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ANALYZING THE EFFECT OF INFILL WALLS ON A RC STRUCTURE

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ABSTRACT

In reinforced concrete buildings, the openings between frames are generally filled by using infill material and by plastering the sides. This application is called infill wall, and it is widely acknowledged as a non-structural element. Therefore, infill walls are often designed assuming that they do not have any effect on the structure other than their weight. However, several experimental and theoretical studies have documented that infill walls, in fact, affect the behavior of a structure under vertical and horizontal loads along with its dynamic characteristics such as its stiffness, period and damping. This study aims to investigate the effect of infill walls on the earthquake performance of a selected building. The structure with and without infill walls has been modelled in SAP2000 structural analysis software and the pushover analysis has been carried out. The infill walls have been modelled as commonly used diagonal bracing without any tensile capacity, which are compatible to their actual behavior. As a result of the comparison of the analyses, infill walls have been found to increase the earthquake performance of the structure, limit the displacement and contribute to the base shear force.
Keywords: Infill Wall Effect, Pushover Analysis, Performance Point, Base Shear Force

1. INTRODUCTION

In the production of infill walls in RC buildings, materials such as hollow concrete and clay bricks, whose bearing capacities are generally ignored, are used. It has been emphasized in several experimental and theoretical studies that infill walls, sides of which are plastered, have, although limited, a capacity of bearing horizontal load, and that they also affect the behavior of a structure under horizontal loads and its dynamic characteristics such as its stiffness, period and damping [1-3]. This finding has also been confirmed in the examinations done in the buildings affected by an earthquake. However, the effect of infill walls on the dynamic characteristics and stiffness of a structure is still prevalently neglected during design process and they are only taken into account as dead load. One of the reasons for this is that there is no standard concrete strength value for the material properties of infill walls [4]. As is seen in Table 1 [5], in most of the studies, the elasticity modulus of the infill walls (E_{me}) get values in wide range while elasticity modulus of the concrete (E_{fe}) which forms the frame gets closer values

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited [6-17].

Researcher and Year	E_{me}	E_{fe}	Researcher and Year	E_{me}	E_{fe}
Aydoğdu,1995	5200	30000	Dündar,2006	700	25310
Erkaya,1996	6000	28500	Özdoğu,2006	1650	25000
Yalçın,1999	1240	30000	Budak,2006	17000	28500
Tüzün,1999	5000	28500	Çağlayan,2006	714	29600
Öktem,2003	6000	12000	Tarakçı,2006	1000	28000
Erçetin,2004	15200	29600	TSC	1000	-

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Another reason is the difficulty of representing infill walls originally in models and considering them in designs, since the stiffness of infill walls varies depending on the material used such as type of the bricks, mortar, the way the wall is built, the thickness of plaster and joint and even the workmanship. Moreover, it is challenging to inspect infill walls since they do not have a standard strength, and they cannot be modelled in accordance with their original form due to their heterogeneous and anisotropic properties. Thus, infill walls are modelled by using a certain approaches. The effect of infill walls on the dynamic parameters of a structure is directly related to the accuracy of the selected approach. There are approaches in which infill walls are accepted as shell elements or elements increasing the strength of the frame it is sitting in; yet, the most commonly used approach is the one in which infill walls are modelled as equivalent diagonal strut [2]. The elasticity modulus and thickness of equivalent diagonal strut fictively represent infill "walls (Equation 1-2). The thickness of diagonal bracing for infill with openings (r_{inf}) is obtained as presented below [18].

$$\lambda = \sqrt[4]{\frac{E_{me} * t_{inf} * Sin(2\theta)}{4 * E_{fe} * I_{col} * h_{inf}}} \tag{1}$$

$$a = \lambda_{graf} * 0{,}175 * (\lambda * h_{col})^{-0{,}4} * \sqrt{L_{inf} + h_{inf}} \tag{2}$$

Here, a is the thickness of the infill wall without opening and the diagonal bracing; θ is the angle of the diagonal bracing to the horizontal plane; I_{col} is the moment of inertia of the columns; h_{inf} is the height of the infill wall; L_{inf} is the length of the infill wall; h_{col} is the height of the column between the center axes of the beams; λ_{graf} is the stiffness reduction factor that equals to 1 if there is no opening in the wall (Figure 1a and 1b). Another difficulty in modelling is to determine how much the openings in infill walls, left for architectural purposes such as a door and window, decrease the strength. Asteris [19] includes the opening in the infill wall into the calculation with a coefficient, called Stiffness Reduction Factor (λ_{graf}), and it is obtained depending on the ratio of the opening to the gap in the infill wall as shown in Figure 2.

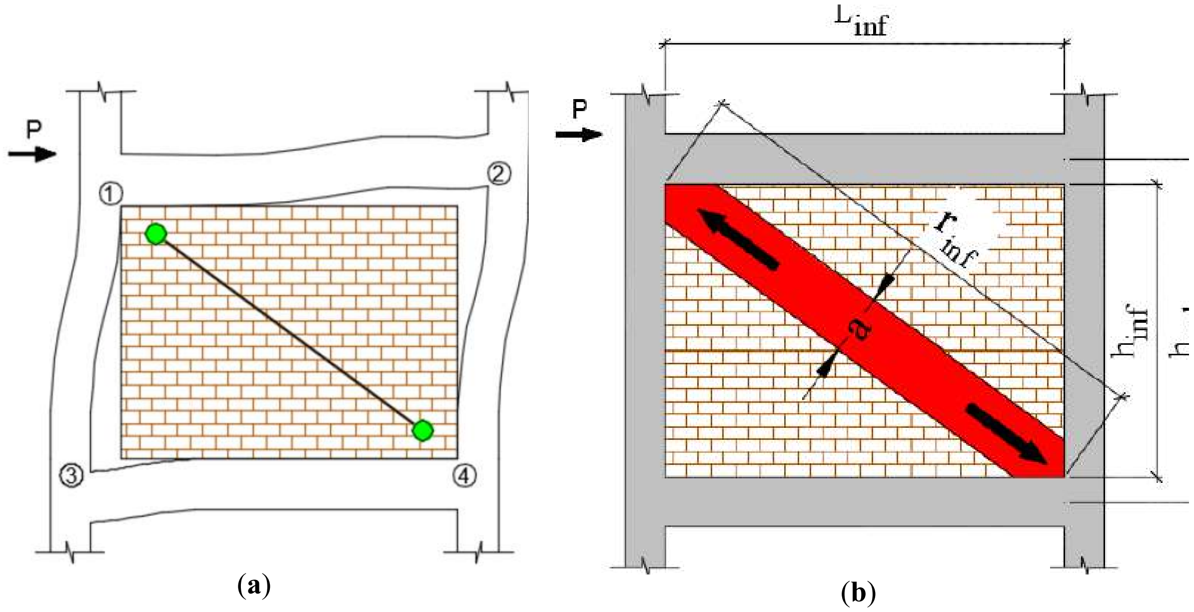


Figure 1. (a) Axial pressure points; (b) Thickness of I=infill wall

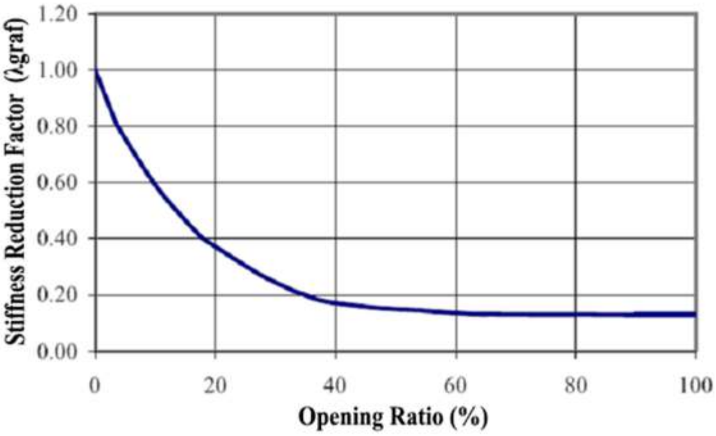


Figure 2. Relationship between the Opening Ratio and the Stiffness Reduction Factor

Though it is quite challenging to determine the stiffness and strength and to model them, it is well-known that infill walls have an effect on a structure. Despite their low bearing capacity, infill walls generally behave similar to shear walls; that's why, they reduce top displacement in the horizontal a little, and support the structure by carrying the shear force. In spite of their contributions, infill walls may have some undesirable effects such as torsional irregularity due to the asymmetrical placement in the design (A1), weak storey irregularity for being built after the ground floor (B1) and short column formation [20,21]. Therefore, it has been suggested that infill walls are taken into account in a way that their effects can be reflected in models to benefit from their positive sides, or at least to determine and avoid their negative effects [3]. The effect of infill walls should be taken into account in the standard of many countries [4]. In 2016 Turkish Earthquake Draft Code [22], designing the connection between the infill wall and the frame jointed is allowed in order to avoid the possible negative effects of infill walls. In this way, buildings designed as jointed allow twice as much displacement compared to the ones without joints [23].

The contribution of infilled frames to the horizontal load bearing is up to 40 % more than the frames without infill walls. However, experimental studies have demonstrated that the results of the analyses are inaccurate, since the strength of infill walls is not taken into account and they are not modelled realistically [1]. In former studies, the effect of infill walls has been analyzed on the models prepared by researchers; yet, in this study, their impact has been examined on a selected building. To do so, the pushover analysis has been performed on the model with and without infill walls which are identified as load and equivalent diagonal strut, and base shear force and performance points are compared.

2. THE SELECTED BUILDING

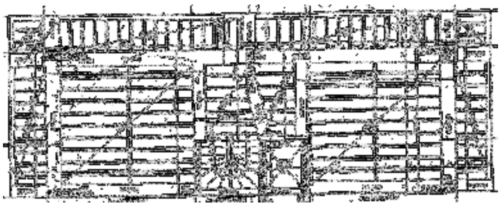
2.1. General Information Regarding the Building

The building with basement+ ground floor+ 4 normal storeys +roof in the center of İskenderun has been chosen for the study (Figure 3a and 3b). The rear facade of the building is attached to another building and the basement floor of this axis is designed with shear wall while all the other storeys are designed with infill walls. The front and left side of the store on the ground floor are window walls. In the building designed with lightweight hollow block slabs (Figure 4a and 4b), concrete and reinforcement classes are respectively C30 and S420a. The seismic information of the building is presented in Table 2.

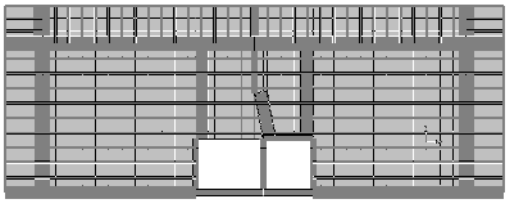
(a)

(b)

Figure 3. (a) Right side of front façade; (b) Left side of front facade



(a)



(b)

Figure 4. The building (a) normal floor plan; (b) Sap2000 model

Table 2. Seismic Information

Earthquake Load	Direction	Eccentricity	Z Code	Sismik Zone	Soil Class	A0	I	R
EXQ	X	0,05	0,36	Zone 1	Z2	0,4	1	8
EYQ	Y	0,05	0,36	Zone 1	Z2	0,4	1	8

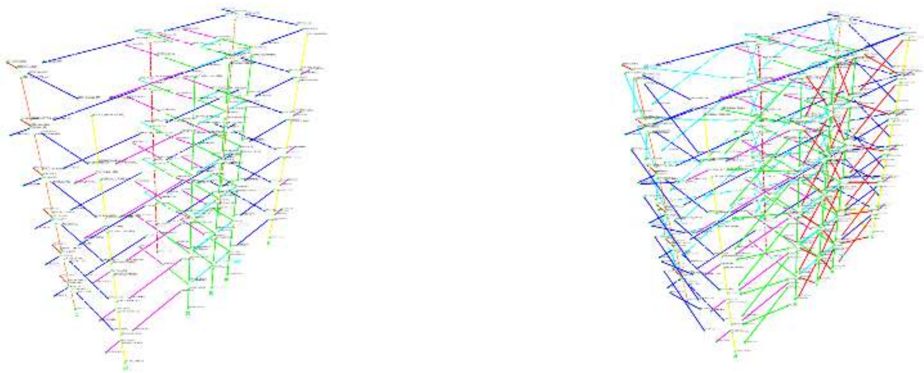
Conclusion section should state clearly the main conclusions of the research and give a clear explanation of their importance and relevance. Summary illustrations may be included.

2.2. Modelling and Analysis

The infill walls of the building have been modelled in two different ways, as dead load and diagonal bracing in Sap2000.v20 [24] structural analysis software in accordance with its actual form (Figure 5a and 5b). In the design, the elasticity modulus of the infill walls has been accepted as 1000Mpa as stated in 2007 Specification for Buildings to be Built in Seismic Zones (Table 1). As suggested by Asteris [19], reduction factor has been applied for the door openings (Figure 2). As a result of the vertical load analysis, the stiffness of beams and columns has been decreased in accordance with 2007 Specification-7.4.13. Hinges have been assigned in a way that axial compressive force occurs in equivalent diagonal strut, bending occurs in beam and bending and axial force occur in columns as stated in FEMA 356 [25] (Figure 6a and 6b). The infill walls within frames are only exposed to compressive force under horizontal earthquake load; that's why, the tensile force in equivalent diagonal strut is eliminated. In analysis features, the material interaction in Sap2000 has been used to perform nonlinear analysis for pushover.

(**a**) (**b**)

Figure 5. Modellings (a) without infill wall; (b) with infill wall

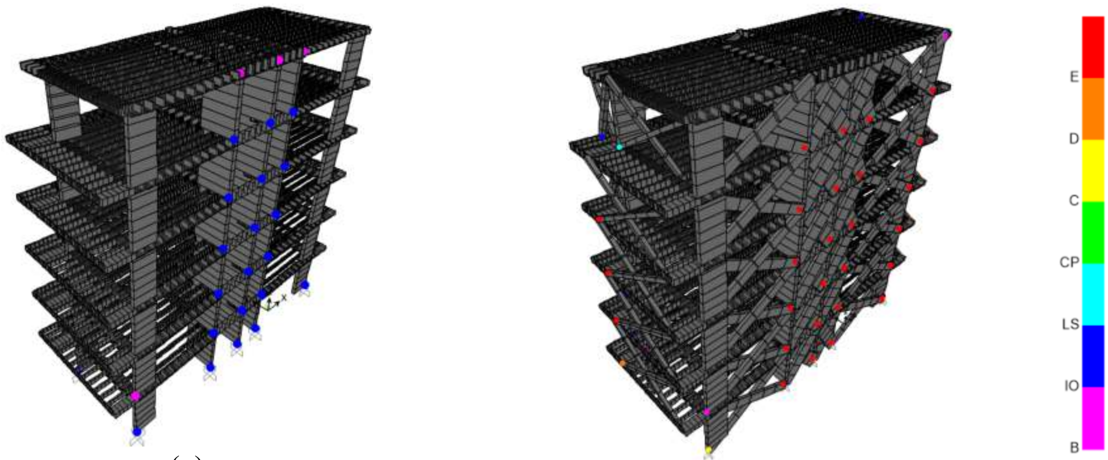


(**a**) (**b**)

Figure 6. Three-dimensional view of model with hinges (a) model with infill wall; (b) model without infill wall

3. FINDINGS AND DISCUSSION

In the pushover analysis, maximum plastic hinges and performance losses have been obtained as a result of the displacement in the models with and without infill walls (Figure 7). The graph regarding the base shear force and top displacement has been presented in Figure 8, and the graph showing the spectral displacement has been given in Figure 9a and 9b. According to the spectral acceleration and spectral displacement graphs, the data regarding the performance points have been provided in Table 3.



(**a**) (**b**)

Figure 7. Formation of hinges (a) model without infill wall; (b) model with infill wall

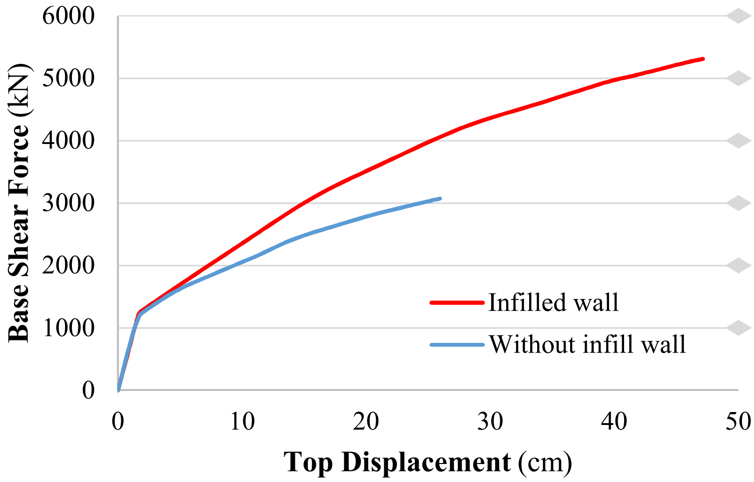
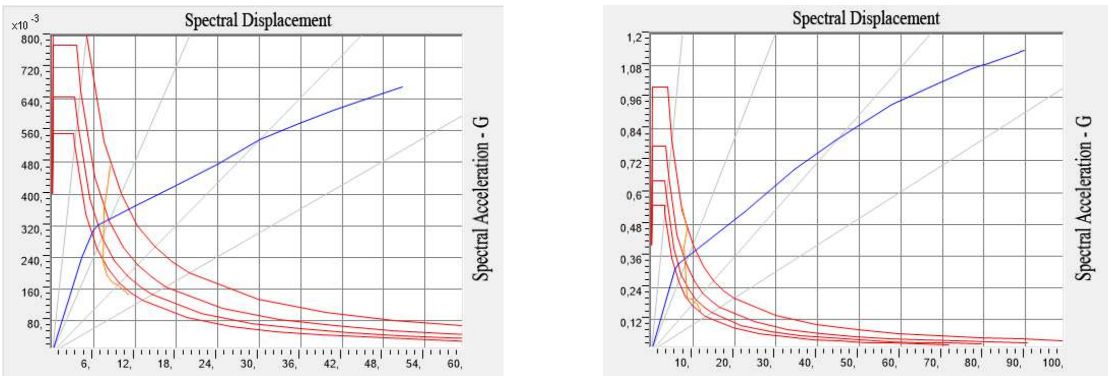


Figure 8. Base shear force-top displacement graphs of the models with and without an infill wall



(a) **(b)**

Figure 9. Spectral acceleration-spectral displacement graphs (a) model without infill wall; (b) model with infill wall

Table 3. Base shear forces and performance points in the building

Infilled Wall					Without Infill Wall				
Step	**Displacement (cm)**	**Base Shear (kN)**	**Sd (cm)**	**Sa**	**Step**	**Displacement (cm)**	**Base Shear (kN)**	**Sd (cm)**	**Sa**
0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00
1	1.13	867.31	4.28	0.24	1	0.00	1.51	0.00	0.00
2	1.65	1156.31	5.92	0.31	2	1.61	1174.56	5.86	0.31
3	*1.93*	*1238.41*	*6.64*	*0.32*	*3*	*1.95*	*1286.11*	*6.77*	*0.34*
4	*4.59*	*1581.38*	*11.73*	*0.37*	*4*	*10.12*	*2310.69*	*22.90*	*0.52*
5	7.32	1830.90	17.06	0.41	5	10.43	2393.96	23.70	0.54
6	10.93	2132.35	23.99	0.48	6	12.93	2632.85	28.16	0.59
7	14.10	2417.81	30.04	0.54	7	13.87	2802.95	30.30	0.63
8	17.29	2624.01	35.69	0.58	8	23.87	3788.90	49.68	0.84
9	20.12	2789.09	40.67	0.61	9	36.05	4648.31	71.09	1.01
10	22.84	2927.17	45.37	0.64	10	39.18	4834.66	76.31	1.05
Performance Point : Sa: 0.33 Sd: 7.73					**Performance Point :** Sa: 0.35 Sd: 7.97				

4. CONCLUSIONS

As a result of the analysis of a building in the center of İskenderun carried out by Sap2000 software, infill walls have been found to affect base shear force by up to 40 % as is seen in Figure 7. The nonlinear pushover analyses have also revealed that infill walls increase the performance of the structure (Figure 8). The forming of hinges in the structure in which infill walls have been modelled reveals that infill walls are effective in absorbing horizontal earthquake energy, which also means infill walls have an effect on the performance of the existing buildings. Instead of ignoring the stiffness and strength of walls in the calculations in commercial softwares, infill walls should be considered in analyses and assessed in terms of the behavior of a structure in an earthquake, which has an utmost importance for Turkey, an earthquake prone country. In that sense, architects and engineers should cooperate and design commercial stores in buildings by keeping economy and safety at an optimum level. It should not be forgotten that in commercial software designs in which infill walls are considered as load, the model and the actual structure will not behave in the same way under earthquake force.

REFERENCES

[1] Baran, M., 2012. Dolgu duvarların betonarme çerçeveli yapıların davranışı üzerindeki etkilerinin incelenmesi. Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 27:275-284.

[2] Beklen C, Çagatay İH. 2009. Çerçevelerde dolgu duvar modellerinin incelenmesi. Çukurova Üniversitesi Mimarlık Mühendislik Fakültesi Dergisi, 24:1019-1011.

[3] Kaplan, S.A., 2008. Dolgu duvarların betonarme taşıyıcı sistem performansına etkisi. Türkiye Mühendislik Haberleri 452:49-62.

[4] Bayülke, N., 2003. Betonarme yapının dolgu duvarı. Türkiye Mühendislik Haberleri, 426:85-98.

[5] Beklen, C., 2009. Investigation of infill walls effect in buildings Doctoral dissertation, Master Thesis, Cukurova University, Institute of Natural and Applied Sciences, Adana.

[6] Aydoğdu, İ., 1995, Dolgu Duvarlı Çerçevelerin Davranışı, Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü, YTÜ, İstanbul.

[7] Erkaya, T. A., 1999. Betonarme Çerçeve Yapılarda Dolgu Duvarların Deprem Davranışına Etkisi. Yüksek Lisans Tezi, Fen Bilimleri Entitüsü , İstanbul Teknik Üniversitesi, İstanbul.

[8] Yalçın, E., 1999, Dolgu Duvarların ve Konumlarının Çok Katlı Betonarme Yapıların Deprem Kuvvetleri Altındaki Davranışına Etkileri, Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü, İstanbul Teknik Üniversitesi, İstanbul.

[9] Tüzün, C., 1999. Dolgu Duvarlı Betonarme Çerçeve Sistemlerin Dinamik Analizi. Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü , Yıldız Teknik Üniversitesi, İstanbul.

[10] Öktem, O., 2003. Betonarme Çerçeve Sistemlerinin Lineer Olmayan Hesabı ve Dolgu Duvarların Modellenmesi, Yüksek Lisans Tezi, Fen Bilimleri Entitüsü , İstanbul Teknik Üniversitesi, İstanbul.

[11] Erçetin, İ., 2004. Düzensiz Betonarme Yapılarda Dolgu Duvar Etkisinin İncelenmesi, Yüksek Lisans Tezi, Fen Bilimleri Entitüsü, Celal Bayar Üniversitesi, Manisa.

[12] Dündar, E., 2007. Çok Katlı Betonarme Yapılarda Bölme Duvarlarının Deprem Davranışına Etkisi. Yüksek Lisan Tezi, Çukurova Üniversitesi, Adana.

[13] Özdoğu, O. Z., 2006. Deprem Etkisi Altındaki Binaların Davranışına Dolgu Duvarların Etkisi. Yüksek Lisans Tezi, Fen Bilimleri Entitüsü ,Sakarya Üniversitesi, Sakarya.

[14] Budak, A., 1997. Dolgu Duvarlı Çerçevelerin Sonlu Elemanlar Yöntemi İle Malzeme Bakımından Doğrusal Olmayan Hesabı. Doktora Tezi, Karadeniz Teknik Üniversitesi, Trabzon.

[15] Çağlayan, E., 2006. Betonarme Çerçevelerin Yatay Yüklere Göre Analizinde Dolgu Duvar Etkisinin İncelenmesi. Yüksek Lisans Tezi, Fen Bilimleri Entitüsü, Celal Bayar Üniversitesi, Manisa.

[16] Tarakçı, U., 2006. Mevcut Yapıların İncelenmesi Ve Dolgu Duvar Takviyesi İle Güçlendirilmesi. Yüksek Lisans Tezi, Fen Bilimleri Entitüsü, Pamukkale Üniversitesi, Denizli.

[17] Turkish Seismic Code (TSC), 2007, Ministry of Public Works and Settlement, Ankara.

[18] Öztürkoğlu O, Uçar T , Yeşilce Y. 2015. Betonarme yapılarda dolguduvar-çerçeve etkileşiminin incelenmesi. Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi 17:109-121

[19] Asteris, P.G., 2003. Lateral Stiffness of Brick Masonry Infılled Plane Frames. Journal of Structural Engineering, 129:1071-1079.

[20] Doğan O, Bakırcı Er Ş. 2011. Hareketli yük ve dolgu duvar dağılımının burulma düzensizliğine etkisi. International Journal of Engineering Research and Development 3:2-5.

[21] Çağatay, İ.H., 2007. Binalarda kısa kolona etki eden paremetrelerin incelenmesi. Altıncı Ulusal Deprem Muhendisliği Konferansı. 229-236

[22] TEC. Türkiye Bina ve Deprem Yönetmeliği (Draft), T.C. Disaster and Emergency Management Presidency, 2016, Ankara.

[23] Erdem MM, Bikçe M. 2017. Maksimum azaltılmış göreli kat ötelemelerinin güncel (2007 DBYBHY) ve yeni yönetmelik taslağına (2016 TBDY) göre mukayesesi. Çukurova Üniversitesi Mimarlık Mühendislik Fakültesi Dergisi 32. DOI: 10.21605/cukurovaummfd.358430

[24] Sap2000 1999,. Structural Analysis Programs Computers & Structures, Inc. University Avenue, Berkeley, California, USA.

[25] FEMA-178, 1989. A Handbook for Seismic Evaluation of Existing Buiidings (Preliminary). Earthquake Hazards Reduction Series 47.