as infill wall element. Compressive strength and dry density of infill walls are assumed to be 2.5 MPa and 400 kg/m^3, respectively [48]. Other dead loads such as slab weight were also considered as a distributed load at the beams. Since there were no records of seismic activity in the study area after construction of buildings and measurements taken just after the completion of construction, uncracked section stiffness is considered for the analytical model to have a more reasonable comparison. Although, diagonal struts modelling according to FEMA-356 is a simplified method, in the literature, it is stated to be a sufficient method to reflect the general stiffness contribution of infill walls [49–51].

Comparison of the dominant periods is shown in Table 5, while the distribution of ratios of analytical and ambient vibration measurement results is given in Figure 7. The measurements of buildings of Set 1 were taken as soon as construction stage completed. When the results are examined, it is seen that analytical models exhibit close period estimates before infill walls implemented. Despite the variance increases between the analytical model and measurements after the infill walls implemented for some cases (especially S1-32), period estimates seem to be closer in most cases. Such differences are expected to be observed due to

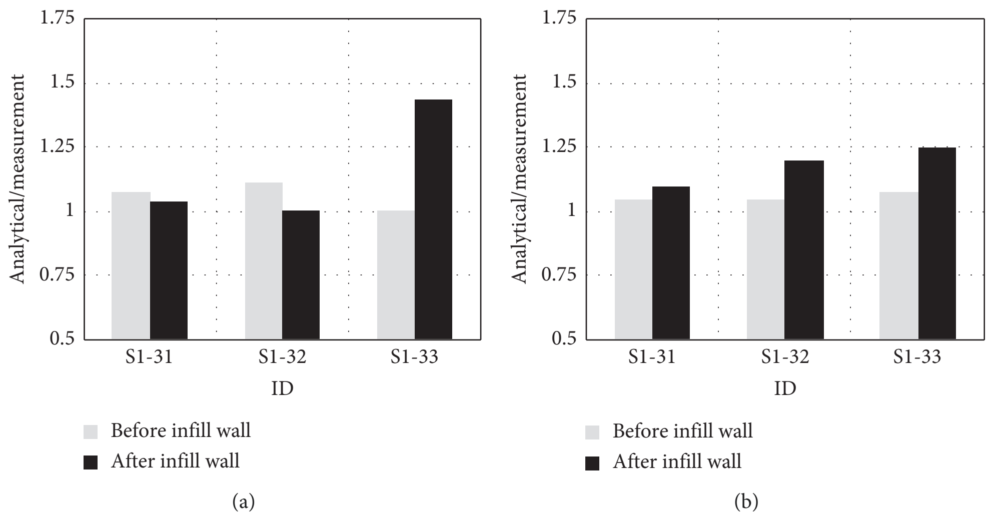

Figure 7: Comparison of period ratios obtained from measurement and analytical analysis. (a) Short direction. (b) Long direction.

various assumptions made for the analytical models. The highest difference was calculated in the S1-32 building with infill wall for the short direction. The building period is measured as 0.32 s, while the building period is calculated as 0.46 s for the analytical model. The limited data in scope of the study suggest that significant differences (up to 70%) may present in analytical and measured periods of the buildings due to infill wall contributions.

4. Conclusions

Realistic determination of dynamic properties of the buildings is essential for consistent estimation of building behaviour. Therefore, a study to examine the factors that may significantly affect the building period is conducted. The ambient vibration measurements (AVM) from 40 buildings are evaluated. The buildings include a set of 36 new residential buildings. Among them, the 6 residential buildings were tested before and after the construction of infill walls. AVMs from 4 buildings are taken before and after the structural retrofit. The conclusions from the study are as follows:

(i) There is a close correlation between natural vibration periods and building height in RC frame buildings without shear walls and seismic damage.

(ii) The period distributions of lightly damaged buildings in Set 2 have more scatter compared to Set 1 buildings. Because of decreased infill wall efficiency and the presence of structural members reaching cracked cross-section stiffness due to seismic effects, the calculated natural vibration periods of Set 2 buildings is higher than those of Set 1 buildings.

(iii) Based on the measurements in this study, an empirical equation with respect to height-period parameters is derived as $T = 0.0343H0.762$. The obtained results revealed a similar distribution with height-period equations in the literature by using ambient vibration signal records, especially to the Gallipoli et al. [32]. However, the relationship "$T = 0.075H0.75$" used in Euro Code 8 and other many regulations revealed higher natural vibration period estimates than the measured periods.

(iv) Six residential buildings in Set 1 are monitored during their construction stages, and ambient vibration measurements were taken before construction of infill walls; then; they were compared with the periods measured afterward. When the results are evaluated, it is found that building periods decreased by 7% to 30% (15% on average) due to infill wall contribution. The efficiency of infill walls decreases as the building height increases.

(v) Based on measurements carried out on lightly damaged buildings located in the Simav region, the structural retrofitting conducted with adding shear walls decreased the vibration period values by 23% to 33% with respect to the shear wall ratio. Moreover, a significant correlation is observed between shear wall ratio and the period change.

(vi) In order to investigate changes of stiffness ratios of different sets, the measured period values are normalized by heights of buildings and compared. The highest period/height ratio, as expected, was found to be 0.030 for preretrofitted damaged buildings. After retrofitting, that ratio is calculated as 0.024 that corresponds to 20% decrease. The average period/height ratio decreased by 21% to 0.019 for Set 1 buildings after construction of infill walls. When average values of preretrofitted Set 2 and Set 1 buildings were compared, a 37% difference was observed. It can be said that the 37% difference is attributable to the damages observed on infill walls of Set 2 buildings and the presence of structural members reaching their cracked cross-section stiffness.

(vii) Three buildings in the Set 1 are modelled in the computer environment; the natural vibration periods obtained from the modal analyses are compared with ambient vibration signal data. When the results are examined, it is seen that the analytical models have closer period estimates before infill walls are implemented. The limited data in scope of the study suggest that significant differences may present in analytical and measured periods of the buildings due to infill wall contributions.

Data Availability

The data used may be provided by contacting the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. F. Smirnov, *The Static and Dynamic Stability of Structures*, Transzheldorizdat, Moscow, Russia, 1947.

[2] Y. S. Sorokin, *Dynamic Analysis of Load-Bearing Structures of Buildings (Dinamicheskiy Raschet Nesushchikh Konstruktsiy Zdaniy)*, Gos. Izd-vo lit-ry po stroitel'stvu, arkhitekture, Moscow, Russia, 1956.

[3] S. S. Ivanovic, M. D. Trifunac, and M. I. Todorovska, "Ambient vibration tests of structure-a review," *Journal of Earthquake Technology*, vol. 37, no. 4, pp. 165–197, 2000.

[4] B. Demirtas, A. Bayraktar, and A. Dumanoglu, "Model updating effects on the seismic behavior of tall buildings under far and near-fault ground motions," *Research on Engineering Structures and Materials*, vol. 3, no. 2, pp. 99–112, 2016.

[5] A. Asgarian and G. McClure, "Using ambient vibration measurements to generate experimental floor response spectra and inter-story drift curves of reinforced concrete (RC) buildings," *Procedia Engineering*, vol. 199, pp. 92–97, 2017.

[6] D. S. Carder, "Vibration observations," in *Earthquake Investigations in California 1934-1935*, Chapter 5, Special Publication No. 201, Washington, DC, USA, 1936.

[7] D. E. Hudson, "Dynamic tests of full-scale structures," in *Earthquake Engineering*, R. L. Wiegel, Ed., Prentice-Hall, Englewood Cliffs, NJ, USA, 1970.

[8] R. Crawford and H. S. Ward, "Determination of the natural periods of buildings," *Bulletin of the Seismological Society of America*, vol. 54, no. 6A, pp. 1743–1756, 1964.

[9] H. S. Ward and R. Crawford, "Wind induced vibrations and building modes," *Bulletin of the Seismological Society of America*, vol. 56, no. 4, pp. 793–813, 1966.

[10] M. D. Trifunac, "Comparisons between ambient and forced vibration experiments," *Earthquake Engineering & Structural Dynamics*, vol. 1, no. 2, pp. 133–150, 1972.

[11] J. G. Bouwkamp and R. Stephen, "Ambient and forced vibration studies of a multistory pyramid-shaped building," in *Proceedings of the Fifth World Conference on Earthquake Engineering*, Rome, Italy, June 1973.

[12] C. R. Farrar and G. H. James, "Identification of dynamic properties from ambient vibration measurements," in *Proceedings of the Pacific Conference on Earthquake Engineering*, pp. 105–114, Melbourne, Australia, Nobember 1995.

[13] S. Ivanovic and M. D. Trifunac, "Ambient vibration survey of full scale structures using personal computers (with examples in kaprielian hall)," Rep. No. 95-05, University of Southern California, Los Angeles, CA, USA, 1995.

[14] L. Ko and Z. W. Bao, *Ambient Vibration Measurements on Existing Tall Buildings in Hong Kong*, Civil & Structural Engineering Department, Hong Kong Polytechnic, Hong Kong, China, 1985.

[15] C. E. Ventura, A. J. Felber, and S. F. Stiemer, "Determination of the dynamic characteristics of the Colquitz River bridge by full-scale testing," *Canadian Journal of Civil Engineering*, vol. 23, no. 2, pp. 536–548, 1996.

[16] I. Çalık, A. Bayraktar, T. Türker, and A. O. Ayan, "Dynamic identification of historical Molla Siyah mosque before and after restoration," *Research on Engineering Structures and Materials*, vol. 3, no. 3, pp. 164–175, 2017.

[17] E. Safak and M. Celebi, "Method to estimate center of rigidity using vibration recordings," *Journal of Structural Engineering*, vol. 116, no. 1, pp. 85–97, 1990.

[18] C. Yang and D. Llu, "The effect of stiffness degradation of shear wall and floor horizontal deformation on the frame-shear wall buildings," in *Proceedings of the Nineth World Conference on Earthquake Engineering*, pp. 17–22, Tokyo, Japan, August 1988.

[19] D. Foti, M. Diaferio, N. I. Giannoccaro, and M. Mongelli, "Ambient vibration testing, dynamic identification and model updating of a historic tower," *NDT & E International*, vol. 47, pp. 88–95, 2012.

[20] H. Hashim, Z. Ibrahim, and H. A. Razak, "Dynamic characteristics and model updating of damaged slab from ambient vibration measurements," *Measurement*, vol. 46, no. 4, pp. 1371–1378, 2013.

[21] I. Çalık, A. Bayraktar, T. Türker, and H. Karadeniz, "Structural dynamic identification of a damaged and restored masonry vault using ambient vibrations," *Measurement*, vol. 55, pp. 462–472, 2014.

[22] P. G. Asteris, C. C. Repapis, A. K. Tsaris, F. Di Trapani, and L. Cavaleri, "Parameters affecting the fundamental period of infilled RC frame structures," *Earthquakes and Structures*, vol. 9, no. 5, pp. 999–1028, 2015.

[23] K. Guler, E. Yuksel, and A. Kocak, "Estimation of the fundamental vibration period of existing RC buildings in Turkey utilizing ambient vibration records," *Journal of Earthquake Engineering*, vol. 12, no. sup2, pp. 140–150, 2008.

[24] M. E. Arslan and A. Durmus, "Finite element model updating of in-filled RC frames with low strength concrete using ambient vibration test," *Earthquakes and Structures*, vol. 5, no. 1, pp. 111–127, 2013.

[25] M. Mirtaheri and F. Salehi, "Ambient vibration testing of existing buildings: experimental, numerical and code provisions," *Advances in Mechanical Engineering*, vol. 10, no. 4, pp. 1–9, 2018.

[26] F. Aras, "Ambient and forced vibration testing with numerical identification for RC buildings," *Earthquakes and Structures*, vol. 11, no. 5, pp. 809–822, 2016.

[27] H. B. Ozmen, M. Inel, and E. Meral, "Evaluation of the main parameters affecting seismic performance of the RC buildings," *Sadhana*, vol. 39, no. 2, 2014.

[28] E. Bozkurt and H. Sözbi̇li̇r, "Tectonic evolution of the Gediz Graben: field evidence for an episodic, two-stage extension in western Turkey," *Geological Magazine*, vol. 141, no. 1, pp. 63–79, 2004.

[29] F. Bilim, "Investigations into the tectonic lineaments and thermal structure of Kutahya-Denizli region, western Anatolia, from using aeromagnetic, gravity and seismological data," *Physics of the Earth and Planetary Interiors*, vol. 165, no. 3-4, pp. 135–146, 2007.

[30] M. Hançer, "Study of the structural evolution of the Babadağ-Honaz and Pamukkale fault zones and the related earthquake risk potential of the Buldan region in SW Anatolia, east of the Mediterranean," *Journal of Earth Science*, vol. 24, no. 3, pp. 397–409, 2013.
[31] Goggle maps, 2011, http://maps.google.com/.
[32] M. R. Gallipoli, M. Mucciarelli, B. Šket-Motnikar et al., "Empirical estimates of dynamic parameters on a large set of European buildings," *Bulletin of Earthquake Engineering*, vol. 8, no. 3, pp. 593–607, 2010.
[33] Geopsy project, 2017, http://www.geopsy.org/.
[34] Turkish Earthquake Code-TEC (2007), *Specifications for Structures to be Built in Seismic Areas*, Ministry of Public Works and Settlement, Ankara, Turkey, 2007.
[35] H. B. Ozmen, M. Inel, S. M. Senel, and A. H. Kayhan, "Load carrying system characteristics of existing Turkish rc building stock," *International Journal of Civil Engineering*, vol. 13, no. 1, pp. 76–91, 2015.
[36] H. B. Ozmen, M. Inel, E. Akyol, B. T. Cayci, and H. Un, "Evaluations on the relation of RC building damages with structural parameters after May 19, 2011 Simav (Turkey) earthquake," *Natural Hazards*, vol. 71, no. 1, pp. 63–84, 2014.
[37] M. Inel, H. B. Ozmen, and E. Akyol, "Observations on the building damages after 19 May 2011 Simav (Turkey) earthquake," *Bulletin of Earthquake Engineering*, vol. 11, no. 1, pp. 255–283, 2013.
[38] Turkish Earthquake Code-TEC (1975), *Specifications for Structures to be Built in Disaster Areas*, Ministry of Public Works and Settlement, Ankara, Turkey, 1975.
[39] ATC, *Tentative Provisions for the Development of Seismic Regulation for Buildings*, ATC, Washington, DC, USA, 1978.
[40] CEN Eurocode 8, *Design of Structures for Earthquake Resistance—Part 1: General Rules, Seismic Actions and Rules for Buildings*, European Committee for Standardization, Brussels, Belgium, 2004.
[41] NBCC, *National Building Code of Canada*, Associate Committee on the National Building Code, Ottawa, Canada, 2005.
[42] L. Chiauzzi, A. Masi, M. Mucciarelli et al., "Estimate of fundamental period of reinforced concrete buildings: code provisions vs. experimental measures in Victoria and Vancouver (BC, Canada)," in *Proceedings of the 15th World Conference on Earthquake Engineering*, Paper No: 3033, Lisbon, Portugal, 2012.
[43] M. Inel, H. Bilgin, and H. B. Ozmen, "Seismic capacity evaluation of school buildings in Turkey," *Proceedings of the Institution of Civil Engineers—Structures and Buildings*, vol. 161, no. 3, pp. 147–159, 2008.
[44] M. Dolsek and P. Fajfar, "Soft storey effects in uniformly infilled reinforced concrete frames," *Journal of Earthquake Engineering*, vol. 5, no. 1, pp. 1–12, 2001.
[45] M. Inel, H. Un, H. B. Ozmen, E. Akyol, B. T. Cayci, and G. Ozcan, "Investigation of the feasibility of retrofitting the moderately damaged buildings in Simav region and surroundings," Report for Disaster and Emergency Management Presidency, Pamukkale University, Denizli, Turkey, 2011.
[46] CSI, *SAP2000. Integrated Software for Structural Analysis and Design*, Computers and Structures Inc., Berkeley, CA, USA, 2011.
[47] FEMA-356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, Federal Emergency Management Agency, Washington, DC, USA, 2000.
[48] N. Narayanan and K. Ramamurthy, "Structure and properties of aerated concrete: a review," *Cement and Concrete Composites*, vol. 22, no. 5, pp. 321–329, 2000.
[49] F. J. Crisafulli and A. J. Carr, "Proposed macro-model for the analysis of infilled frame structures," *Bulletin of the New Zealand Society for Earthquake*, vol. 40, no. 2, pp. 67–77, 2007.
[50] T. Sevil, M. Baran, and E. Canbay, "Tuğla dolgu duvarların B/A çerçeveli yapıların davranışına etkilerinin incelenmesi; deneysel ve kurumsal çalışmalar," *International Journal of Engineering Research and Development*, vol. 2, no. 2, pp. 35–42, 2010.
[51] H. B. Kaushik, D. C. Rai, and S. K. Jain, "A rational approach to analytical modeling of masonry infills in reinforced concrete frame buildings," in *Proceedings of the 14th World Conference on Earthquake Engineering*, Beijing, China, October 2008.