Effect of infill wall and wall openings on the fundamental period of RC buildings

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Abstract

The effect of infill walls to stiffness of the structures has been known for a long time and this effect has taken many of the earthquake regulations with empirical relationships and equations into account. However, in strength-based calculations, buildings are taken as bare frames and infill walls are effected as vertical load to system, whereas infill walls contribute to stiffness at the beginning of the earthquake and help meet seismic loads by incurring damage during an earthquake.

In this study, contribution of infill walls to stiffness of the structure was analyzed in reinforced concrete framed and load-bearing buildings. Also, the effect of openings in the infill walls to stiffness was examined.

Keywords: reinforced concrete frame, infill wall, wall openings, period.

1 Introduction

A large number of buildings are constructed with infill walls in Turkey. Infill walls are constructed for divide the interior area of buildings. These walls are ignored on design and calculation of buildings due to modelling of infill walls are hard and complex. Effect of the infill walls are modelled as mass and weight which are applied to floors or beams as a static load. However, effects of the infill walls are taken into consideration with some coefficients which calculated by using some experiential formulas in some country regulations. It is well known that there are a lot of effects of infill walls on behavior of structures under earthquake and vertical loads and dynamics properties like stiffness, fundamental

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period and damping. Infill walls enhance the lateral behavior of the frames they fill up.

For simplify the effect of infill wall on behavior of frame system, a lot of research have been made in years. The first study about behavior of frames with infill wall was examined by the Polyakov [1] in 1956. After Polyakov, Holmes [2] proposed replacing the panel by an equivalent diagonal strut with same material as the infill. Width of this equivalent diagonal strut is determined as 1/3 of the infill diagonal length. Smith [3] and Smith and Carter [4] has developed furthermore the idea of Holmes's equivalent strut, and suggested two pin-connected equivalent diagonal struts related the width of the equivalent diagonal strut to the infill/frame contact lengths using an analytical equation. In 1971, based on experimental and analytical data, Mainstone [5] proposed an empirical equation for the calculation of the equivalent strut width of infill walls on frames by using stiffness and strength of infilled frames. These equations was changed by Mainstone and Weeks [6] and Mainstone [7] later and this formula was included in FEMA-274 (Federal Emergency Management Agency 1997) [8] for the analysis and rehabilitation of buildings as well as in FEMA-306 (Federal Emergency Management Agency 1998) [9] and Turkish Seismic Code of 2007 [10], as it has been proven to be the most popular over the years. Decanini and Fantini [11] changed suggested another experimental formula which using same idea with Stafford Smith. 1/4 of the infill diagonal length for equivalent diagonal strut width, which were assumed as all stresses was carried by infill wall before horizontal joint deformation, was suggested by Paulay and Priestley [12] in 1992. Durrani and Luo [13] suggested some equations by using γ and μ coefficients which were affected by properties of beams, columns and walls.

Also some other studies were carried out to investigate effect of infill wall on frames. Govindan *et al.* [14] found twice as high bearing capacity of infilled walls, five times higher rigidity and 2.6 times smaller displacement ratio at the top of the frame. Govindan *et al.* [14] subjected cyclic loads to two different 7-storey buildings with infill walls and bare frames. They calculated and compared the horizontal rigidity, ductility and energy dissipation capacities of infill walls and frames. Dowrick [15] concluded that infill walls did increase the structural strength and rigidity. Aytun [16] and Bayülke [17], on the other hand, stated that infill walls decreased the building periods while also increasing the rigidity of the system. Altın *et al.* [18] reported an increase of 6 to 28% of the initial rigidity if a whole connection between the infill wall and the frames are considered. Mehrabi *et al.* [19] conducted experiments on bricks with and without hollow spaces and concluded that when vertical loads on the infill walls are increased, then the total horizontal bearing capacity of the composite frame also increases by 25%. Mehrabi *et al.* [19] and Asteris [20] observed the effects of reinforced concrete framed infill walls at earthquake conditions and the effects of infill walls with or without the door and window openings. They concluded that frames with door and window openings are less rigid and have higher periods than those without any openings. Mostafaei and Kabeyasawa [21] achieved three dimensional non-linear time history analyses for both bare frame and infilled frame in order to obtain an analytical answer for the performance of an existing building and an approach was developed to model masonry infill walls with or without opening. On the other hand, Amanat and Hoqueb [22] observed that, the beam and column stiffness have negligible effect on the period. This study also shows that randomness in the distribution of infill does not have a significant effect on the period; instead, it is the total amount of infill that is important. Puglisi *et al.* [23] proposed a model for the behavior of infill panels in framed structures which is based on the equivalent strut model, the plastic concentrator concept, and damage mechanics. Güler *et al.* [24] performed a numerical analysis of data collected from an experimentally vibrated building, in which infill walls were defined as diagonal compression struts. Güney *et al.* [25] studied effect of nonlinear behavior of infill walls on symmetric and asymmetric structures. Budak [26] observed effect of infill walls on structural loads. Kocak and Yıldırım [27] studied effects on infill wall ratio on the period of reinforced concrete framed buildings and an equation for obtain for structural fundamental period is suggested.

Masonry walls contribute to the stiffness of the infill under the lateral load. The term 'infilled frame' is used to denote a composite structure which combination of a moment resisting plane frame and infill walls. The composite behavior of an infilled frame imparts lateral stiffness and strength to the building. The typical behavior of an infilled frame subjected to lateral load is illustrated in Figures 1(a) and (b).

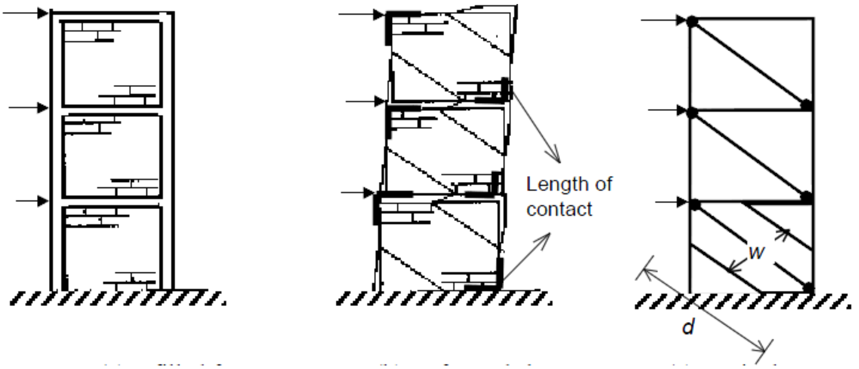


Figure 1: The typical behavior of an infilled frame subjected to lateral load [28].

In this study, a 1-storey building with one opening is taken into account and effect of the infill walls opening on system is investigated, firstly. Then, equivalent strut model is suggested for each system with different openings. At the second part, 3, 6, 9 and 11-storey buildings are taken into consideration and suggested strut models are used for each one. In this way effect of the openings on infill wall is examined and a coefficient for equivalent strut with openings (β) is suggested. Then, resulting period values are compared with the other literature sources.

2 Equivalent strut models for infilled frames

There are a lot of models in literature for modelling infilled walls as an equivalent strut frames but, Mainstone which suggested by Turkish Seismic Code, FEMA-274 and FEMA-306, is used for this study. In this method, first stiffness parameters are determined by using eqn. (1) and equivalent strut width is determined by using eqn. (2). Then equivalent strut width, w, is implemented the frame model with a single diagonal strut which have width as w and thickness as t.

$$\lambda h = \left[h_{column} \times \sqrt[4]{\frac{E_{wall} \times t_{wall} \times \sin 2\theta}{4 \times E_{column} \times I_{column} \times h_{wall}}} \right] \tag{1}$$

$$w = 0.175 \times \left(\lambda h\right)^{-0.4} \times d \tag{2}$$

Figure of infill wall and equivalent strut models are given in figure 2.

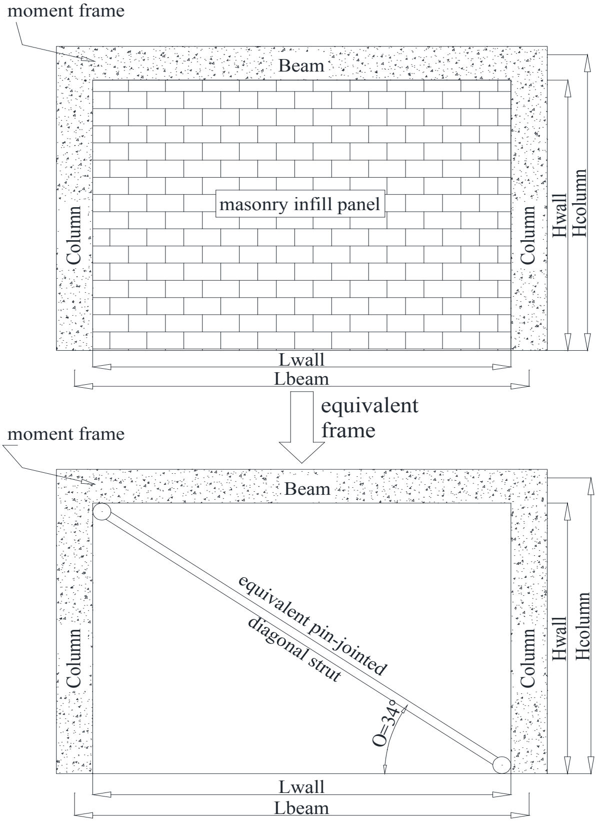


Figure 2: Equivalent strut model for masonry infill walls.

Then two different fully closed reference model is made up. First model is created with shell element (denoted as SH) while the second one equivalent pin-jointed diagonal strut (denoted as EF). Thickness of the wall in SH is taken as 0.25m and equivalent pin-jointed diagonal strut width is found as 0.516m by using eqn. (1) and eqn. (2).

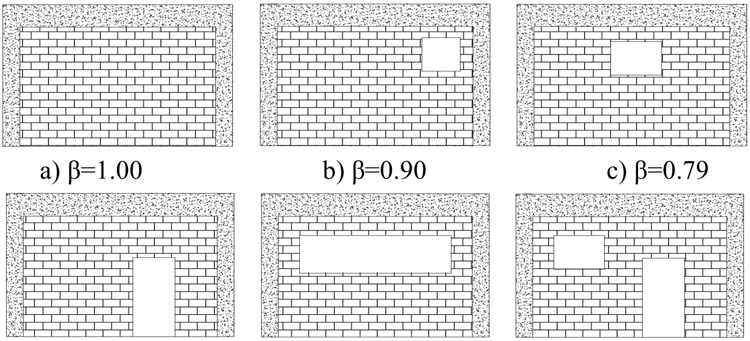
Table 1: Properties of infill wall and moment frame elements [24].

		Modulus of Elasticity (MPa)		
		E_{PER}	E_{PAR}	E_{AVE}
Infill Wall	Without Plaster	2500	4600	3550
	With Plaster	4200	7800	6000
Beam (Concrete)		30250		
Columns (Concrete)		30250		

The experimental values of the modulus of elasticity of directions parallel (Epar) and perpendicular (Eper) to the holes of the bricks are given in table 1. Average modulus elasticity value for infill wall with plaster is taken into account in this study. Average compressive strength of the concrete, which used for beams and columns and infill wall are taken as 25 MPa and 2.5 MPa, respectively.

3 Determination of modulus of elasticity coefficient

For determination of modulus of elasticity coefficient both models are subjected to modal analysis which is using for determine the natural mode shapes and frequencies of a structure during free vibration by using SAP2000 14.2.4 [29]. Then fundamental period of the structures are found by using frequencies. Thereafter, this procedure is applied to six different opening scenarios so different modulus of elasticity coefficients (β) are achieved for equivalent pin-



a) β=1.00 b) β=0.90 c) β=0.79

d) β=0.52 e) β=0.23 f) β=0.41

Figure 3: Different opening scenarios for infill wall. a) fully closed, b) small windows, c) small windows at middle, d) door, e) large window, f) small windows and door.

jointed diagonal strut models. Figures and calculated modulus elasticity coefficients (β) of different opening scenarios are given in figure 3.

4 Numerical analysis and results

The considered buildings are modeled according to the condition that infill walls existed under all of the frames except entrance floor, and then the analyses are repeated with the different wall opening scenarios. Typical floor plan of model is given in figure 4.

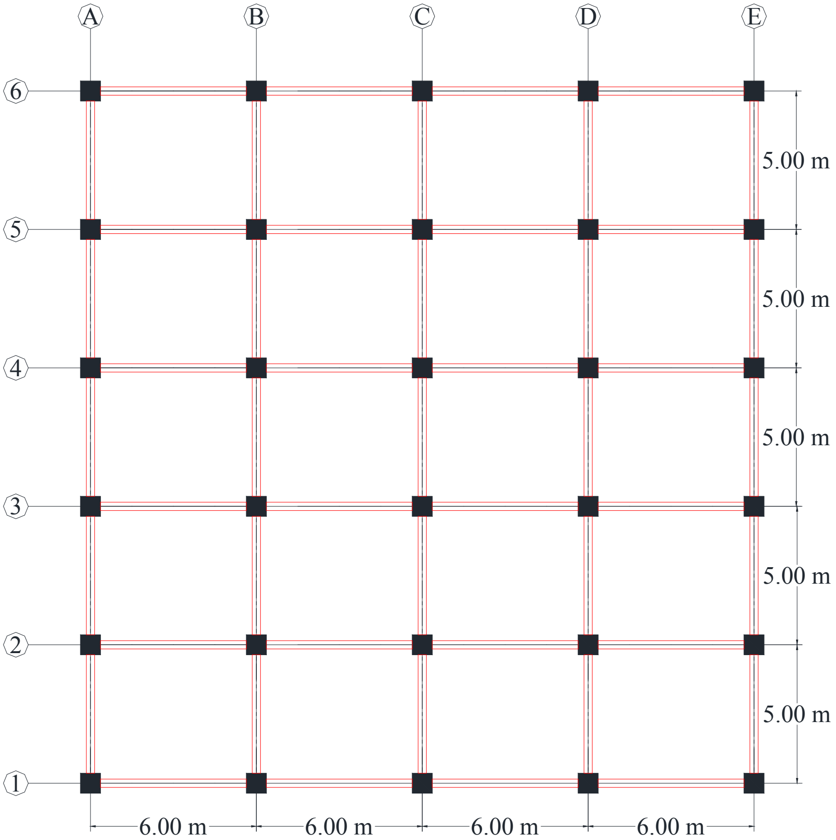


Figure 4: Typical floor plan of fully closed wall model.

The analysis is conducted for 6 different combinations of outer and inner infill walls and is given in table 3. Each model is created in ETABS 3D Analysis of Building Systems 9.7.48 [30] then fundamental period results is taken after modal analysis. Each scenario is repeated for 3, 6, 9 and 11-storey buildings. Size of the columns, which 45cm×45cm at basement, is decreased with the storey height while the all beams and walls have 35cm/40cm sizes and 25cm thicknesses, respectively.

Table 2: Analysis combination and modulus of elasticity values for outer-inner infill walls.

Cases	**Exterior Infill Wall**	**Interior Infill Wall**	**Modulus Elasticity of Exterior Infill Wall (MPa) β×ESH**	**Modulus Elasticity of Interior Infill Wall (MPa) β×ESH**
Case #1	Fully Infilled	Fully Infilled	15150	15150
Case #2	Fully Infilled	Door	15150	7945
Case #3	Small Window	Door	13671	7945
Case #4	Small Window at Center	Door	11990	7945
Case #5	Large Window	Door	3479	7945
Case #6	Bare Frame		6000	6000

Analysis results and calculated fundamental period values is given in table 4. According to the table, it is obvious that infill walls increase the stiffness of buildings and effects to behavior of the structures remarkably in a positive way. Openings in infill walls like door or windows reduce the stiffness and resulted as higher fundamental period values.

Table 3: Analysis results, changing of fundamental period due to case types and storey number.

	3-Storeys		**6-Storeys**		**9-Storeys**		**11-Storeys**	
	Tx(s)	**Ty(s)**	**Tx(s)**	**Ty(s)**	**Tx(s)**	**Ty(s)**	**Tx(s)**	**Ty(s)**
Case #1	0.117	0.112	0.224	0.216	0.342	0.329	0.424	0.409
Case #2	0.140	0.130	0.263	0.248	0.395	0.373	0.485	0.460
Case #3	0.142	0.133	0.269	0.254	0.403	0.381	0.493	0.469
Case #4	0.146	0.137	0.275	0.261	0.412	0.391	0.504	0.480
Case #5	0.169	0.167	0.321	0.314	0.476	0.464	0.579	0.566
Case #6	0.527	0.502	0.914	0.866	1.220	1.115	1.351	1.282

These fundamental period values which found from analysis compared with the equations in literature. Güler *et al.* proposed eqn. (3) where H(m) is the height from base to roof in meter., to determine the period considering the effect of the infill wall according to building height.

$$T_A = 0.026 \times H^{0.9} \tag{3}$$

Chopra and Goel [31] have also proposed an expression for moment resisting frame buildings that is given in eqns (4) and (5).

$$T_{LC} = 0.047 \times H^{0.9} \tag{4}$$

$$T_{UC} = 0.067 \times H^{0.9} \tag{5}$$

In Eurocode 8 [32], another period-height relationship is suggested for uncracked infilled RC buildings.

$$T_{A} = 0.075 \times H^{0.75} \tag{6}$$

Also another analytical period-height relationship is examined by Crowley and Pinho [33], for RC buildings bare frames (T_{BF}), fully infilled frames (T_{FIF}) and frames with openings (T_{FWO}).

$$T_{BF} = 0.054 \times H \tag{7}$$

$$T_{FIF} = 0.025 \times H \tag{8}$$

$$T_{FWO} = 0.034 \times H \tag{9}$$

According to analytical equations and infill wall scenarios fundamental period of the buildings with 3, 6, 9, 11-storey are calculated and given in table 4 and figure 5.

Table 4: Analysis results, changing of fundamental period due to case types, analytical equation and storey number.

	3-Storeys		6-Storeys		9-Storeys		11-Storeys	
	Tx(s)	Ty(s)	Tx(s)	Ty(s)	Tx(s)	Ty(s)	Tx(s)	Ty(s)
Case #1	0.117	0.112	0.224	0.216	0.342	0.329	0.424	0.409
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Case #6	0.527	0.502	0.914	0.866	1.220	1.115	1.351	1.282
Güler *et al.* [24] (eqn. (3))	0.188		0.351		0.505		0.605	
Chopra and Goel [31] (eqn. (4))	0.340		0.634		0.913		1.093	
Chopra and Goel [31] (eqn. (5))	0.484		0.903		1.301		1.559	
Eurocode 8(eqn. (6))	0.390		0.655		0.888		1.033	
Crowley and Pinho [33] (eqn. (7))	0.486		0.972		1.458		1.782	
Crowley and Pinho [33](eqn. (8))	0.225		0.450		0.675		0.825	
Crowley and Pinho [33] (eqn. (9))	0.306		0.612		0.918		1.122	

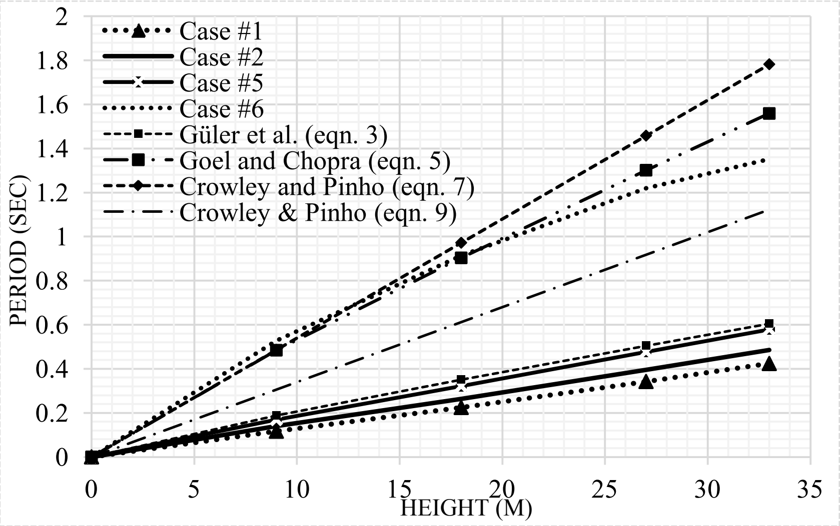

Figure 5: Period–height relationship of different infill wall cases and analytical equations.

5 Conclusion

Infill walls decrease the fundamental period of the structure and increase the stiffness as can be seen from the studies above. On the other hand, some openings in the infill wall like window, door openings affect the infill wall stiffness and increase the fundamental period of the building. Also, it is obviously seen that some analytical equations in country regulations and codes are mostly suitable for the structures which close to the frame system with low infill wall stiffness.

In brief, there is

- 78%–68% decreasing between fundamental period values of bare frame and fully infilled frame.
- 18%–13% decreasing between infilled frame with window-door openings buildings and fully infilled frame buildings.

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