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Investigation Of Effect Of Infill Walls With Brick In Buildings

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ABSTRACT

Infill walls are widely used as partitions worldwide. Field evidence has shown that continuous infill walls can help reduce the vulnerability of a reinforced concrete structure. Often, engineers do not consider infill walls in the design process because the final distribution of these elements may be unknown to them, or because walls are regarded as non-structural elements.

It is known that infill walls considerably change the behaviour of frames under lateral loads. Contribution of infill walls in the strength and stiffness of reinforced concrete (RC) frames is neglected in the design of RC frame buildings. This leads to incorrect idealization of the structure. Separation between masonry walls and frames is often not provided and, as a consequence, walls and frames interact during strong ground motion. This leads to structural response deviating radically from what is expected in the design.

Previous experimental research on the response of RC frames with masonry infill walls subject to static and dynamic lateral cyclic loads (1-2 etc.) have shown that infill walls lead to significant increases in strength and stiffness in relation to bare RC frames.

This study focuses on, several story building was designed with bricks which has different modulus of elasticity were selected for its infill walls. The infill wall was considered as weight and equivalent diagonal compression strut model. It is found that infill walls have significant effect on stiffness, period, lateral displacement, base shear force and structural behavior. The performance and rigidity of structure having infilling walls increased and these were exhibited positive behavior under seismic loads compared to structure having bare frame.

1. INTRODUCTION

Masonry infills are frequently used as interior partitions and exterior walls in buildings. They are usually applied as non-structural elements, and their interaction with the bounding frame is, therefore, often is neglected to the design. Nevertheless, their strengths are not negligible, and they will interact with the bounding frame when the structure is subjected to strong lateral loads induced by earthquakes. The interaction may or may not be effected positively effected to the performance of the structure, and the subject has been discussed in the last few decades. Infill walls have been identified as a contributing factor to catastrophic structural failures in earthquakes. Frame–infill interaction can cause to be the brittle shear failures of reinforced concrete columns and short-column phenomena. Moreover, infills can over-strengthen the upper stories of a structure and induce a soft first storey, which is highly undesirable from the earthquake resistance standpoint. In spite of the abovementioned shortcomings that have sometimes been observed, masonry infills have been used to strengthen existing structures, and there is strong laboratory and field evidence that they can improve the earthquake resistance of a frame structure if they are properly designed. Unfortunately, there are neither well-developed design recommendations nor well-accepted analytical procedures for infilled frames. Despite of the numerous studies in past years, many of the controversial issues still remain. The main difficulty in consideration the performance of an infilled structure is to determine the type of interaction between the infill and the frame, which has a main impact on the structural behaviour and load-resisting mechanism.

Studies have shown that infilled frames can improve a number of possible failure mechanisms, depending on the strength and stiffness of the bounding frames with respect to those of the infillsand the geometric configuration of the framing system. Most analytical models recommended today focus on one type of mechanism or the other, and they are not universally applicable to all infilled structures. Hence, the design of engineered infilled frames and the evaluation of existing infilled structures still remain a challenge. However, in any respect, recent research has shed more light on the behaviour of infilled frames, and has resulted in advanced analytic tools. Out-of-plane behaviour of infilled frames has been studied in addition to the in-plane response. Classical diagonal strut models have been subjected to more thorough evaluations with new experimental data, and various limit analysis methods have been improved to account for the different load-resisting mechanisms of infilled frames. Advanced finite element models have been developed to analyse the nonlinear behaviour of infilled frames in a detailed manner. This paper summarizes some of these recent findings and developments, and provides some thoughts for new studies.

2. BEHAVIOUR OF INFILLED FRAMES

The behaviour of masonry-infilled steel and reinforced concrete frames subjected to in-plane lateral loads was investigated by a number of researchers. In late 1970s, Fiorato et al.[1] tested 1/8-scale non-ductile reinforced concrete frames infilled with brick masonry under monotonically increasing as well as cyclic lateral loads. These were followed by the studies of Klingner & Bertero[2], Bertero & Brokken[3], Zarnic & Tomazevic[4], and Schmidt[5]. Lately, single-storey reinforced concrete frames with masonry infills were studied by Mehrabi et al.[6,7] and Angel et al.[8]. The latter study also examined the behaviour of masonry infill under outof-plane loads.

Masonry-infilled steel frames were tested by Dhanasekar et al.[9], Dawe & Seah[10], Mander et al.[11], Mosalam et al.[12], Buonopane & White[13], and Flanagan & Bennett[14]. The last study considered structural clay tile infills.

All studies have shown that the behaviour of an infilled frame is heavily influenced by the interaction of the infill with its bounding frame. In most instances, the lateral resistance of an infilled frame is not equal to a simple sum of those of the infill and the bounding frame because frame–infill interaction can alter the load-resisting mechanisms of the individual components. At a low lateral load level, an infilled frame acts as a monolithic load resisting system. As the load increases, the infill tends to partially separate from the bounding frame and form a compression strut mechanism as observed in many early studies (e.g., Stafford Smith[15]). However, the compression strut may or may not evolve into a primary load-resistance mechanism of the structure, depending on the strength and stiffness properties of the infill with respect to those of the bounding frame.

While most of the studies today have focused on unreinforced masonry panels, Klingner & Bertero[2], and Bertero & Brokken[3] investigated the behaviour of engineered infilled frames. They tested 1/3-scale, three-storey, reinforced concrete frames infilled with fully grouted concrete masonry that had both horizontal and vertical reinforcement. The infill panels were securely tied to the bounding frames. They have demonstrated that properly engineered infilled frames can provide superior performance, interms of strength, stiffness, and energy dissipation, compared with a bare frame. Reinforced infills are, however, not common. An over-reinforced infill may risk the brittle shear failure of the bounding reinforced concrete columns. Studies by Mehrabi et al.[6,7] have shown that relatively weak unreinforced masonry infills can enhance the stiffness and strength of a non-ductile reinforced concrete frame significantly without jeopardizing ductility.

In summary, the failure mechanism and load resistance of an infilled frame depend very much on the strength and stiffness of an infill with respect to those of the bounding frame. It is evident that the strength of the mortar joints is also a dominant factor. A relatively weak infill is most desirable. Studies have shown that infill panels can significantly enhance the performance of a bare frame under earthquake loads, provided the short-column phenomenon and the brittle shear behaviour of the columns can be prohibited[3,6].

3. MODULUS OF ELASTICITY OF INFILL WALL MATERIAL

Generally, living states are multistoreys reinforced concrete buildings. Masonry infill walls which have carrier effect under lateral and vertical loads are neglect in the available analysis and design methods. However, masonry infill walls have been changed behavior of structure. It has been seen major effect of infill walls on lateral stiffness and properties of dynamic until cracking from past to present studies.

Modulus of elasticity of infill wall which is influenced of wall rigidity is great importance on frame systems which are effected by behaviour of infill wall. Modulus of elasticity varies with according to the various directions because the infill wall is nonhomogenous. The compressive strength, elastic modulus of bricks and mortar are major factors, which influence the properties of brick masonry. The behaviour of brick masonry is also dependent on other factors that interfacial bond strength between brick and mortar, moisture in the brick at the time of laying, thickness of mortar joints, arrangement of bricks, workmanship etc.

Table 1 Modulus of Elasticity of Brick Infill Wall

Researcher	**E_d (MPa)**	**E_c (MPa)**	**E_d /E_c**
Yalcın (22)	1240	30000	1/24
Tuzun (23)	5000	28500	1/6
Cagatay (24)	2850	28500	1/10
Budak (21)	17000	28500	1/1.7
TDY-2007 (25)	1000	-	-

3.1. Approaches of Infill Wall Analysis

When the literature studies were examined, basically, using of two methods in the examination of behaviours of frame infill wall under the lateral loads has been seen.

-Equivalent Strut Models

-Finite Elemens Models

3.1.1.Equivalent Strut Models

As mentioned previously, an infill panel tends to separate from its bounding frame at a relatively low lateral load level. After this, its contact with the bounding frame is limited to the two opposite compression corners, forming a resistance mechanism similar to that of a diagonal strut. For this reason, the in-plane behaviour of an infilled frame is distinctly different from that of a shear wall or shear beam. Fiorato et al.[1] have proposed the use of a shear beam model to estimate the initial stiffness of an infilled frame. They have found good correlations with their experimental results. Nevertheless, it must be pointed out that they have compared it with the initial stiffness of their infilled frames that was developed within a very low load level (10–30% of the ultimate load). This may not be reflective of the overall behaviour of an infilled frame before peak. Mehrabi et al.[6,7] have defined a secant stiffness that is more reflective of the average behaviour of an infilled frame before reaching the ultimate load. It is defined as the slope of a line connecting the extreme points of a displacement cycle in which the peak load is about 50% of the maximum lateral resistance. They have compared the secant stiffness of the infilled frames they tested with the shear beam model. They have found that for most frames with weak infills, the shear beam model provides a very close correlation. Nevertheless, for frames with strong infills, the shear beam model tends to overestimate the secant stiffness by more than two-fold. The latter indicates the separation of the infills from the bounding frames at a low load level.

Holmes[20] has proposed that the effective width of an equivalent strut depends primarily on the thickness and the aspect ratio of the infill. Stafford Smith[21] has used an elastic theory to show that this width should be a function of the stiffness of the infill with respect to that of the bounding frame. By analogy to a beam on elastic foundation, Stafford Smith has defined a dimensionless relative stiffness parameter as follows to determine the degree of frame–infill interaction and thereby, the effective width of the strut.

Nevertheless, Stafford Smith[22] has found that his theory tends to overestimate the effective width of an equivalent strut, based on his experimental results. He has subsequently developed a set of empirical curves that relate the stiffness parameter to the effective width of an equivalent strut.

Mainstone & Weeks[2] have proposed an empirical relation between the effective width of an equivalent strut and Stafford Smith’s stiffness parameter for masonry infills. This relation results in a lower value of the effective width than that given by Stafford Smith’s model.The accuracy of the above models in predicting the lateral stiffness of masonry-infilled frames varies significantly from one study to another. Mehrabi et al.[6,7] and R.D. Thomas & R.E. Klingner (personal communications) have found that Mainstone &Weeks’ model significantly underestimates the lateral stiffness of the infilled frames considered.

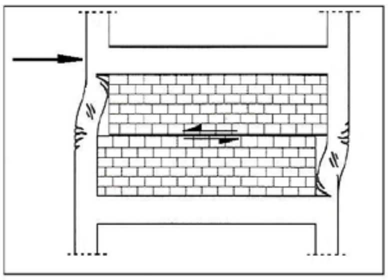

Figure 1 Behaviour of masonry infill wall frame under the lateral loads

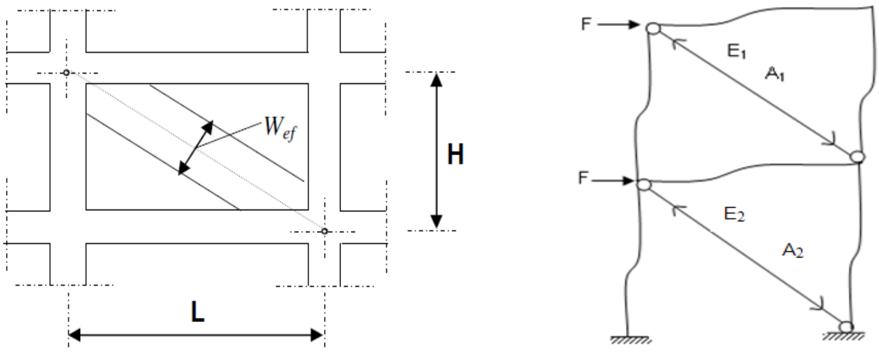

Figure 2 Compression Strut Analogy

In which, E_i and t are the elastic modulus and thickness of the infill, E_cI_c is the bending stiffness of the columns, and H_i and θ are the height and the angle between the diagonal and horizontal of the infill.

$$w_{ef} = 0.175(\lambda_h H)^{-0.4}\sqrt{H^2 + L^2} \tag{1}$$

$$\lambda_h = \sqrt[4]{\frac{E_i \ t \sin 2\theta}{4E_c I_c H_i}} \tag{2}$$

$$\theta = \tan^{-1}\left(\frac{h_{inf}}{L_{inf}}\right) \tag{3}$$

3.1.2.Finite Element Models

In this approach, the plane fill system adopted continously medium is modelled with the elements that consisting of two-dimensional triangles or rectangles. Thus, the system was occurred with the finite elements that provide only equilibrium and continuity conditions in the points of joint. Additionally, the system appeared as a hyperstatic problem of plane stress in very high degree.In this approach that can be solved by using computer, appropriation between infill and frame can be exactly provided.However, much computer time-span is required in this method even if the solution of one-story frame. Therefore this method is not seen as practical for the analysis of building yet. Ultimately, the equivalent compressive strut method was observed more appropriate than the finite element method for using practical purposes.

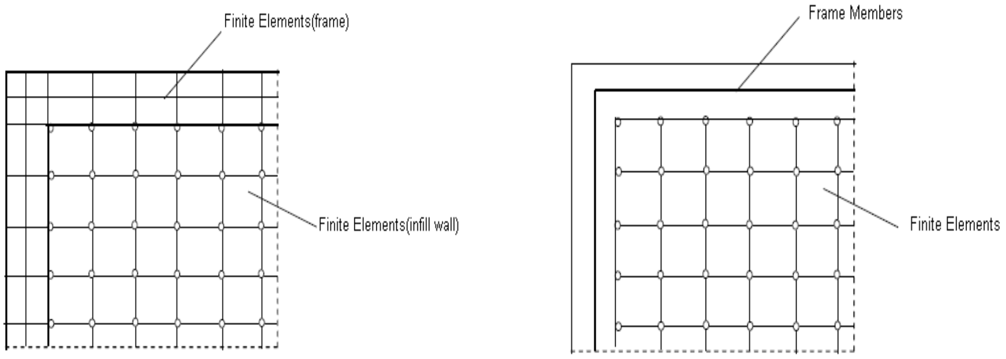

Figure 3 Frame infill wall models created by using finite elements [21]

4. Numerical Application

For analytical application, a sample RC structure is selected. The concrete material is C20 for sample structure. Young's Modulus is E_c=28500MPa. Young's Modulus are (E_d-1):1000 and (E_d-2) :2850 MPa for infill walls. The beam and column sections are 0.25 m X 0.45 m and 0.40 m X 0.40 m respectively. Story height is 3 m. Total story height is 30 m.The thicknesses of equivalent bracings and representing infill walls are exterior wall 10 cm. The sample structure is assumed to be in 1st earthquake zone according to Turkish design code'98 (25). Equivalent earthquake static loads are determined by using live loads, dead loads and story weights. The plan of the sample structure are given in figure 4. The sample structure is analyzed as 2 different infill wall applications with shear wall as given in Figure 6 to determine the effects of possible infill wall applications on the structural response.

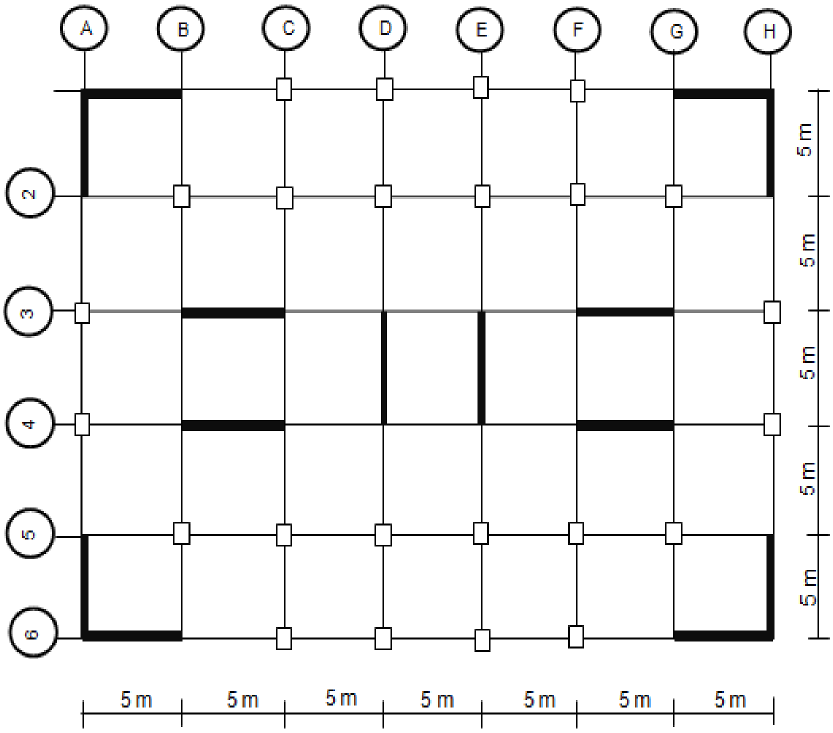

Figure 4 Plan of the Sample Structure

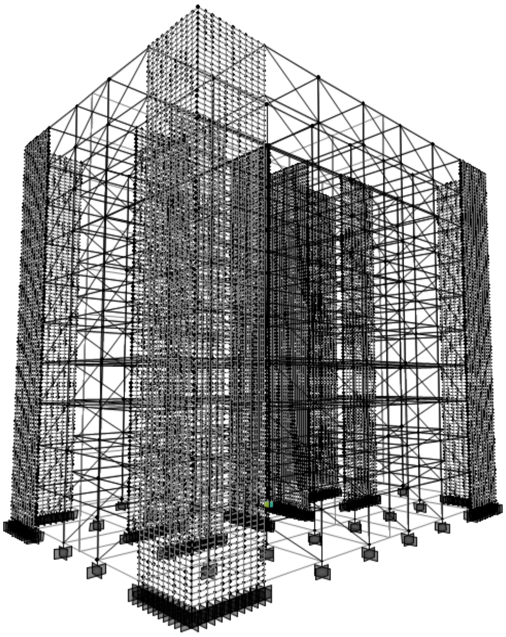

Figure 5 View of the three dimensional structure in SAP2000N

The analysis of building gave the master plan in Fig 4. was solved in 3 types. While in the first analysis, wall was not placed in the system when building wall was evaluated as weigth, in the remaining two solution, wall was reflected as both of weigth and model. Thus, The results were evaluated by analysis of with or without shear wall.

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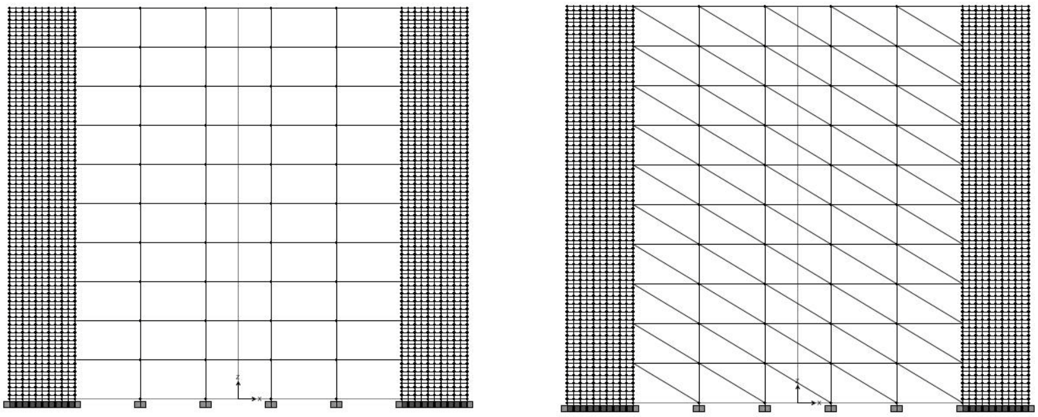

Model 1

Model 2

Figure 6 Infill Wall Models

Table 2 Story Weights of Structure

Modulus of Elasticity for Wall	Kat	W_i(t)		
		DSÇ	DÇ	FEM
		1	2	3
E-1	**N**	770.83	770.83	770.83
	Ç	757.70	757.70	757.70
	W	7695.13	7695.13	7695.13
E-2	**N**	770.83	770.83	770.83
	Ç	757.70	757.70	757.70
	W	7695.13	7695.13	7695.13

Table 3 Thickness of Equivalent Struts (w)

w(m)	
Tuğla Duvar Kalınlıkları	
L(m)	**10'luk**
5**(E-1)**	0.81
5**(E-2)**	0.77

Table 4 The Values Of Period And Shear Force According to Different Elasticity Values In Towards to the X Direction in Ten Floors of Building

Elasticity Modulus of Wall	V_t (t)		Period (sn)	
	DSÇ	DÇ	DSÇ	DÇ
	1	2	1	2
E-1	361.73	804.07	2.04	0.75
E-2	361.73	961.89	2.04	0.54

According to the changes of modulus of elasticity with period and shear force values have been given in Table 4. Calculations that were carried out by with equivalent compression strut models were compared with according to the both frame infill wall and bare frames. It was observed that values of shear force were increased while values of period were decreased by supported of infill wall to system.

Table 5 Minimum and Maximum Displacements of Building Towards to The X Direction in the First and Tenth Floors

Frame Systems	First Floor			
	Minimum and Maximum Displacements			
	E-1		E-2	
	$(d_i)_{min}$	$(d_i)_{max}$	$(d_i)_{min}$	$(d_i)_{max}$
	(m)		(m)	
DSÇ	0.00585	0.00657	0.00585	0.00657
DÇ	0.00087	0.00094	0.00093	0.00101
Frame Systems	**Tenth Floor**			
	Minimum and Maximum Displacements			
	E-1		**E-2**	
	$(d_i)_{min}$	$(d_i)_{max}$	$(d_i)_{min}$	$(d_i)_{max}$
	(m)		**(m)**	
DSÇ	0.07339	0.08168	0.07339	0.08168
DÇ	0.03522	0.03764	0.03406	0.03634

Table 6 Control of Torsional Irregularity and Rigidity Irregularity Towards to the X Direction in the Building

Floor No	Torsional Coefficients (η_{bi})			
	E-1 (1000) MPa		E-2 (2850) MPa	
	DSÇ	DÇ	DSÇ	DÇ
10	1.0516	1.0328	1.0516	1.0317
2	1.0922	1.0529	1.0921	1.0528
1	1.0000	1.0000	1.0000	1.0000
Floor No	**Rigidity Irregularity Coefficients (η_{ki})**			
	E-1 (1000) MPa		**E-2 (2850) MPa**	
	DSÇ	**DÇ**	**DSÇ**	**DÇ**
10	0.66	0.99	0.66	0.98
2	1.53	1.85	1.53	1.82
1	-	-	-	-

Table 7 Control of Relative Story Displacemet and Second Degree Value Towards to the X Direction

Floor No	Relative Story Displacemet Coefficients ($(\delta i)max/hi$)			
	E-1		E-2	
	DSÇ	DÇ	DSÇ	DÇ
10	0.0082	0.0123	0.0082	0.0082
1	0.0166	0.0024	0.0166	0.0166
Floor No	**Second Degree Value (θ_i)**			
	E-1		**E-2**	
	DSÇ	**DÇ**	**DSÇ**	**DÇ**
10	0.0083	0.0060	0.0083	0.0047

1	0.0432	0.0030	0.0432	0.0027

5. CONCLUSION

The results of the present study show that structural infill walls have very important effects on structural behavior under earthquake effects. Structural capacity under earthquake effect, displacement and relative story displacement are affected by the structural irregularities. Calculations that were carried out by with equivalent compression strut models were compared with according to the both frame infill wall and bare frames. It was observed that values of shear force were increased while values of period were decreased by supported of infill wall to system.

Regarding with the results of the, especially, infill walls have very important effects on structural behavior. In the present study, the infill walls are under investigation dynamics and static analyses. 10-story R/C frame structure is used and this structure is designed according to (25) and (26). 2 different Models of this structure with different wall application are taken into consideration for analyses. The results of dynamics analysis show that …The stability and integrity of reinforced concrete frames are enhanced with masonry infill walls. Presence of masonry infill wall also alters displacements and base shear of the frame. Irregular distributions of masonry infill walls in elevation can result in unacceptably elastic displacement in the soft storey frame. The behavior of structure with infilled walls can be predicted by means of simplified diagonal models. Relatively simple and accurate approach can be obtained by using these models for including the effects of the infill walls.

6. REFERENCES

[1] Fiorato, A.E, Sozen, M.A and Gamble, W.L. (1970) An investigation of the interaction of reinforced concrete frames with masonry filler walls. *Report UILU-ENG-70-100*. Department of Civil Engineering, University of Illinois,Urbana-Champaign IL, USA

[2] Klingner, R.E. and Bertero, V.V. (1976) Infilled frames in earthquake-resistant construction. *Report EERC/76-32*. Earthquake Engineering Research Center, University of California, Berkeley, CA, USA.

[3] Bertero, V.V. and Brokken, S. (1983) Infills in seismic resistant building. *Journal of Structural Engineering.,* ASCE. 109(6). 1337–1361.

[4] Zarnic, R. and Tomazevic, M. (1985) Study of the behaviour of masonry infilled reinforced concrete frames subjected to seismic loading. *Proceedings of the 7th International Conference on Brick Masonry*, 1315–1325. Australia.

[5] Schmidt, T. (1989) Experiments on the nonlinear behaviour of masonry infilled reinforced concrete frames. Darmstadt Concrete, *Annual Journal on Concrete and Concrete Structures*. 4, 185–194.

[6] Mehrabi, A.B, Shing, P.B, Schuller, M.P and Noland, J.L. (1994) Performance of masonry-infilled r/c frames under in-plane lateral loads. *Report CU/SR-94–6*, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder CO, USA.

[7] Mehrabi, A. B, Shing,P.B, Schuller,M.P and Noland, J. L. (1996) Experimental evaluation of masonry infilled rc frames. *Journal of Structural Engineering*, ASCE 122(3), 228–237

[8] Angel,R, Abrams, D, Shapir, D, Uzarski, J and Webster, M. (1994) Behaviour of reinforced concrete frames with masonry infills. *Report No. UILU-ENG-94-2005*. Department of Civil Engineering, University of Illinois, Urbana-Champaign, IL, USA.

[9] Dhanasekar, M, Page, A.W and Kleeman, P.W. (1985) The behaviour of brick masonry under biaxial stress with particular reference to infilled frames. *Proceedings of the 7th International Conference on Brick Masonry*, Melbourne, Australia, 815–824.

[10] Dawe, J.L. and Seah, C.K. (1989) Behaviour of masonry infilled steel frames. *Journal of the Canadian Society of Civil Engineering*, 16, 865–876.

[11] Mander , J.B, Nair, B, Wojtkowski, K and Ma, J. (1993) An experimental study on the seismic performance of brick-infilled steel frames with and without retrofit. *Report NCEER-93-0001*, National Center for Earthquake Engineering Research, State University of New York, Buffalo, NY, USA.

[12] Mosalam, K.M, White, R.N and Gergely, P. (1997) Static response of infilled frames using quasi-static experimentation. *Journal of Structural Engineering*, ASCE, 123(11), 1462–1469.

[13] Buonopane, S.G and White, R.N. (1999) Pseudodynamic testing of masonry infilled reinforced concrete frame. *Journal of Structural Engineering*, ASCE,125(6),578–589.

[14] Flanagan, R.D. and Bennett, R.M.(1999) In-plane behaviour of structural clay tile infilled frames. *Journal of Structural Engineering* ASCE, 125(6), 590–599.

[15] Stafford, S.B. Lateral stiffness of infilled frames. *Journal of the Structural Division.*, ASCE, 1962, 88(6),183–199.

[16] Dawe, J.L. and Seah, C.K. (1989) Out-of-plane resistance of concrete masonry infilled panels. *Journal of the Canadian Society of Civil Engineering*, 16, 854–864.

[17] Holmes, M. (1961) Steel frames with brickwork and concrete filling. Proceedings of the Institute of Civil Engineers, 19(6501), 473–478.

[18] Stafford, S.B. (1966) Behaviour of square infilled frames. Journal of the Structural Division, ASCE, 92(1), 381–403.

[19] Stafford, S.B. (1967) Methods for predicting the lateral stiffness and strength of multi-storey infilled frames. *Building Science*, 247–257.

[20] Mainstone, R.J. and Weeks, G.A. (1970) The influence of bounding frame on the racking stiffness and strength of brick walls. *Proceedings of the 2nd International Conference on Brick Masonry*, Stoke-on-Trent, UK, 165–171.

[21] Budak, A.(1997) Dolgu Duvarlı Çerçevelerin Sonlu Elemanlar Yöntemi İle Malzeme Bakımından Doğrusal Olmayan Hesabı. *Doktora Tezi,* Karadeniz Teknik Üniversitesi, 125s.

[22] Yalcın, E. (1999) Dolgu Duvarları ve Konumlarının Çok Katlı Betonarme Yapıların Deprem Kuvvetleri Altındaki Davranışına Etkileri. *Yüksek Lisans Tezi,* İTÜ, 67s.

[23] Tuzun,C.(1999) Dolgu Duvarlı Betonarme Çerçeve Sistemlerin Dinamik Analizi.*Yüksek Lisans Tezi,* Yıldız Teknik Üniversitesi, 104s.

[24] Çagatay, İ. H. And Güzeldag, S. (2002) *Yeni Deprem Yönetmeliği (TDY 98) SAP2000N Uygulamaları*. Birsen Yayınevi, 213s. İstanbul.

[25] Turkish Code, (ABYYHY). (1998) Afet Bölgelerinde Yapılacak Yapılar Hakkında Yönetmelik Bayındırlık ve İskan Bakanlıgı Afet İsleri, Ankara.

[26] TS 500. (2000) Turkish Standard Betonarme Yapıların Tasarım ve Yapım Kuralları.T.S.E. Ankara.