




Research Article

Evaluation of the period and soft story conditions of reinforced concrete buildings with and without infill walls

Başak Zengin^a 

^a Department of Construction Technology, Elbistan Vocational High School, Kahramanmaraş İstiklal University, 46340 Kahramanmaraş, Turkey

ABSTRACT

Since the ground floor of most of the buildings in our country is designed as a shop or ground floor (in the buildings created as a workplace), there is very little infill wall ratio on the ground floors due to architectural and functional reasons, and some of them do not even exist at all. However, infill walls significantly increase the horizontal rigidity and strength of the structure, thus causing a decrease in the period value that determines the earthquake loads that will affect the structure. However, the infill wall meets the first destructive forces of the earthquake, and during this time, it cracks and absorbs some of the earthquake energy. The structural system elements of the building (columns and shear walls) start to meet the earthquake forces only when the infill walls are damaged and fail. In this direction, the aim of this study is to investigate to what extent the amount of infill wall on the ground floor affects the period of the building, and whether there are soft storey irregularities in the building according to the change in the amount of infill wall on the ground floor. In this study, while there are infill walls on all floors and all axes of buildings of various heights (3, 6, 9 and 11 floors), the amount of infill walls in the x and y directions on the ground floors is reduced to a certain extent, and many models are created until the ground floor is completely without infill walls. All these models created were analyzed with the support of the SAP2000 program, and the period values were determined and examined according to the soft storey problems and compared with the case of the entire building with and without infill walls. In addition, it was examined whether the period formulas determined as a result of the studies and taking into account the infill wall give realistic results for the situation examined in this study.

ARTICLE INFO

Article history:

Received 8 July 2021

Revised 16 August 2021

Accepted 22 August 2021

Keywords:

Reinforced concrete buildings

Infill wall

Period

Soft storey irregularities

1. Introduction

Today, in the design and analysis of buildings, the effects of infill walls, which are defined as non-structural elements, on building behavior are often neglected. However, infill walls have properties that affect dynamic characteristics such as mode shape, damping and vibration period in buildings. In addition, the fact that the contribution of the infill walls to the horizontal rigidity is not taken into account in the calculations gives rise to the thought of staying on the safe side, the distribution and ratio of the infill walls in the floor; It can cause some negativities such as torsional irregularity, short column, soft

storey irregularity (Köse and Karşlıoğlu 2007; Kose 2009). For this reason, infill walls should be considered during the design and analysis of buildings in order to obtain the true structural behavior.

This increase in stiffness during an earthquake can increase the base shear force demand of the structure and cause greater earthquake forces to act on the structure. Damages in infill walls mean the damping of earthquake energy, which requires infill walls to be taken into account in analytical models. In the literature study, it has been seen that there are many studies that reveal the effect of infill walls on the earthquake behavior of reinforced concrete buildings. The approaches proposed by

* Corresponding author. E-mail address: basak.zengin@istiklal.edu.tr (B. Zengin)

TEC-2007 and Hendry were used to model infill walls with equivalent pressure bar. As a result of the study, it was determined that the infill walls changed the rigidity of the structure, thus reducing the period, relative story drift and shear force on the columns, and increasing the base shear force (Sağlıyan, 2018).

In the research of Akyürek et al. (2018), residential type reinforced concrete buildings with different number of spans and floors were chosen as models. The seismic performance of these buildings, which are designed with and without infill walls, was made using the linear inelastic evaluation method. The effects of infill wall amount and placement change on the building's capacity curve, first natural period, target displacement request, damage distribution of the first-floor columns, and building performance level were examined on the selected buildings. The results showed that the infill wall placement significantly affects the building behavior. Therefore, in order to obtain more accurate results in describing the earthquake performance of buildings, infill walls should be taken into account in the analysis. That is also important to emphasize the importance of correctly defining the characteristics of the infill wall (Akyürek et al., 2018).

By Furtado et al. (2017), it is emphasized that most of the damages in reinforced concrete buildings in earthquake zones are caused by infill walls, infill walls significantly affect the earthquake behavior of the building and cause different collapse mechanisms in the building. For this reason, an experimental study was carried out in order to observe in-plane and out-of-plane infill wall damages. In the report published as a result of the Van-Edremit earthquake that took place in 2011, it is stated that in the case of structures with infill walls made of hollow bricks, if the drift ratio between floors exceeds approximately 0.5% - 0.7%, the partition walls are crushed and/or toppled out of its plane, and as a result, the damage observed in the structural system increases. Koçak (2013) investigated the short column damages caused by infill walls in a reinforced concrete building damaged in the 1992 Erzincan earthquake.

By Ning et al. (2017), as a result of the analytical studies they carried out to investigate the effects of infill walls used in buildings on the performance of load-bearing system elements, they determined that infill walls affect the collapse mechanisms of buildings and plastic hinge positions. Qian and Li (2017) investigated the effects of infill wall on the failure mechanisms and load-displacement curves of the frames in their experimental studies on infilled and non-infilled frames. Asteris et al. (2011) and Asteris (2003) presented a reduction parameter to the equivalent pressure bars, which are widely used in the modeling of infill walls in the literature, in order to reflect the voids in the infill walls. For this purpose, they used analytical models that they updated according to the data obtained from various experimental studies. In the study of Güler et al. (2008), effect of infill wall on the building period was studied and they considered a twelve-storey building without infill wall, with infill wall (unplastered) and infill wall (plastered). Using the microtremor (small vibration measurements) method, for all these cases, they found the periods of the

structure in small ground motion (not taking into account the earthquake effect) in the two earthquake directions.

In Borekçi's study (2019), the dominant period of a building consisting of 6-storey reinforced concrete frames, which is thought to represent the building stock in Turkey, was obtained both analytically and directly by formulas by modeling in the SAP2000 program. In this study, in which the building periods are obtained with two different models, with and without walls, the approaches of the proposed formulas in obtaining the period and how much they take into account the wall effect were investigated. In buildings with few floors and no irregularities, the dominant mode is the translation mode, and it is possible to consider such buildings as a single degree of freedom. Since a single mode can be used in the design of buildings under seismic loads whose displacement mode can be considered as dominant and equivalent single degree of freedom, it will be sufficient to obtain only the period of this mode. Direct formulas that will help to obtain this period quickly without the need for long calculations have been proposed in various studies in the literature. Walls are built in order to create rooms in buildings and it is clear that these walls will change the period with their contribution to rigidity. However, during the design, the contribution of the walls to the rigidity is neglected and only the weight is taken into account. While some of the direct formulas proposed in the literature to obtain the period do not take into account the effect of the wall, some take into account the contribution of the wall stiffness.

In the modeling studies on infill walls, the properties of the materials or the form of construction caused differences in the period. By Lemonis et al. (2019), the proposed model was evaluated parametrically against the numerical results obtained from the frame analyzes with varying number of frame plies, infill openings, wall thickness and modulus of elasticity. Evaluation of the proposed model was performed against regular frames with uniform infill properties across all of its panels. No deterioration in filling properties was observed. They found that more research is needed for frames with irregularities in their structural form or walls, particularly where a soft ply is created. In Asteris et al.'s study (2015), this article examines the foundation vibration period of reinforced concrete buildings through finite element macro modeling and modal eigenvalue analysis. As a baseline study, a large number of 14-storey reinforced concrete buildings were rated as "designed according to code" and "not designed according to code". Various parameters were examined, including the number of apertures; span length in the direction of movement; hardness of fillings; percentage openings of fillings and; location of soft floors. The calculated values of the fundamental period are compared with the values obtained from the seismic codes and equations proposed by various researchers in the literature. From the analysis of the results, it has been found that the span length, the stiffness of the infill wall panels and the position of the soft floors are very important parameters that affect the foundation period of reinforced concrete buildings. In a different study by Asteris (2015), it was found that the number of

floors, span length, rigidity of infill wall panels, location of soft floors and floor type are very important parameters that affect the foundation period of reinforced concrete buildings. Asteris further developed his research (2016, 2019) and estimated the base periods with neural network support. By Asteris (2017), effect of the number of floors, number of spans, span length, infill wall panel stiffness and percentage of openings in the infill panel on the foundation period of infilled reinforced concrete frames were investigated. Based on these results, a regression analysis is applied to propose a new empirical equation for the estimation of the fundamental period. The derived equation has been shown to be better. Predictive power compared to equations are available in the literature.

The aim of the present work is to investigate the period of vibration of 3, 6, 9 and 11 floors-storey bare and infilled RC frame building by means of finite element modelling under various geometric and other parameters, including the influence of the number of storey, the floor irregularities as well as the soft storey position.

2. Material and Method

In this section, the effects of the changes in the ratio of the infill walls on the ground floor on the period of the building in infilled buildings are examined. As a result of the analyzes made on building models with different heights and different sizes of load-bearing systems, varying period values depending on the rate of change of the infill wall on the ground floor were obtained, these values were interpreted and compared with the results obtained from the period formulas considering the infill wall (Fig. 1).

The axial stiffness of the crossbars was determined by Ersin's (1997) formula for the axial stiffness of infill walls. In this study, while determining the axial stiffness of the crossbars, window openings on the outer walls and door openings on the inner walls were taken into account, and parameters such as the plastered infill wall elasticity modulus, wall thickness, and the length of the cross were used.

$$w = \alpha \cdot L_d \quad (1)$$

where E is the elastic modulus of the wall, t is the thickness of the wall, and w is the width of the wall.

$$EF = E \cdot t \cdot \alpha \cdot L_d \quad (2)$$

where L_d is the diagonal length of the infill wall, and α is the coefficient that allows the pendulum bar width to be defined according to the infill wall diagonal length.

This expression is multiplied by a factor such as β to include void infill walls and γ to take all other effects into account.

$$EF = E \cdot t \cdot \alpha \cdot L_d \cdot \beta \cdot \gamma \quad (3)$$

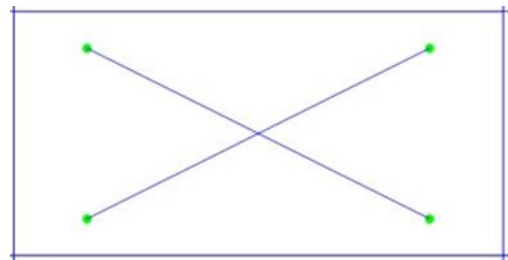


Fig. 1. A pair of articulated crossbars representing the infill wall.

In the four different building models created, the infill walls on the ground floor were reduced at certain rates, and analyzes of the models in each case were examined in detail. As a result of these analyzes, the relationships between this change of the infill wall on the ground floor and the period values, soft storey irregularity were evaluated.

2.1. Features of the created carrier systems

The plan views of the four different (3, 6, 9, 11 storey) mechanical building models are the same, but the building heights are different. The floor thickness is fixed in each building model and on each floor and is 15 cm. Concrete class C25 and reinforced concrete steel class S420 concrete were used in all structures. Floor heights in all buildings are fixed and 3 m. All four building models have 4 openings in the x direction and 5 openings in the y direction (Table 1).

Table 1. Building elements case.

Building	Storey	Square Column	Rectangle Column	Beam
3 Storey	1. 2.	45/45	40/45	35/40
	3.	40/40	40/40	35/40
6 Storey	1. 2.	55/55	40/55	35/55
	3. 4.	50/50	40/50	35/50
	5. 6.	45/45	40/45	35/45
9 Storey	1. 2. 3.	55/55	40/55	35/55
	4. 5. 6.	50/50	40/50	35/50
	7. 8. 9.	45/45	40/45	35/45
11 Storey	1. 2. 3.	60/60	40/60	35/60
	4. 5. 6.	55/55	40/55	35/55
	7. 8. 9.	50/50	40/50	35/50
	10. 11.	45/45	40/45	35/45

The ground periods used in the spectral analysis of all these models were taken as $Ta=0.15$ and $Tb=0.40$. In this model, in which infill walls are not included in the mechanical model, equivalent cross-pressure bars represented by infill walls are placed, and the fully infill wall model in Fig. 2 is created.

From the completely infilled model created in each building model, new models were created by reducing the infill wall areas only on the ground floor, and the analyses were repeated.

2.2. No infill wall in the system (bare frame)

In this model, the entire building is designed without infill walls and any element representing the infill wall is not reflected in the mechanical model (Fig. 3).

In this model, the entire building is designed with infill walls, and the elements representing the infill wall with spaces (door, window) on each axis in the x and y directions are reflected in the mechanical model (Figs. 4 and 5).

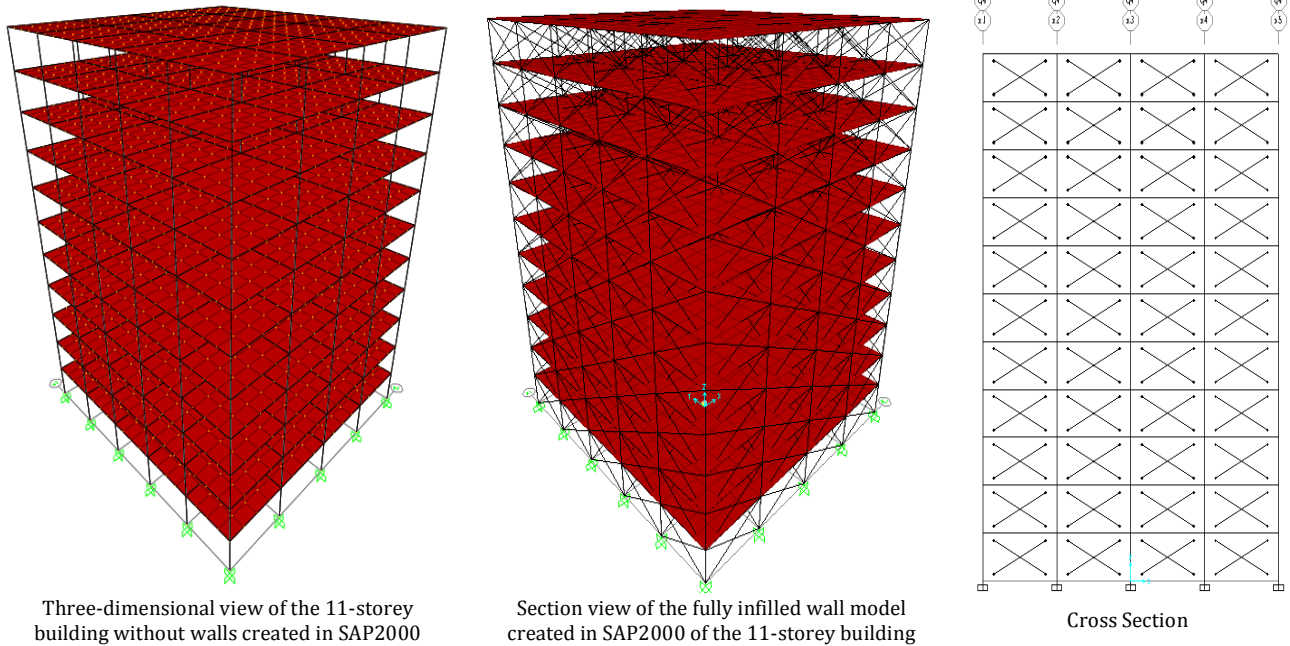


Fig. 2. Storey building of modelling image.

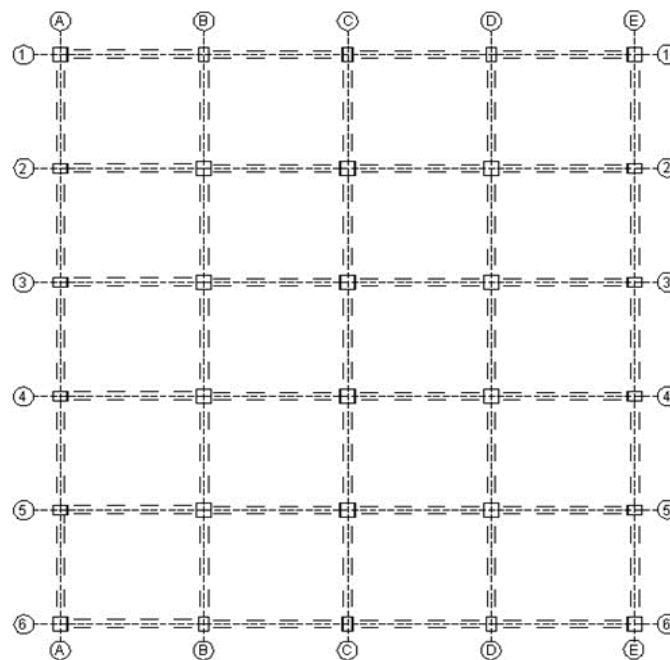


Fig. 3. No walls in the building plan.

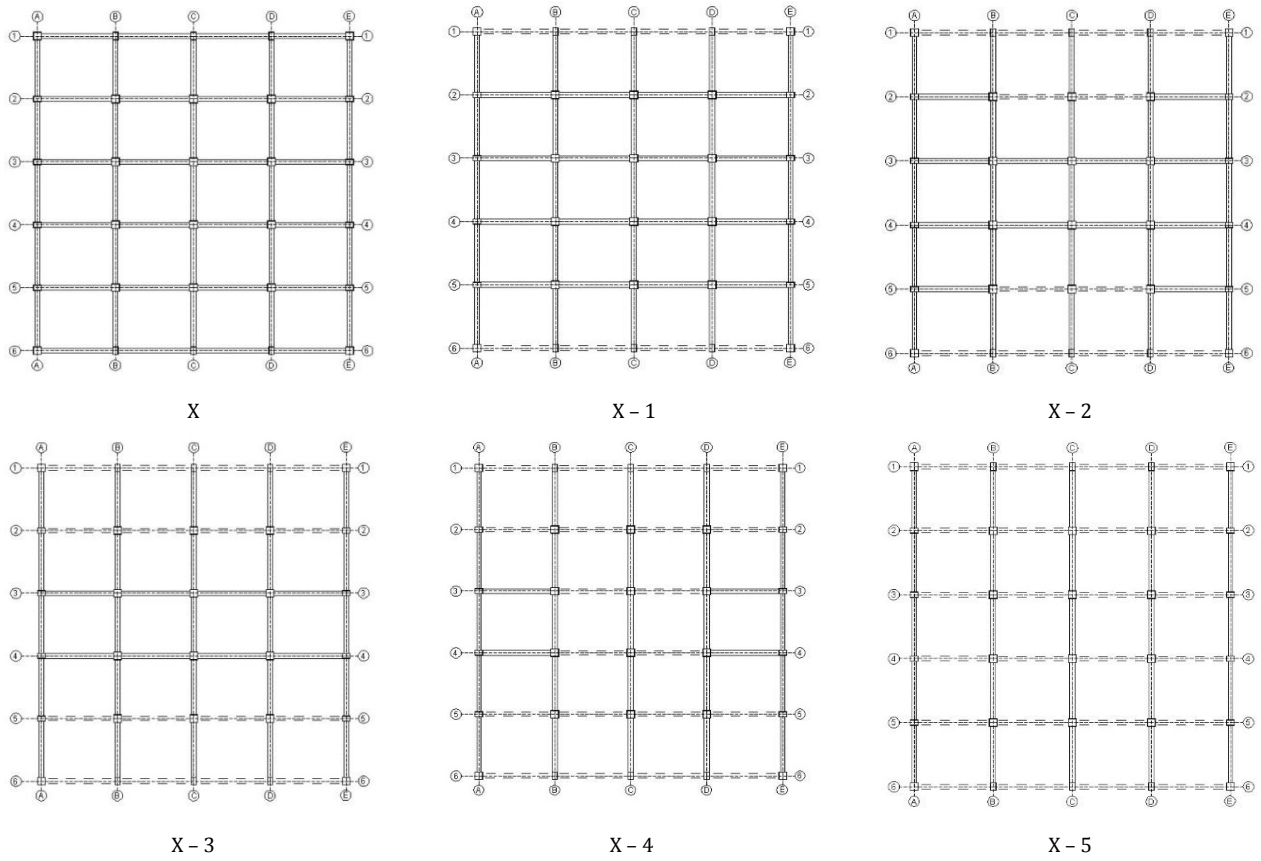


Fig. 4. The case of infill walls in all of the building frames (plan image x-x).

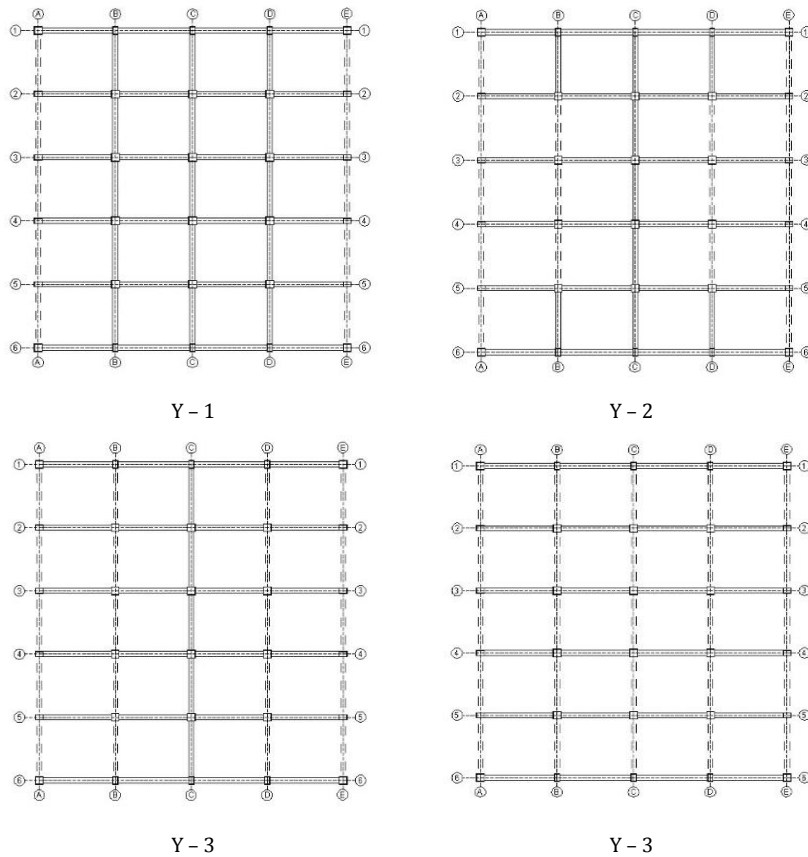


Fig. 5. The case of infill walls in all of the building frames (plan image y-y).

In this model, the absence of infill walls in all of the A and E axes in the y-y direction only on the ground floor is reflected in the model. Except for the ground floor, the plan views of all floors are the same as the plan view of the fully infilled model. The ground floor plan view is as in Fig. 5.

3. Investigation of the Period Values of the Models Created

3.1. Examining the analysis results

Analysis results for 3, 6, 9 and 11 storey buildings show that; the period of the entire structure with infill walls is much smaller than the period when the structure is completely without infill walls (bare frame). In addition, it is seen that the decrease in the infill wall ratios in

the x and y directions only on the ground floor increases the periods of the building in the x and y directions (although not as much as the periods in the bare frame situation). As a result of this period change, it is seen that the period decreases rates compared to the bare frame decrease due to this decrease as the amount of infill wall decreases on the ground floor. Below is the graph showing the period decrease rates in all cases, which express the change in the amount of infill walls on the ground floors of the 3, 6, 9 and 11 storey buildings, depending on A_k (infill wall/ (infill wall + load-bearing system)).

As can be seen from the Fig. 6 graph, the change in the amount of infill wall on the ground floor mostly affects the period of 3-storey buildings, while this effect is very low in 11-storey structures. In other words, as the number of floors increases, the effect of the infill wall reductions on the ground floor to increase the period of the building decreases.

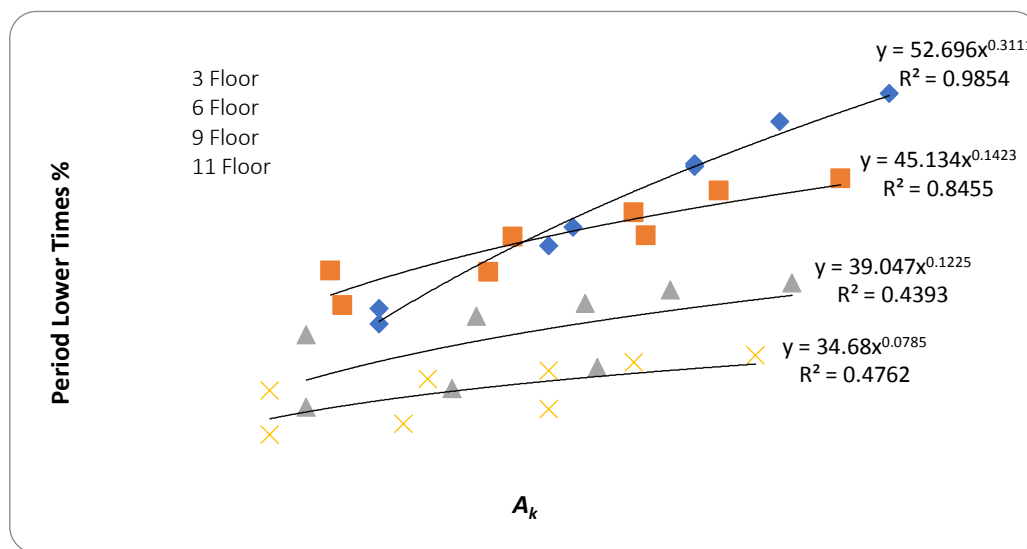


Fig. 6. Relationship between reduction of infill wall area and period reduction in all buildings.

The comparison of the period values obtained from this study with the formulas obtained in other studies is given in Table 2. While the period values obtained as a result of the formula obtained by the infill walls depending on the change in all floors give the same result for the bare frame and all-walled cases, they give higher results than the period values obtained depending on the reduction amount of the infill wall on the ground floor. This result is quite natural since the change of the infill wall only on the ground floor cannot be compared with the change in the amount of infill wall on all floors. The period values obtained as a result of the infill wall reduction on the ground floor are slightly larger than the period values in the completely walled condition, except for the 3-storey building. The results obtained from the other period formulas that take into account the infill wall, on the other hand, are closer to (slightly lower than these periods) the periods of the buildings in the bare frame condition. From these results, it is understood that using the period formulas that take into account the proposed infill wall will not give realistic results for cases where the infill wall is reduced only on the ground floor.

Investigation of soft storey irregularity formation conditions of the created models provides analysis results for 3-storey building in Table 3.

Cases of soft floor irregularities of buildings;

If $\eta_{Ci} = (\Sigma A_e)_i / (\Sigma A_e)_{i+1} < 0.80$, there is soft storey irregularity.

Definition of effective cutting area on any floor:

$$\Sigma A_e = \Sigma A_w + \Sigma A_g + 0.15 \Sigma A_k \tag{4}$$

where η_{Ci} is the strength irregularity coefficient defined at *i*th floor, ΣA_e is the effective shear area at any floor in the direction of the earthquake under consideration, A_w is the effective area of the column cross-section (excluding the area of the column projections perpendicular to the earthquake), ΣA_w is the sum of effective body areas A_{ws} of column cross-section at any storey, ΣA_g is the sum of the cross-sectional areas of the structural system elements operating as a shear parallel to the earthquake direction considered at any floor, and ΣA_k is the sum of the masonry infill wall areas (excluding door and window spaces) parallel to the earthquake direction considered at any floor.

Table 2. Period comparison.

	Study	Study		Koçak et al. (2011, 2018)		Guler et al. (2008)	TEC-1998	UBC-1997	Goel and Chopra (1997)	
		T_x	T_y	T_x	T_y				Lower Limit	Top Limit
3 Storey	Frame	0.476	0.447	0.476	0.447					
	Frame+Wall	0.251	0.244	0.247	0.245					
3 Storey XX direction	X-1	0.258	0.244	0.279	0.245					
	X-2	0.269	0.244	0.304	0.245					
	X-3	0.284	0.244	0.338	0.245					
	X-4	0.304	0.244	0.392	0.245	0.329	0.364	0.38	0.34	0.484
	X-5	0.333	0.244	0.476	0.245					
3 Storey YY direction	Y1	0.251	0.252	0.247	0.285					
	Y2	0.251	0.271	0.247	0.324					
	Y3	0.251	0.289	0.247	0.368					
6 Storey	Y4	0.251	0.324	0.247	0.447					
	Frame	0.798	0.744	0.798	0.744					
6 Storey XX direction	Frame+Wall	0.456	0.440	0.438	0.430					
	X-1	0.461	0.440	0.497	0.430					
	X-2	0.470	0.440	0.538	0.430					
	X-3	0.480	0.440	0.596	0.430					
	X-4	0.494	0.440	0.680	0.430	0.619	0.612	0.639	0.634	0.903
6 Storey YY direction	X-5	0.513	0.440	0.798	0.430					
	Y1	0.456	0.447	0.438	0.496					
	Y2	0.456	0.461	0.438	0.566					
	Y3	0.456	0.474	0.438	0.628					
9 Storey	Y4	0.456	0.496	0.438	0.744					
	Frame	1.038	0.934	1.038	0.934					
9 Storey XX direction	Frame+Wall	0.649	0.619	0.600	0.561					
	X-1	0.653	0.619	0.677	0.561					
	X-2	0.660	0.619	0.730	0.561					
	X-3	0.667	0.619	0.797	0.561					
	X-4	0.677	0.619	0.898	0.561	0.884	0.829	0.866	0.913	1.301
9 Storey YY direction	X-5	0.689	0.619	1.038	0.561					
	Y1	0.649	0.625	0.600	0.650					
	Y2	0.649	0.635	0.600	0.731					
	Y3	0.649	0.644	0.600	0.808					
11 Storey	Y4	0.649	0.659	0.600	0.934					
	Frame	1.151	1.070	1.151	1.070					
11 Storey XX direc- tion	Frame+Wall	0.763	0.735	0.691	0.674					
	X-1	0.767	0.735	0.776	0.674					
	X-2	0.767	0.735	0.835	0.674					
	X-3	0.772	0.735	0.917	0.674					
	X-4	0.777	0.735	1.019	0.674	1.058	0.964	1.006	1.093	1.559
11 Storey YY direc- tion	X-5	0.792	0.735	1.151	0.674					
	Y1	0.764	0.739	0.691	0.776					
	Y2	0.764	0.747	0.691	0.867					
	Y3	0.764	0.753	0.691	0.947					
	Y4	0.764	0.762	0.691	1.070					

In Table 3, the strength irregularity coefficients of the ground floor of all models created for the 3-storey building are given. When the results are examined, it is seen that these coefficients decrease in the x and y directions due to the reduction of the infill wall in the x and y directions. It is seen that the strength irregularity coefficients take the values of 0.785, 0.742, 0.771, (0.742 and 0.771) respectively in the X-4, X-5, Y-4th and ground floor un-walled cases, and it is understood that soft storey irregularity occurs in these models.

In Table 4, the strength irregularity coefficients of the ground floor for all models created for the 6-storey building are given. When the results are examined, it is seen that these coefficients decrease in the x and y directions due to the reduction of the infill wall in the x and y directions. It is seen that the strength irregularity coefficients take the value of 0.774 in both the X-5th and ground floor un-walled cases, and it is understood that weak floor irregularity occurs in these models.

Table 3. Analysis results of 3-storey building models.

Cases		ΣA_w (m ²)	ΣA_k (m ²) (X Direction)	ΣA_k (m ²) (Y Direction)	ΣA_e (m ²) (X Direction)	ΣA_e (m ²) (Y Direction)	η_{c1} (X Direction)	η_{c1} (Y Direction)	Soft Storey Irregularity
Ground Storey	Frame+Wall	5.76	13.35	11.42	77.625	7.473	1.000	1.000	No
	X-1	5.76	8.88	11.42	7.092	7.473	0.914	1.000	No
	X-2	5.76	6.66	11.42	6.759	7.473	0.871	1.000	No
	X-3	5.76	4.44	11.42	6.426	7.473	0.828	1.000	No
	X-4	5.76	2.22	11.42	6.093	7.473	0.785	1.000	Available
	X-5	5.76	0	11.42	5.760	7.473	0.742	1.000	Var
	Y-1	5.76	13.35	6.83	77.625	67.845	1.000	0.908	No
	Y-2.	5.76	13.35	4.10	77.625	6.375	1.000	0.853	No
	Y-3	5.76	13.35	2.28	77.625	6.102	1.000	0.817	No
	Y-4	5.76	13.35	0	77.625	5.760	1.000	0.771	Available
	Non Wall	5.76	0	0	5.760	5.760	0.742	0.771	Available
	Frame	5.76	0	0	5.760	5.760	1.000	1.000	No
First Storey	Frame+Wall	5.76	13.35	11.42	77.625	7.473	-	-	-
	Frame	5.76	0	0	5.760	5.760	-	-	-

Table 4. Analysis results of 6-storey building models.

Cases		ΣA_w (m ²)	ΣA_k (m ²) (X Direction)	ΣA_k (m ²) (Y Direction)	ΣA_e (m ²) (X Direction)	ΣA_e (m ²) (Y Direction)	η_{c1} (X Direction)	η_{c1} (Y Direction)	Soft Storey Irregularity
Ground Storey	Frame+Wall	6.8	13.26	11.33	8.789	84.995	1.000	1.000	No
	X-1	6.8	8.8	11.33	8.120	84.995	0.924	1.000	No
	X-2	6.8	6.6	11.33	7.790	84.995	0.886	1.000	No
	X-3	6.8	4.4	11.33	7.460	84.995	0.849	1.000	No
	X-4	6.8	2.2	11.33	7.130	84.995	0.811	1.000	No
	X-5	6.8	0	11.33	6.800	84.995	0.774	1.000	Available
	Y-1	6.8	13.26	6.75	8.789	78.125	1.000	0.919	No
	Y-2.	6.8	13.26	4.05	8.789	74.075	1.000	0.872	No
	Y-3	6.8	13.26	2.25	8.789	71.375	1.000	0.840	No
	Y-4	6.8	13.26	0	8.789	6.800	1.000	0.800	No
	Non Wall	6.8	0	0	6.800	6.800	0.774	0.800	Available
	Frame	6.8	0	0	6.800	6.800	1.000	1.000	No
First Storey	Frame+Wall	6.8	13.26	11.33	8.789	84.995	-	-	-
	Frame	6.8	0	0	6.800	6.800	-	-	-

In Table 5, the strength irregularity coefficients of the ground floor for all models created for the 9-storey building are given. When the results are examined, it is seen that these coefficients decrease in the x and y directions due to the reduction of the infill wall in the x and y directions. It is seen that none of the strength irregularity coefficients are less than 0.8, and it is understood that weak story irregularity does not occur in any of these cases.

In Table 6, the strength irregularity coefficients of the ground floor for all models created for the 11-storey building are given. When the results are examined, it is seen that these coefficients decrease in the x and y directions due to the reduction of the infill wall in the x and y directions. It is seen that none of the strength irregularity coefficients are less than 0.8, and it is understood that weak story irregularity does not occur in any of these cases.

Table 5. Analysis results of 9-storey building models.

Cases		ΣA_w (m ²)	ΣA_k (m ²) (X Direction)	ΣA_k (m ²) (Y Direction)	ΣA_e (m ²) (X Direction)	ΣA_e (m ²) (Y Direction)	η_{c1} (X Direction)	η_{c1} (Y Direction)	Soft Storey Irregularity
Ground Storey	Frame+Wall	7.92	13.17	11.25	98.955	96.075	1.000	1.000	No
	X-1	7.92	8.72	11.25	9.228	96.075	0.933	1.000	No
	X-2	7.92	6.54	11.25	8.901	96.075	0.899	1.000	No
	X-3	7.92	4.36	11.25	8.574	96.075	0.866	1.000	No
	X-4	7.92	2.18	11.25	8.247	96.075	0.833	1.000	No
	X-5	7.92	0	11.25	7.920	96.075	0.800	1.000	No
	Y-1	7.92	13.17	6.68	98.955	8.922	1.000	0.929	No
	Y-2	7.92	13.17	4.01	98.955	85.215	1.000	0.887	No
	Y-3	7.92	13.17	2.23	98.955	82.545	1.000	0.859	No
	Y-4	7.92	13.17	0	98.955	7.920	1.000	0.824	No
	Non Wall	7.92	0	0	7.920	7.920	0.800	0.824	No
	Frame	7.92	0	0	7.920	7.920	1.000	1.000	No
First Storey	Frame+Wall	7.92	13.17	11.25	98.955	96.075	-	-	-
	Frame	7.92	0	0	7.920	7.920	-	-	-

Table 6. Analysis results of 11-storey building models.

Cases		ΣA_w (m ²)	ΣA_k (m ²) (X Direction)	ΣA_k (m ²) (Y Direction)	ΣA_e (m ²) (X Direction)	ΣA_e (m ²) (Y Direction)	η_{c1} (X Direction)	η_{c1} (Y Direction)	Soft Storey Irregularity
Ground Storey	Frame+Wall	9.12	13.08	11.16	11.082	10.794	1.000	1.000	No
	X-1	9.12	8.64	11.16	10.416	10.794	0.940	1.000	No
	X-2	9.12	6.48	11.16	10.092	10.794	0.911	1.000	No
	X-3	9.12	4.32	11.16	9.768	10.794	0.881	1.000	No
	X-4	9.12	2.16	11.16	9.444	10.794	0.852	1.000	No
	X-5	9.12	0	11.16	9.120	10.794	0.823	1.000	No
	Y-1	9.12	13.08	6.60	11.082	10.110	1.000	0.937	No
	Y-2	9.12	13.08	3.96	11.082	9.714	1.000	0.900	No
	Y-3	9.12	13.08	2.20	11.082	9.450	1.000	0.875	No
	Y-4	9.12	13.08	0	11.082	9.120	1.000	0.845	No
	Non Wall	9.12	0	0	9.120	9.120	0.823	0.845	No
	Frame	9.12	0	0	9.120	9.120	1.000	1.000	No
First Storey	Frame+Wall	9.12	13.08	11.16	11.082	10.794	-	-	-
	Frame	9.12	0	0	9.120	9.120	-	-	-

4. Conclusions

In this study, it has been investigated to what extent the amount of infill wall on the ground floor affects the period of the building, and whether soft floor and weak floor irregularities occur in the building according to the change in the amount of infill wall on the ground floor. For this research, analyses were made for various situations of 4 types of buildings with 3, 6, 9 and 11 floors. The results obtained are as follows.

- In order to take the infill walls into account in the analyses, it has been seen that representing the infill walls in the load-bearing system of the buildings as a cross-pendulum rod with two ends gives very realistic results.
- In the examined structures, it was observed that the infill walls significantly increased the rigidity of the structure and as a result, they caused a significant decrease in the construction period.

The 3-storey building was the most affected by the period-reducing effect of the infill wall. The period value obtained when all floors and all axes of the 3-storey building are in infilled condition (all-walled condition) is 47.27% less than the period value obtained when all floors and all axes of the 3-storey structure are without infill walls (bare frame condition).

The 11-storey building was least affected by the period-reducing effect of the infill wall. The period value obtained when all floors and all axes of the 11-storey building are in infilled state (all-walled state) is 33.71% less than the period value obtained when all floors and all axes of the 11-storey building are without infill walls (bare frame state).

Even though the period-reducing effect of the infill wall decreases as the structure rises, it is still very large. Regardless of the height of the structure, it should be noted that the infill wall greatly reduces the period of the structure.

- The decrease in the amount of infill wall on the ground floor of a building with infill walls on all floors and all axes (all-walled condition) increases the period of the building somewhat compared to the period of the building with all walls.

While this increase was significant in the 3-storey building, it was observed that it was too small to be ignored in the 11-storey building. From this, we can conclude that the change in the amount of infill wall only on the ground floor has a large effect on the period of the building in buildings with low height, and negligible effect on the period of the building in buildings with high height. In addition, we can say that this effect increases and decreases inversely with the height of the building (the lower the structure, the greater the effect, the larger the structure, the less the effect).

- It has been seen that the period values obtained from the period formulas that take into account the infill wall effect, which have been revealed as a result of the studies carried out by various people before, do not give appropriate results for all-walled structures where the amount of infill wall changes only on the ground floor.

In all buildings except the 3-storey building, the periods obtained by reducing the wall on the ground floor are closer to the period of the whole building with walls. Although the values obtained from the other period formulas are between the periods of all the buildings with walls and bare frames, they are quite far from the period values obtained by reducing the wall on the ground floor, except for the 3-storey building.

- Reducing the amount of infill walls only on the ground floors of the buildings considerably increases the relative floor offsets on the ground floors of the buildings.
- In low-rise buildings and in the case of medium-height (6-7-storey) buildings, only the ground floors have very little or no infill walls (all of the other floors are infilled), weak floor irregularities may occur in the ground floor of the buildings. In very high buildings, although the building is completely filled with infill walls, even if there is no infill wall on the ground floor, weak floor irregularities do not occur on the ground floor of the building.

If we want to design earthquake-resistant structures, we need to know the behaviour of structures under the influence of earthquakes and design our structures in the most appropriate way to this behaviour. As can be understood from the results above, the infill walls created to fulfil the architectural and functional functions in a building have a great effect on the behaviour of the building under the influence of earthquakes. Since this effect cannot be neglected in many respects, the infill wall must be reflected in the analysis and calculations in the building design. Otherwise, the reliability of the building may be shaken in many respects, unexpected negativities and even catastrophic destructions may occur under the influence of earthquakes. In this case, ignoring the effects of the infill wall on the structure under the influence of an earthquake can be equivalent to neglecting human life.

From the results of the analysed four different (3, 6, 9, 11 storey) regularity, it was shown that current code equations are unable to accurately predict the effect of horizontal and vertical regularities on the period. It was also shown that structures with vertical irregularities, like a setback, tend to have shorter period than the regular structures and compared formulations. Especially we will try to achieve it by means of regressive techniques, using as data all the above studied parameters and corresponding results, irregularity systems.

REFERENCES

- Akyürek O, Tekeli H, Demir F (2018). Effect of infill wall placement in plan on building performance. *International Journal of Engineering Research and Development*, 10(1), 42-55.
- Asteris PG (2003). Lateral stiffness of brick masonry infilled frames. *Journal of Structural Engineering*, 129(8), 1071-1079.
- Asteris PG, Chrysostomou CZ, Giannopoulos IP, Smyrou E (2011). Masonry infilled reinforced concrete frames with opening. *III ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering*, Greece.

- Asteris PG, Nikoo M (2019). Artificial bee colony-based neural network for the prediction of the fundamental period of infilled frame structures. *Neural Computing and Applications*, 31(9), 4837-4847.
- Asteris PG, Repapis CC, Tsaris AK, Di Trapani F, Cavaleri L (2015). Parameters affecting the fundamental period of infilled RC frame structures. *Earthquake and Structures*, 9(5), 999-1028.
- Asteris PG, Repapis C, Cavaleri L, Sarhosis V, Athanasopoulou A (2015). On the fundamental period of infilled RC frame buildings. *Structural Engineering and Mechanics*, 54(6), 1175-1200.
- Asteris PG, Tsaris AK, Cavaleri L, Repapis C, Papalou A, Di Trapani F, Karypidis DF (2016). Prediction of the fundamental period of infilled RC frame structures using artificial neural networks. *Computational Intelligence and Neuroscience*, 5104907, 12.
- Asteris PG, Repapis CC, Foskolos F, Fotos A, Tsaris AK (2017). Fundamental period of infilled RC frame structures with vertical irregularity. *Structural Engineering and Mechanics*, 61(5), 663-674.
- Börekçi M (2019). Obtaining the dominant period of reinforced concrete buildings with infill walls directly by formulas. *Haliç University Journal of Science and Technology*, 2(2), 161-178.
- Ersin UD, Yuksel E, Kocak A, Hayashi M, Karadogan F (1998). System identification by means of micro tremor measurements. *Second Japan-Turkey Workshop on Earthquake Engineering*, 1-633-648, İstanbul.
- Furtado A, Rodrigues H, Arêde A (2015). Modelling of masonry infill walls participation in the seismic behaviour of RC buildings using OpenSees. *International Journal of Advanced Structural Engineering*, 7, 117-127.
- Goel RK, Chopra AK (1997). Period formulas for moment resisting frame buildings. *Journal of Structural Engineering, ASCE*, 123(11), 1454-1461.
- Guler H, Yuksel E, Kocak A (2008). Estimation of the fundamental vibration period of existing RC buildings in Turkey utilizing ambient vibration records. *Journal of Earthquake Engineering*, 12, 140-150.
- Koçak A (2013). The effect of short columns on the performance of existing buildings. *Structural Engineering and Mechanics*, 46(4), 505-518.
- Koçak A, Börekçi M, Zengin B (2018). Period formula for RC frame buildings considering infill wall thickness and elasticity modulus. *Scientia Iranica Transaction A*, 25(1), 118-128.
- Koçak A, Yildirim MY (2011). Effects of infill wall ratio on the period of reinforced concrete framed buildings. *Advances in Structural Engineering*, 14, 731-743.
- Kose MM (2009). Parameters affecting the fundamental period of RC buildings with infill wall. *Engineering Structures*, 31(1), 93-102.
- Kose MM, Karshoğlu O (2007). Effects of infill walls on building natural modal period and mode shape. *6th National Conference on Earthquake Engineering*, İstanbul.
- Lemonis ME, Asteris PG, Zitouniatis DG, Ntasis GD (2019). Modelling of the lateral stiffness of masonry infilled steel moment-resisting frames. *Structural Engineering and Mechanics*, 70(4), 421-429.
- Ning N, Yu D, Zhang C, Jiang S (2017). Pushover analysis on infill effects on the failure pattern of reinforced concrete frames. *Applied Sciences*, 7(4), 428.
- Qian K, Li B (2017). Effects of masonry infill wall on the performance of RC frames to resist progressive collapse. *Journal of Structural Engineering*, 143(9), 04017118.
- Sağlıyan S (2018). The Effect of modelling approaches of infill walls on reinforced concrete frame behaviour. *Science and Engineering Journal of Firat University*, 30(2), 165-174.
- SAP2000 (2021). Structural Analysis Program. Computer and Structures, USA.
- TBDY-2018 (2018). Turkish Building Earthquake Regulation. Ministry of Environment and Urbanization, Ankara, Turkey.
- TEC-1998 (1998). Turkish Earthquake Regulation, Ministry of Public Works and Settlement, Ankara.
- UBC-1997 (1997). Uniform Building Code, Structural Design Requirements. International Code Council, International Conference of Building Officials.