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RESEARCH ARTICLE

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Monitoring the dynamic properties of a nine-story reinforced concrete building during its demolition

Fuat Aras

Civil Engineering Department, Istanbul Medeniyet University, Istanbul, Turkey

Correspondence
Fuat Aras, İstanbul Medeniyet Üniversitesi, Kuzey Yerleşkesi, Ünalan mahallesi F Blok, No. 133, 34732 Üsküdar/Istanbul, Turkey.
Email: fuataras@hotmail.com; fuat.aras@medeniyet.edu.tr

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Summary

Dynamic properties of an existing nine-story reinforced concrete building were monitored during its demolition period, in Istanbul. Based on the municipal regulations, the number of the story of the building was reduced to five first by the removal of the top stories one by one. Later on, the remaining building was demolished by an excavator-like vehicle working on the ground. At the particular stages of the demolition, vibration measurements were taken from the present phase of the building to obtain its dynamic properties within the basis of operational modal analysis. The stage of the building and its dynamic properties were elaborated in detail to analyze the effects of the structural changes into the dynamic properties of existing reinforced concrete buildings. Thereby, the effects of floor removal and area reduction in the dynamic properties of existing reinforced concrete buildings were revealed.

KEYWORDS

demolition, dynamic testing, floor removal, full-scaled test, operational modal analysis, size reduction

1 | INTRODUCTION

In the second half of the 20th century, the construction of reinforced concrete (RC) buildings became highly popular in Turkey. With the rural depopulation in the 1980s, many RC buildings were built to meet the shelter need for the newcomers in the metropolitan cities like Istanbul. Kocaeli and Duzce earthquakes (1999) are the milestone for the seismic risk awareness of the Turkish community due to the high life and economic losses that they caused. These events highlighted the need for seismic risk assessment of existing building stock. Henceforth, two validated seismic codes[1,2] included a detailed chapter devoted to the seismic assessment of existing buildings in Turkey. Furthermore, the physical obsolescence and increased comfort expectations of the inhabitants forced the owners to renew their buildings. Indeed, the renewal cost, as the overall replacement of an old building by a new one is affordable because the renewed building is mostly located near the central locations. In these conditions, in 2012, The Law about the Transformation of the Areas under Disaster Risk (LTADR)[3] was released officially to pave the way of building renovation projects. After the validation of the LTADR, many poor buildings were demolished and their areas occupied by new buildings.

This study is performed over one of the buildings that will be demolished under LTADR. The nine-story building is located in Kadıköy district of Istanbul and composed of RC frames with one-way ribbed slab system. As the result of the seismic evaluation performed according to Turkish Earthquake Code (TEC),[1] the seismic performance of the building was determined as inadequate, and its collapse and transformation were approved by the municipality of Kadıköy.[4] The municipal regulations arrange the demolishing techniques according to sites of the building with the minimum disturbance and discomfort to the neighborhood. In this respect, the studied building was planned to be demolished by two steps. The first step is the removal of ninth, eighth, seventh, and sixth stories one by one. After the total height of the building is reduced to a specific limit, the demolishing can continue with a more prominent building demolishing machine working on the ground level.

In this study, dynamic testing was used to monitor the variation of modal parameters for the studied building during its demolition. For this aim, the dynamic characteristics of the studied building were determined before the demolition, during the story removal and its demolition from the ground phase.

As a full scaled destructive research performed in a real building, this study first evaluates the relationship between the natural period or dominant frequency and number of story or height of the building. The period of an existing building can be computed experimentally by forced vibration survey or ambient vibration survey (AVS). In forced vibration survey, the building is tested under artificially produced vibration,[5,6] whereas AVS is performed under existing small amplitude sources of vibration like wind or traffic activities.[7-10] Aras[11] tested an existing RC building under a set of impacts applied by a building demolishing machine and in ambient conditions. He confirmed that the dominant frequencies decrease as the excitation magnitude increases. The modal frequencies obtained under impacts were 2–3% less than those obtained in ambient conditions. For this reason, as practical and easy testing, AVS was proposed because the former method is usually citizen perturbing and expensive strategy compared with the latter one. In the literature, the results of AVS are mainly used for the condition assessment, validation and tune of the numerical models, and investigation of structural changes in the existing structures.[12-16] For this reason, AVS is used as the leading experimental technique in this study.

The building codes also provide empirical equations for the prediction of fundamental periods of the buildings. Uniform Building Code (UBC),[17] Federal Emergency Management Agency (FEMA) 450,[18] Eurocode 8,[19] and Swiss Code[20] relate the fundamental period of the building to its height, whereas Algerian code,[21] Korean Building Code (KBC),[22,23] and French code[24] add the geometrical dimensions of the building in the direction of considered mode to their formula. Furthermore, Canadian National Building Code (NBC) [25] accounts only the number of the story of the building for the estimation of the natural period of the RC buildings. The details of codes' approaches can be found in the study of Salameh et al.,[26] Crowley and Pinho,[27] and Kose.[28] Moreover, there are several studies devoted to proposing more exact formulas with parameters than the type and height of the structure.[29-31] Indeed, the proposed formulas are the results of extensive surveys and researches performed over many buildings with different geometry, structural system, material, soil–structure interaction, non-structural components, live load, and boundary conditions.

On the other hand, the results of this study purely elaborate the number of story or height of the building and the dimension of the building in the natural periods of RC buildings because the other parameters remain unchanged. Furthermore, this study was performed over an existing real building, and a well-known technique, AVS, was employed. In that respect, the results of the study are more reliable than those obtained from the numerical investigations and tests performed in laboratories.

2 | STUDIED BUILDING

The studied building is a nine-story, RC building located in Kadıköy district of Istanbul, which lies on the most dangerous earthquake zone according to TEC.[1] The building with its plan layout on the third floor is shown in Figure 1. Its structural system contains columns and shear walls with one-way ribbed slab system except for the slab system of bathrooms, which is an ordinary flat slab surrounded by beams. Column sizes were reduced through the height of the building. The type of foundation is single footing. The story height is measured as 3 m for all stories.

The building was analyzed on the basis of the regulations for the determination of risky buildings LTADR,[3] and its performance was assessed as inadequate because the life safety performance level was not satisfied according to TEC.[1] During the performed assessment work, the concrete quality of the building was determined as C6 with 26 core samples taken from the building. Reinforcement details were also searched, and it was seen that S220 steel grade (characteristic yielding stress is 220 MPa) was used in the structural elements. Inadequate use of lap splice length, unconfined members, and heavy corrosion on reinforcement bars were also noted.[4] As a result of the seismic assessment, the building was decided to be demolished, and the opportunity to monitor the variation of its dynamic properties during its demolishing was realized.

3 | MEASUREMENTS AND ANALYSIS OF THE ORIGINAL BUILDING

AVS of the building was performed after the evacuation of the building and removal of recycling items before the demolition starts. Five SARA, Acebox, force balance accelerometers, with three sensors, oriented along with two orthogonal

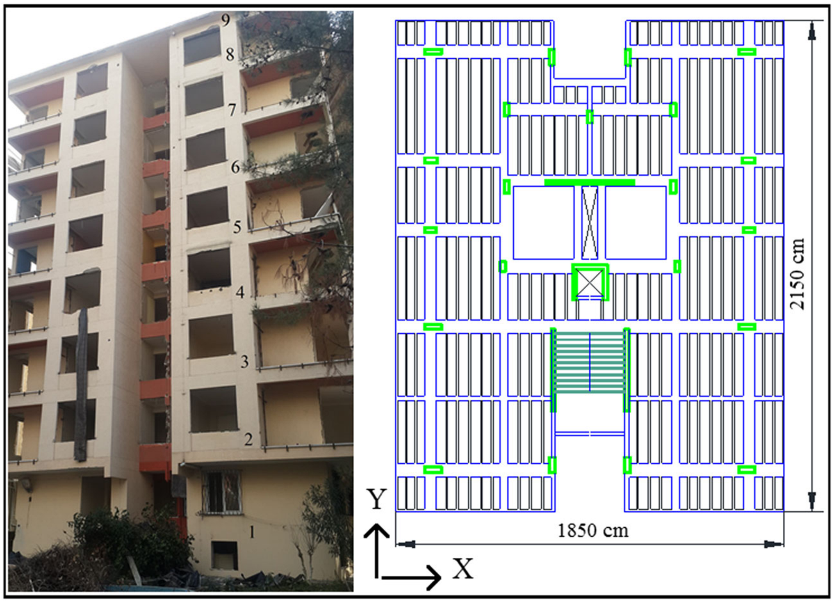

FIGURE 1 Studied building and its plan layout

horizontal directions and one vertical direction, were used for data collection. Each accelerometer has its own data storage unit and works separately without a particular data acquisition system. The required synchronization for the dynamic identification is provided by a global positioning system antenna. The linear acceleration range of each sensor is ±2 g, and its noise floor is less than 20 ng/$\sqrt{\text{Hz}}$. The recording was performed with 200 samples per second.

The dynamic properties of the building were determined by vibration recording at each story's front left corner. Thereby, modal frequencies and translation modes in two horizontal directions were determined. Two horizontal directions of the accelerometers were oriented along with the X and Y directions of the building (Figure 1). Two sets of measurements are required for AVS of the nine-story building with five accelerometers. In each set, one of the accelerometers was used as a reference sensor and located on the fourth floor. In the first set, five accelerometers were located on the fourth, fifth, sixth, seventh, and eighth floors, whereas in the second set, they were on the fourth, third, second, first, and ground floors of the building. The ninth floor of the building was closed during the surveys, and no measurement was taken from that level.

The literature on modal identification methodologies is vast, and a survey of the methodologies is out of the scope of this study. The well-known enhanced frequency domain decomposition methodology was used in this study by using Artemis Modal 6.0 software.[32] Detailed information on the enhanced frequency domain decomposition method is found in the studies of Brincker et al.[33,34] and Michel et al..[35] For this reason, theory of the methodology was not repeated in this study. No filtering was applied to the data, and modal identification was performed between 0 and 20 Hz, which is adequate for the identification of the studied building. Figure 2 shows the singular values of spectral density presentation of the signals taken through the height of the building along with X and Y directions.

Dominant frequencies were determined as 1.97, 2.67, 6.11, and 8.40 Hz. Figure 3 shows the mode shapes of the building. The first mode of the building was determined as the movement in the X direction with a frequency of 1.97 Hz, whereas the second mode is the movement in the Y direction with 2.67-Hz dominant frequency. The third and the fourth modes are dual curvature modes, in X and Y directions with 6.11- and 8.40-Hz dominant frequencies, respectively. Figure 4 shows the modal assurance criterion (MAC). If the MAC is near zero, this shows that the mode shapes are not consistent. If it is near unity, the mode shapes are consistent.[36] The obtained MAC values prove the consistent mode shapes determined in this study.

4 | MODAL ANALYSES DURING THE FLOOR REMOVAL

The demolition of the studied building was performed first by the removal of the top stories. For this aim, a building demolishing machine was located on the roof level of the building, and it demolished its surroundings to reach to the story below. The wrecks were thrown down. Figure 5 shows the nine-, eight-, seven-, and five-story phases of the studied building.

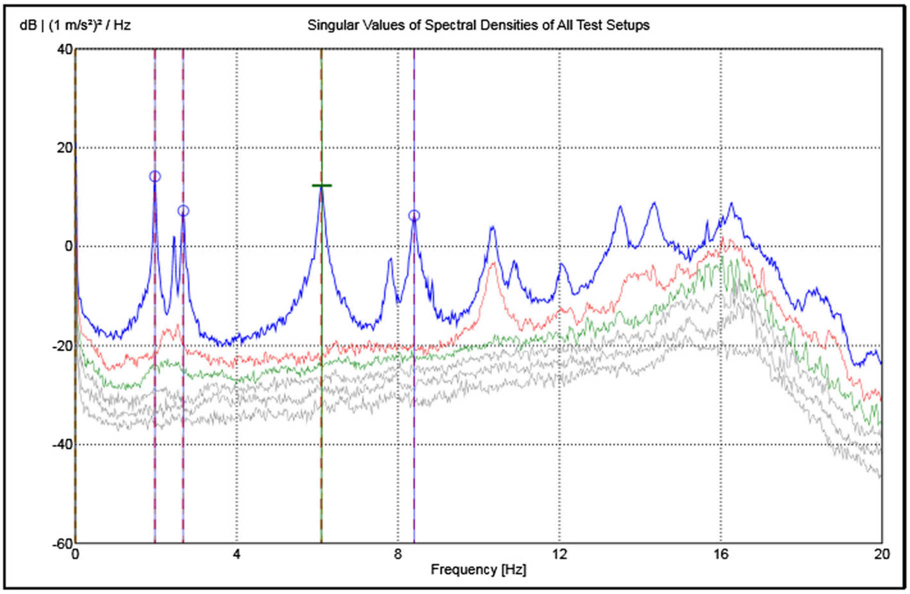

FIGURE 2 Singular values of spectral densities for the nine-story building

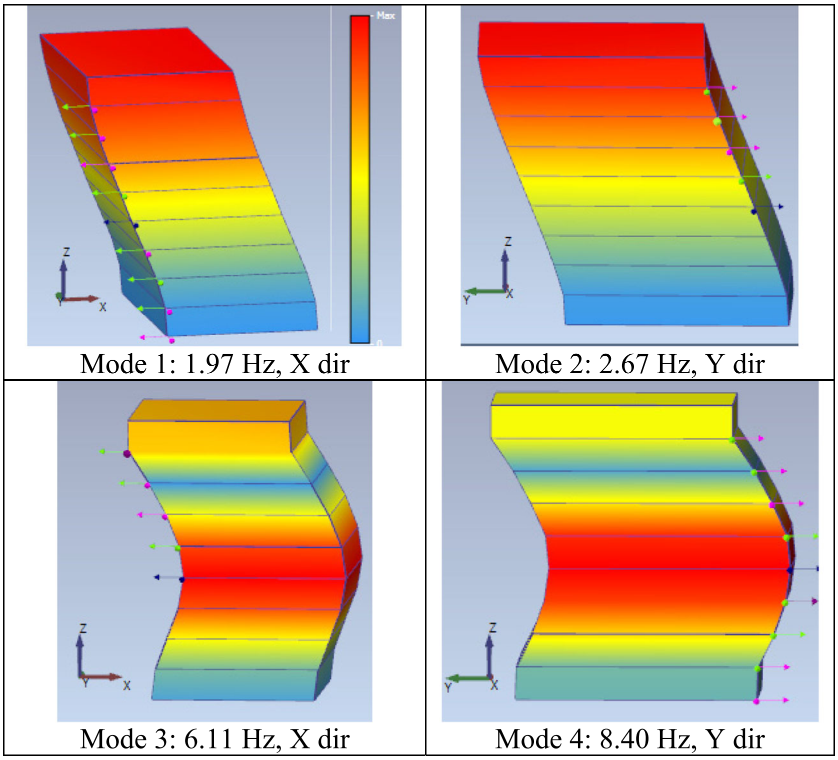

FIGURE 3 Mode shapes of the original building

4.1 | Modal analysis of eight-story building

The vibration measurements for the eight-story building were performed when the demolishing works were in progress. The performed modal identification was simplified to decrease the level of risk because the demolition continued permanently. Instead of having vibration measurements through each floor, acceleration records gathered from second, fourth, and sixth floors of the building. The acceleration records were analyzed with the same principles, and dominant frequencies along with X and Y directions were determined as shown in Figure 6. It was seen that the mode shapes of the building remained almost the same, but the increase in the frequencies were noted. The first four dominant

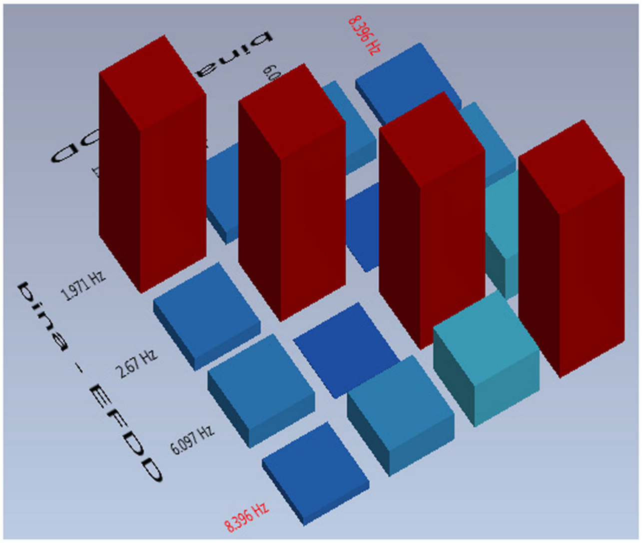

FIGURE 4 Mode shapes of the original building along with Y direction. EFDD, enhanced frequency domain decomposition

FIGURE 5 Floor removal in the studied building

frequencies of the building were determined as 2.21, 3.01, 6.76, and 9.36 Hz. The effects of the ninth floor removal in the studied building can be summarized as the increase in the modal frequencies.

4.2 | Modal analysis of seven-story building

The modal analysis for the seven-story phase of the building was performed by gathering vibration records from the second and fourth stories of the building because working on a floor near the construction demolishing machine that spreads concrete wrecks and particles was assessed as dangerous. Moreover, many wrecks were thrown through the staircase of the building, which is the only way of reaching the floor areas. The analysis of the recorded acceleration showed that the dominant frequencies are 2.51, 3.51, 7.53, and 10.54 Hz as seen in Figure 7. The mode shapes remained the same. In that respect, the removal of the eighth floor of the building increased the modal frequencies.

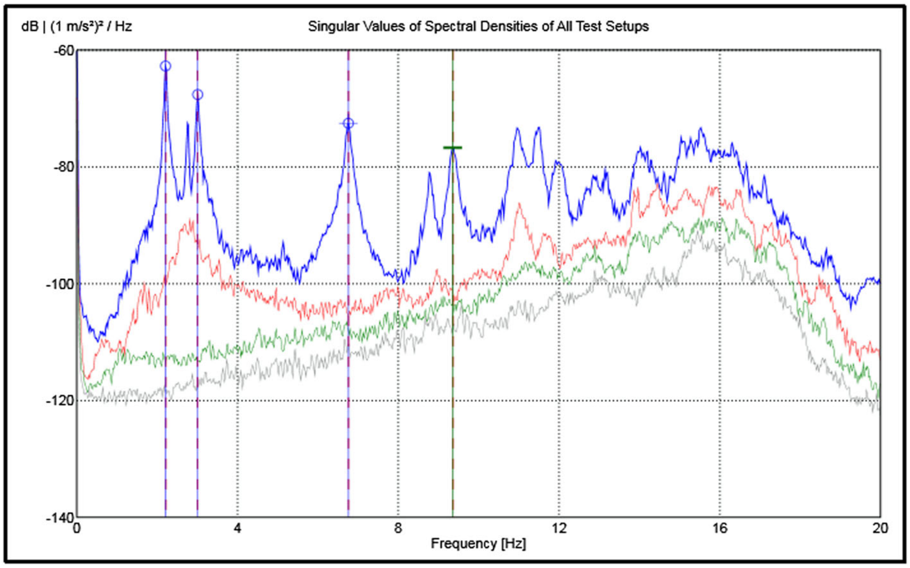

FIGURE 6 Singular values of spectral densities for the eight-story building

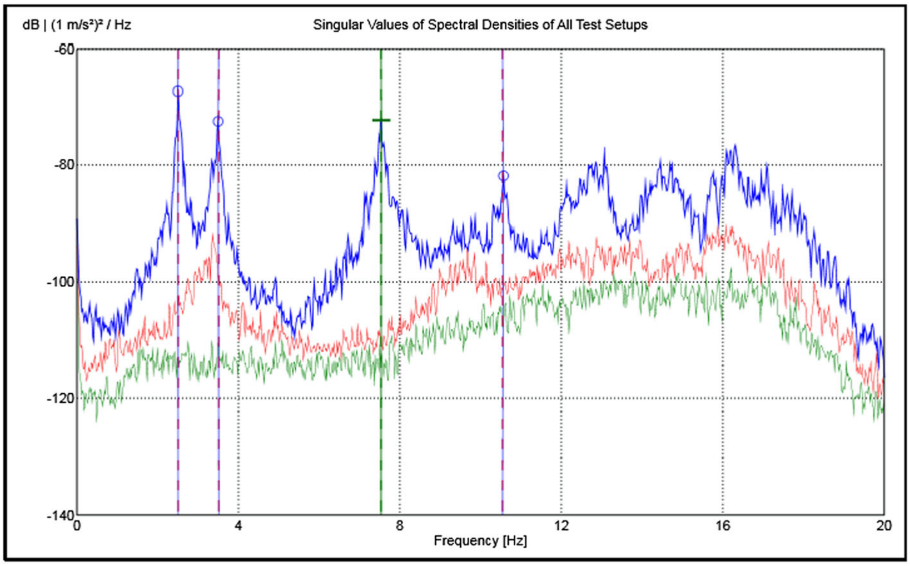

FIGURE 7 Singular values of spectral densities for the seven-story building

4.3 | Modal analysis of five-story building

The modal analysis for the six-story building could not be performed because the operators accidentally damaged the sixth floor of the building and demolished two stories together. The five-story phase of the building is analyzed by gathering vibration records from the second and fourth stories of the building. The dominant frequencies were obtained as 3.18, 4.42, and 9.51 Hz in Figure 8. The first and third modes of the building are in the X direction, whereas the second mode represents the movement of the building in the Y direction. The fourth mode is disappeared. It is concluded that the removal of the seventh and sixth floors altered the mode shapes of the building and increased the dominant frequency of the building.

5 | MODAL ANALYSES DURING THE GROUND DEMOLISHING

After the number of the story of the building was reduced to five, the demolishing continued with an excavator working on the ground level. It was transported to the backyard of the building where the demolition can progress without

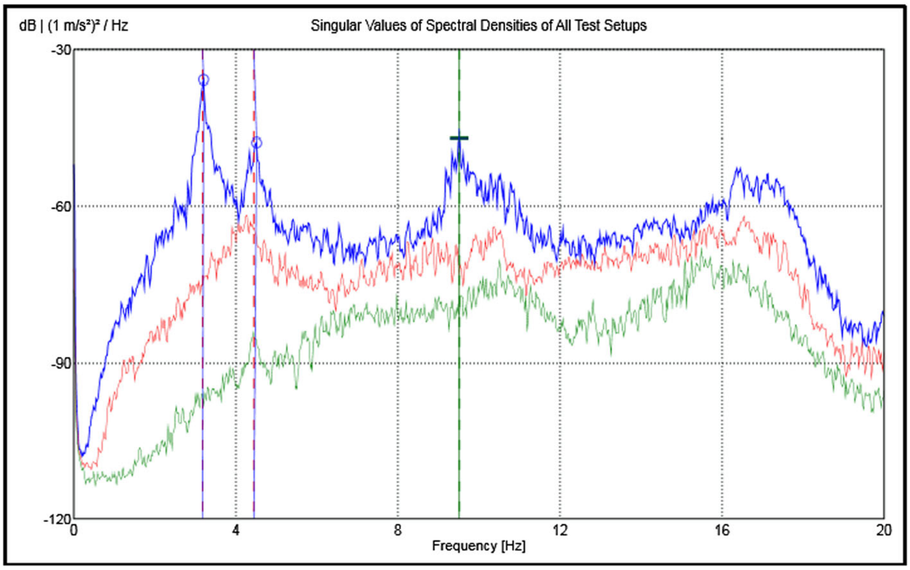

FIGURE 8 Singular values of spectral densities for the five-story building

damaging the neighborhood. The size of the excavator required to cut the right-hand side overhangs of the building on the third-floor level to be transported to the backyard.

5.1 | Modal analysis after first vertical demolishing

After a working day, approximately 20% of the plan area, taking the third floor as the reference, was demolished as seen in Figure 9. The modal analysis was performed in that stage with the measurements gathered from the second and fourth stories of the building. The dominant frequencies were obtained as 3.51, 5.20, and 9.05 Hz as shown in Figure 10. All the dominant frequencies correspond to torsion mode. Therefore, the structural behavior of the building is governed by three torsional modes.

5.2 | Modal analysis after second vertical demolishing

After an additional day, 30% of the plan area of the building was demolished. The present phase of the studied building is shown in Figure 11 with its plan layout on its third floor. The analysis of the measurements, gathered from the second and fourth stories of the building, gave the dominant frequencies as 3.41, 4.77, and 8.74 Hz as seen in Figure 12. Like in the previous form of the building, the dynamic modes were governed by torsional behavior.

FIGURE 9 The studied building after the first ground demolishing

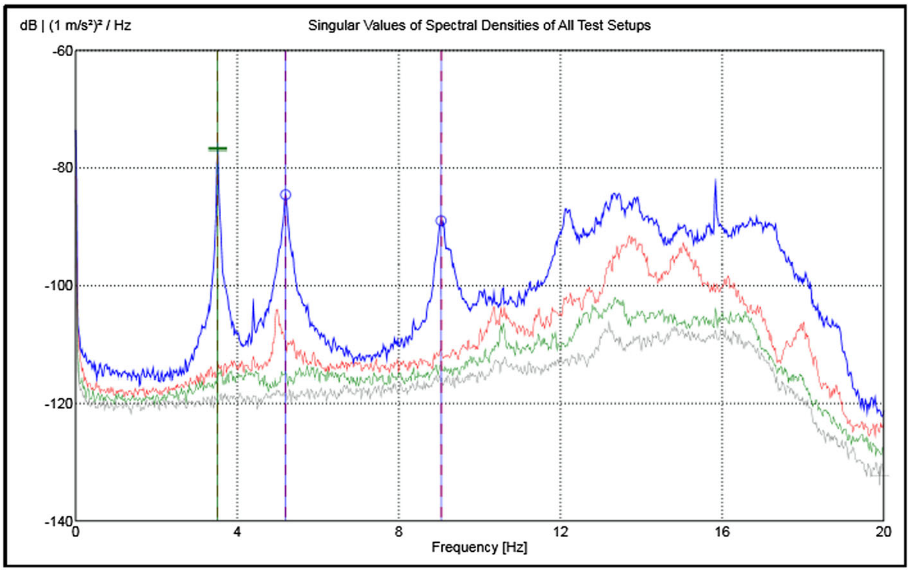

FIGURE 10 Singular values of spectral densities after the first ground demolishing

FIGURE 11 The studied building after the second ground demolishing

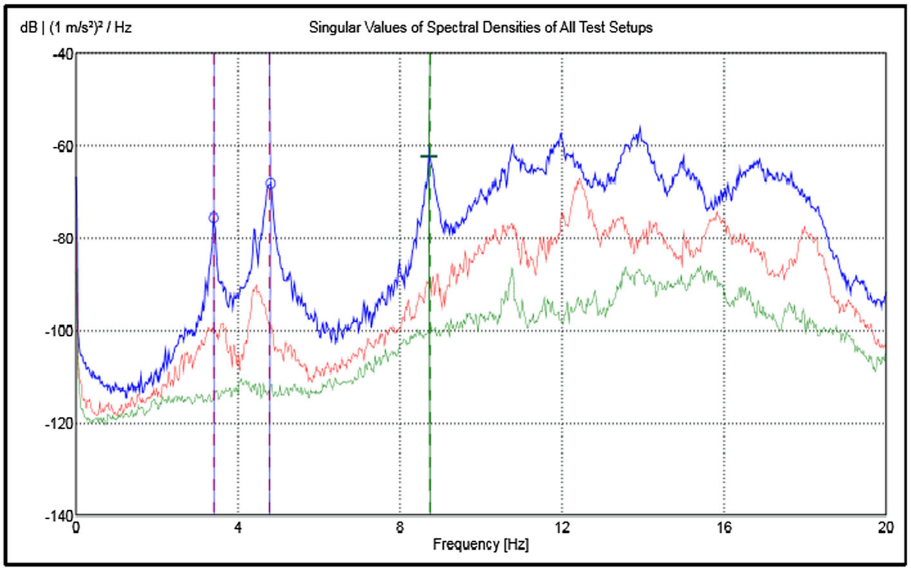

FIGURE 12 Singular values of spectral densities after the second ground demolishing

5.3 | Modal analysis after third vertical demolishing

Almost 50% of the plan area of the building was demolished in the next day. Figure 13 shows the building with its remaining portion. The analysis of the measurements, gathered from the second and fourth stories of the building showed that the number of peaks is increased for the accounted frequency range. In that respect, a furcation phenomenon took place. As seen in Figure 14, 3.15, 4.41, 5.01, 6.86, 7.83, and 9.82 Hz are the dominant frequencies referring to the torsional modes.

5.4 | Modal analysis after fourth vertical demolishing

The last vibration recording is performed when 65% of the plan area of the building was demolished. The building with its plan layout is shown in Figure 15. Because of the broken stairs of the building, the fourth floor could not be reached; thereby, the vibration measurement is performed on the second floor of the building. As seen in Figure 16, the analysis of the measurements revealed the increased number of dominant frequencies as in the previous case. In this stage, singular values of spectral densities are represented for each direction separately in Figure 17 by analyzing the data in Matlab.[37] As it is seen, the dominant frequencies can be detected in both directions separately, referring to a modal displacement also proving the torsional behavior.

FIGURE 13 The studied building after the third ground demolishing

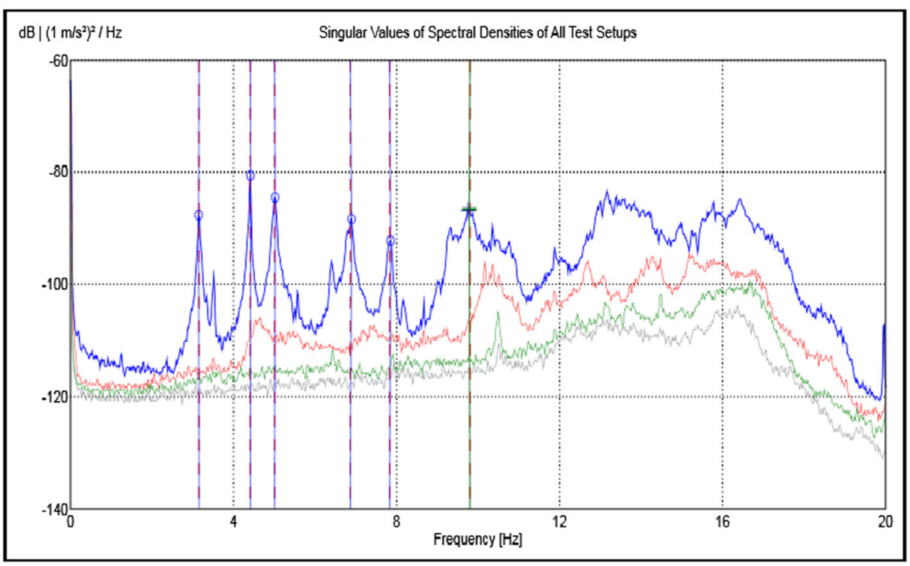

FIGURE 14 Singular values of spectral densities after the third ground demolishing

FIGURE 15 The studied building after the fourth ground demolishing

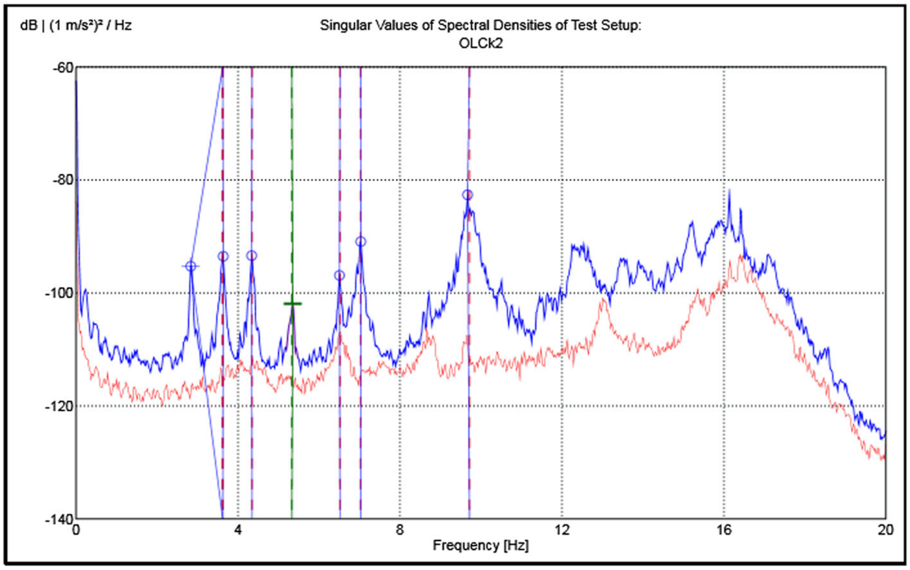

FIGURE 16 Singular values of spectral densities after the fourth ground demolishing

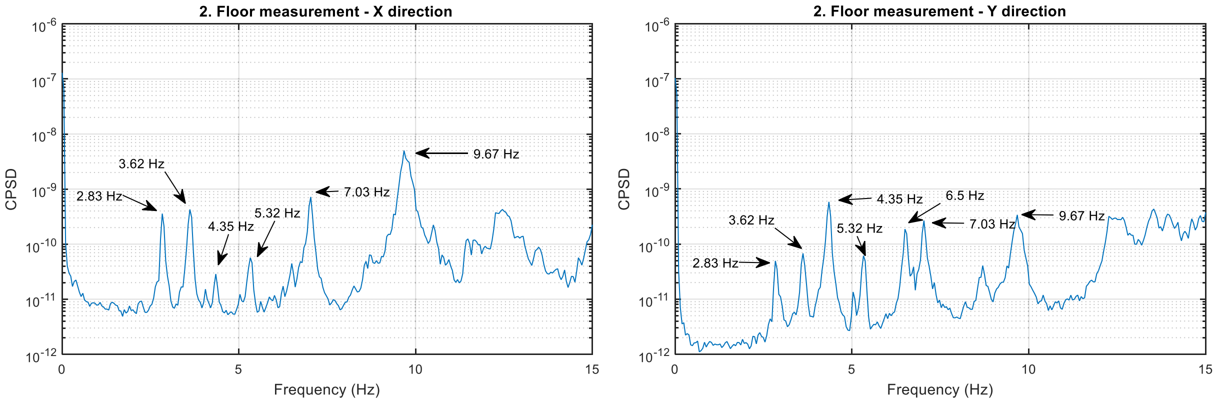

FIGURE 17 Singular values of spectral densities in X and Y directions after the fourth ground demolishing. CPSD, cross power spectral density

6 | EVALUATION OF THE OBTAINED RESULTS

Due to the demolition strategy followed for the studied building, the obtained results were interpreted in two main sections. The first section covers the effects of the number of the story in the dynamic frequencies whereas the second section deals with those obtained from vertical ground demolishing.

6.1 | Frequency variation for story removal

As the result of the story removal, the detected frequency increase was evaluated with the current code formulas shown through Equation (1),[17] Equation (2),[18] Equation (3),[19] Equation (4),[25] and Equation (5).[22] In these formulas, T is the fundamental period of the building, H is the height of the building, N is the number of story, and B is the full plan dimension of the building in the considered direction. For this aim, Table 1 summarizes the numerical values of fundamental periods obtained from experimental analyses and code based formulas. Figure 18 shows how the natural periods of the building vary concerning the number of stories. Note that KBC provides two direction-respective natural periods.

$$T = 0.073\ H^{0.75}\ (\text{UBC}). \tag{1}$$

$$T = 0.0466\ H^{0.9}\ (\text{FEMA 450}). \tag{2}$$

$$T = 0.075\ H^{0.75}\ (\text{Eurocode 8}). \tag{3}$$

$$T = 0.1\ N\ (\text{NBC of Canada}). \tag{4}$$

$$T = 0.09\ \frac{H}{\sqrt{B}}\ (\text{KBC}). \tag{5}$$

As it is seen in Figure 18, UBC,[17] FEMA 450,[18] Eurocode 8,[19] and NBC of Canada[25] values are in the same range. The average of the experimentally obtained values is about 50% of the average of the values estimated by these codes for the

TABLE 1 Comparison of the obtained fundamental periods to those derived from codes

Number of story	Building height (m)	Fundamental periods (s)							
		Experiment—X	Experiment—Y	KBC—X	KBC—Y	UBC	FEMA 450	Eurocode 8	NBC
9	27	0.51	0.37	0.62	0.56	0.86	0.90	0.89	0.90
8	24	0.45	0.33	0.55	0.50	0.79	0.81	0.81	0.80
7	21	0.41	0.28	0.48	0.44	0.72	0.72	0.74	0.70
5	15	0.31	0.22	0.34	0.31	0.56	0.53	0.57	0.50

Abbreviations: FEMA, Federal Emergency Management Agency; KBC, Korean Building Code; NBC, National Building Code; UBC, Uniform Building Code.

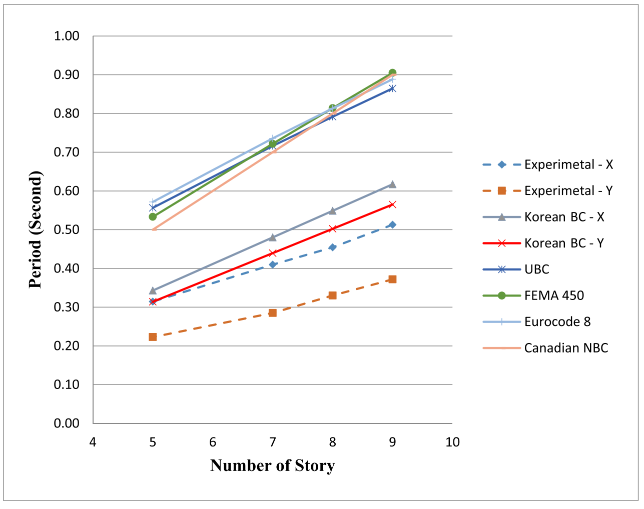

FIGURE 18 Relation between the number of story and fundamental periods. BC, Building Code; FEMA, Federal Emergency Management Agency; NBC, National Building Code; UBC, Uniform Building Code

nine-story building. In other words, these codes doubled the fundamental period of the studied building. On the other hand, KBC[22] estimations separated from the values of other codes and remained closer to the experimental results. Still, it overestimates the real period values. Experimentally obtained natural periods in X and Y directions are 82% and 66% of the values estimated by KBC[22] in X and Y directions, respectively, for the nine-story building.

Empirical code formulas usually overestimate the real fundamental periods of RC buildings. The main reason of this overstatement is the ignorance of infill walls in seismic design of the buildings by the codes.[26,28,38,39] The ambient vibration tests performed for a six-story RC residential building has shown that infill walls can increase the dominant frequencies by 60%.[40] As the non-structural and brittle elements, the infill walls are expected to fail under design earthquake and be ineffective to contribute to the lateral stiffness of RC buildings. For this reason, the codes aim to calculate the period-dependent seismic forces in the absence of infill walls.

On the other hand, the role of infill walls in the seismic design of RC buildings is a complex and versatile subject. The level or frequency of the ground shaking and the stiffness characteristics of the building should be elaborated altogether. Under a frequent or low-magnitude earthquake, the infill walls remain undamaged and contribute the lateral stiffness of the building. In this condition, their ignorance in the period estimation causes miscalculation of seismic forces. This phenomenon is more vital for the performance-based design and assessment philosophy, which require determining the performance of the buildings under different levels of earthquakes. Moreover, overestimated fundamental period can cause overestimated seismic forces for a stiff building while it underestimates seismic forces for a flexible building. For these reasons, for the seismic design of RC buildings, period estimation is a crucial issue.

6.2 | Frequency variation for vertical demolishing

Demolition of the five-story building with an excavator is pursed with vertical slices. Here, impacts are applied, and structural members were broken down. In these stages, the geometry of the building is changed as seen through Figures 9, 11, 13, and 15.

The modal analyses performed after the first and second vertical demolishing showed that the general dynamic behavior of the building is governed by torsion. The main reason for torsional behavior can be shown as the plan geometry of the building. Moreover, it is seen that the first slice caused an increase in the dominant frequencies as compared with the previous phase of the building, which is five-story, unsliced building. On the other hand, the second slice caused a decrease in the dominant frequencies as compared with the first slice. At the stages, the demolishing changes both mass and rigidity of the building, which are two critical parameters for dynamic behavior. For this reason, these results are case dependent. Therefore, it is hard to obtain general conclusions.

The third and fourth slices demolished 50% and 65% of the studied five-story form of the building and caused vital effects on the general dynamic behavior. As seen in Figures 14 and 16, many dominant frequencies are developed by furcating. As proved in Figure 17, these peaks exist in both X and Y directions. In a previously completed study, Aras has monitored construction of a three-story steel building, starting from the erection of structural members to its completion.[41] It was noted that the fast Fourier transform spectrums had many peaks and most of them were mutual until the general building behavior had been formed. After the general building behavior was achieved, the number of peaks in the fast Fourier transform spectrums decreased, and modal frequencies of the building were obtained. Therefore, it can be concluded that, after the third vertical demolishing, the building loses its building behavior.

7 | CONCLUSION

AVS in this study has monitored the demolition of an existing nine-story RC building. The number of the story of the building was first decreased to five by story removal. Then, an excavator-like vehicle working on the ground level razed the remaining five-story building. Dynamic characteristics of the building obtained at the different stages of the demolition and their comparison revealed the facts listed below.

The story reduction has resulted in increases in the dominant frequencies of the building. In parallel, the fundamental periods decreased. An almost linear relationship between the number of the story or building height and fundamental period was derived.

Obtained fundamental periods were compared with those estimated by different codes. It was noted that the code-based periods accounting only the height of buildings are in agreement with each other, but they are approximately two times greater than those extracted from the performed experiments.

The code formulas additionally accounting the geometrical plan dimensions of the building gave closer results to those determined experimentally. However, they are still higher than the experimental results.

For the design of RC buildings, the estimation of the fundamental periods is a crucial issue because the seismic forces are dependent on it. For this reason, overestimation of the fundamental period of RC buildings with the code formulae can cause miscalculation of seismic forces.

The demolition of the building with vertical slices resulted in the change of general building behavior. The general building behavior was turned to torsion governed dynamic modes as a result of the nonrectangular plan layout of the sliced building.

After 50% of the building plan layout was demolished, many dominant frequencies were obtained. This feature is grasped as the signs of losing the stability of the studied building.

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ORCID

Fuat Aras https://orcid.org/0000-0002-2560-4607

REFERENCES

1. Ministry of Environment and Urbanization. *Turkish Earthquake Code: specification for structures to be built in disaster areas*. Ankara, Turkey; 2007.
2. Ministry of Environment and Urbanization. *Turkish Earthquake Code: specification for the design of buildings under earthquake effect*. Ankara, Turkey; 2018.
3. Turkish Republic. LTADR: The Law about the Transformation of the Areas under Disaster Risk. Law No: 6306, Date: 31.05.2012. Official Gazette of Turkish Republic. 2012. Available on: http://webdosya.csb.gov.tr/db/altyapi/editordosya/6306 SAYILI KANUN-degisiklik islenmis son hali.pdf
4. Akbal E. Fazilet Apartmanı, Riskli Bina Tespit Raporu İnceleme Formu, Çevre ve Şehircilik Bakanlığı. 2017.
5. Trifunac MD. Comparisons between ambient and forced vibration experiments. *Earthq Eng Struct D*. 1972;1(2):133-150. https://doi.org/10.1002/eqe.4290010203
6. Crowley H, Pinho R. Period-height relationship for existing European reinforced concrete buildings. *J Earthq Eng*. 2004;8(spec01):93-119.
7. Gutenberg B. Microseisms. *Adv Geophys*. 1958;5:53-92.
8. Asten M, Henstridge J. Array estimators and the use of microseisms for reconnaissance of sedimentary basins. *Geophysics*. 1984;49(11):1828-1837. https://doi.org/10.1190/1.1441596
9. Bonnefoy-Claudet S, Cotton F, Bard PY. The nature of noise wavefield and its applications for site effects studies: a literature review. *Earth Sci Rev*. 2006;79(3):205-227.
10. Guler K, Yuksel E, Kocak A. Estimation of the fundamental vibration period of existing RC buildings in Turkey utilizing ambient vibration records. *J Earthq Eng*. 2008;12(S2):140-150.
11. Aras F. Ambient and forced vibration testing with numerical identification for RC buildings. *Earthq Struct*. 2016;11(5):809-822. https://doi.org/10.12989/eas.2016.11.5.809
12. Bayraktar A, Altunişik AC, Birinci F, Sevim B, Türker T. Finite-element analysis and vibration testing of a two-span masonry arch bridge. *J Perform Constr Fac*. 2010;24(1):46-52. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000060
13. Aras F, Altay G. Investigation of mechanical properties of masonry in historic buildings. *Gradev*. 2015;67(5):461-469.
14. Sevim B, Altunışık AC, Bayraktar A. Earthquake behavior of Berke arch dam using ambient vibration test results. *J Perform Constr Fac*. 2012;26(6):780-792. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000264
15. Soyöz S, Taciroğlu E, Orakçal K, et al. Ambient and forced vibration testing of a reinforced concrete building before and after its seismic retrofitting. *J Struct Eng*. 2013;139(10):1741-1752. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000568
16. Catbas FN, Lenett M, Aktan AE, Brown DL, Helmicki AJ, Hunt VJ. "Damage detection and condition assessment of Seymour Bridge," In Proceedings of the 16th International Modal Analysis Conference, Santa Barbara, CA. 1998; 1694-1702.

17. International Conference of Building Officials. Uniform building code. California, Wilier. 1997.
18. Federal Emergency Management Agency. FEMA 450. NEHRP recommended provisions for seismic regulations for new buildings and other structures. Part 1: provisions. Washington (DC). 2003.
19. Comité Européen de Normalisation. Eurocode 8: design of structures for earthquakes resistance – Part 1: general rules, seismic actions and rules for buildings. Pr-EN 1998-1 Final Draft. 2003.
20. Swiss Society of Engineers and Architects. SIA 261: Swiss code, actions on structures. 2003.
21. Algeriennes RP. *RPA-88: regulation of Algerian seismic code*. Algiers: Publication OPU; 1988.
22. Korean Ministry of Construction. *National Building Code of Korea (KBC)*. Seoul: Korean Ministry of Construction; 1988.
23. Lee LH, Chang K-K, Chun YS. Experimental formula for the fundamental period of RC buildings with shear-wall dominant systems. *Struct Des Tall Buil*. 2000;9(4):295-307. https://doi.org/10.1002/1099-1794(200009)9:4<295::AID-TAL153>3.0.CO;2-9
24. Règles de construction parasismique. PS92 DR. DTU Rgles PS92. 1995.
25. The National Building Code (NBC). National Research Council, Canada. 1995.
26. Salameh C, Guillier B, Harb J, et al. Seismic response of Beirut (Lebanon) buildings: instrumental results from ambient vibrations. *B Earthq Eng*. 2016;14(10):2705-2730. https://doi.org/10.1007/s10518-016-9920-9
27. Crowley H, Pinho R. Revisiting Eurocode 8 formulae for periods of vibration and their employment in linear seismic analysis. *Earthq Eng Struct D*. 2010;39(2):223-235.
28. Kose MM. Parameters affecting the fundamental period of RC buildings with infill walls. *Eng Struct*. 2009;31(1):93-102. https://doi.org/10.1016/j.engstruct.2008.07.017
29. Chopra AK, Goel RK. Period formulas for moment-resisting frame buildings. *J Struct Eng*. 1997;123(11):533_6.
30. Hong L, Hwang W. Empirical formula for fundamental vibration periods of reinforced concrete buildings in Taiwan. *Earthq Eng Struct D*. 2000;29(3):327-337. https://doi.org/10.1002/(SICI)1096-9845(200003)29:3<327::AID-EQE907>3.0.CO;2-0
31. Amanat KM, Hoque E. A rationale for determining the natural period of RC building frames having infill. *Eng Struct*. 2006;28(4):495-502.
32. Artemis Modal Software
33. Brincker R, Zhang L, Andersen P. Modal identification from ambient responses using frequency domain decomposition. In: *Proceedings of The 18th International Modal Analysis Conference (IMAC)*. San Antonio, Texas; 2000:625-630.
34. Brincker R, Andersen P, Jacobsen NJ. Automated frequency domain decomposition for operational modal analysis. In: *Proceedings of The 25th International Modal Analysis Conference (IMAC)*; 2007.
35. Michel C, Gueguen P, Bard PY. Dynamic parameters of structures extracted from ambient vibration measurements: an aid for the seismic vulnerability assessment of existing buildings in moderate seismic hazard regions. *Soil Dyn Earthq Eng*. 2008;28(8):593-604. https://doi.org/10.1016/j.soildyn.2007.10.002
36. Allemang RJ. The modal assurance criterion – twenty years of use and abuse. *Sound Vib*. 2003;37(8):14-23.
37. Matlab. *The MathWorks, Inc., Natick*. Massachusetts: United States; 2012.
38. Perrone D, Leone M, Aiello MA. Evaluation of the infill influence on the elastic period of existing RC frames. *Eng Struct*. 2016;123:419-433. https://doi.org/10.1016/j.engstruct.2016.05.050
39. Ricci P, Mario Verderame GM, Manfred G. Analytical investigation of elastic period of infilled RC MRF buildings. *Eng Struct*. 2011;33(2):308-319. https://doi.org/10.1016/j.engstruct.2010.10.009
40. Aras F. Betonarme binalarda bölme duvar etkilerinin tam ölçekli deneylerle araştirilmasi. *Tek Dergi*. 2018;29(5):8651-8668.
41. Aras F. Frequency variation in construction stages and model validation for steel buildings. *Steel Compos Struct*. 2016;22(3):647-662. https://doi.org/10.12989/scs.2016.22.3.647

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