An Overview of the Modelling of Infill Walls in Framed Structures

Uğur Albayrak, Eşref Ünlüoğl, and Mizam Doğan
Dept. of Civil Engineering, Eskisehir Osmangazi University, Eskisehir, Turkey
Email: {albayrak, esrefu, mizan}@ogu.edu.tr

***Abstract*—Infill walls are considered to non-bearing structural members but affect not only structure masses also lateral rigidities which may cause free vibration behavior of the buildings. Although infill walls are not considered structural members, they are acting together with the frame when subjected to seismic loads. Analyze and calculation models including infill wall contribution are difficult and complex especially on major construction projects. Behavior of masonry infilled R.C. frames under seismic loads should be modeled to consider the effect of the infill walls on the seismic performance of the structure. In this study an overview of the modelling methods of infill walls in reinforced concrete frames is presented. The advantages or disadvantages of the presented methods are discussed and an easy and effective procedure is suggested for using in practice design.**

***Index Terms*—infill wall, masonry, infilled frame, modelling**

I. Introduction

Turkey is an earthquake country that more than 92% of its territory is exposed to seismic hazards and 95% of the total population lives under high earthquake damage risk according to earthquake zones map of Turkey [1]. In last decade some major earthquakes causing light, medium or heavy damages (The 6th major earthquake in last century with 20 Billion USD $ economic losses) on more than 245.000 buildings in the Marmara Region subjected to 17 August 1999 Marmara Earthquake [2].

Infill walls which are placed in the gaps between the structural members composed of columns and beams play a significant role under seismic loads. According to Turkish Seismic Code 2007 [3], infill walls are only accepted as vertical uniform loads on beams and floors on the design of reinforced concrete structures. On the existing analysis and design techniques; beams, columns and slabs of reinforced concrete framed buildings are assumed to be load-bearing members while the contribution to rigidity and strengths are ignored. In other words, stiffness and strength of a brick infill wall is not taken into account while modeling reinforced concrete framed structures in practice. On the other hand, infill walls in framed structures affect the dynamic characteristics of the building such as stiffness, strength and ductility of the entire structure and response to earthquakes.

Manuscript received January 21, 2016; revised August 21, 2016.

The infill walls are considered to non-bearing structural members but affect not only structure masses also lateral rigidities which may cause free vibration behavior of the buildings. Although infill walls are not considered structural members, they are acting together with the frame when subjected to seismic loads. There is a widespread scientific literature on reinforced concrete frames with masonry infills to assess the effect of the relative strength and stiffness of an infill with respect to the bounding frame [4]-[9]. According to the research or investigations about the damages on reinforced concrete building members during earthquakes, large residual deformations on infill walls are observed. Infill walls are cracked instantly under a seismic activity in this way resist earthquake forces substantially and mitigate seismic impacts by cracking [10]. Despite the presence of infill walls increase the lateral rigidity of the structure, in some cases as a result of the uncontrolled infill wall construction, the distance between the location of the center of rigidity and the floor center of mass is changed. This shift causes torsion and/or short column behavior at some part of the structure. The seismic behavior of bare framed structure and the frames with infill walls are not same in this way infill walls should be considered on the design of structures.

II. Behavior of Masonry Infilled R.C. Frames Subjected to Seismic Loads

The effect of infill walls on structural rigidity of whole structure are ignored despite the fact that reinforced concrete frames with infill walls are the most commonly used building systems. Analyze and calculation models including infill wall contribution are difficult and complex especially on major construction projects. Behavior of masonry infilled R.C. frames under seismic loads should be modeled to consider the effect of the infill walls on the seismic performance of the structure.

The gaps occurred between the frame elements (beam or columns) and the walls and the cracks on the walls are the most important parameters for structural design if infill walls are considered as structural members.

Determination of the maximum load capacity and the behavior of the frames with infill walls subjected to seismic forces are complex and questionable problems. Seismic response of infilled frames has long been investigated analytically and experimentally. According to the researches, infill walls and frame elements move

doi: 10.18178/ijscer.6.1.24-29

together as shear walls in cases where minor seismic forces exposed to. In case of increment on load and horizontal displacement, some deformations occur on the elements. Cracks occur along the diagonal of ınfill wall with applied lateral load and in the middle part of wall while the gaps are formed between the opposite corners of the diagonal line and infill. On the other hand, the corners on the loading directions of the diagonal are conglutinated with the frame shown in Fig. 1.

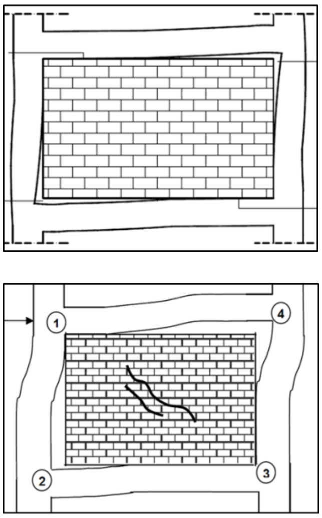

Figure 1. Infill wall – R.C. frame elements interaction under lateral movement.

III. Modelling of Masonry Infilled Frames

Analytic modelling of masonry infill frames comprise different parameters as infill bricks, mortars and friction surfaces between frame elements and infill wall etc. There are two different main approaches for the modelling of infill walls which are Micro Modelling and Macro Modelling.

The main difference between two methods is precision that micro modelling dealing with all individual components brick, block unit and mortar while macro modelling consider the all masonry as a composite unit shown in Fig. 2. [11].

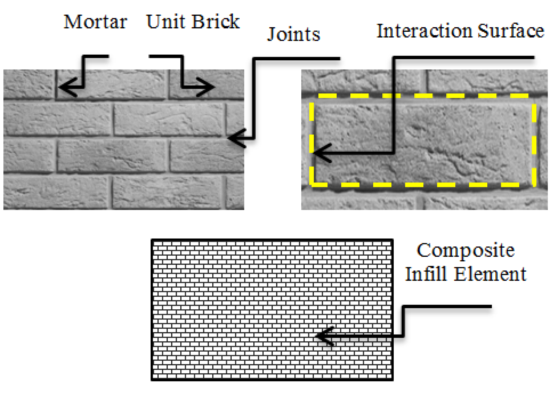

Figure 2. Analytic modelling of masonry infill [11] (a) detailed micro-modeling; (b) simplified micro-modeling; (c) macro-modeling

Macro models are used to investigate the overall response of the infill wall. Modelling of a wall using macro elements can be defined as using different type of springs instead of structural elements [12]. The behavior of macro models are based on physical behavior of infill walls. Mortar joints and units are recognized together considering collective mechanical and physical properties to obtain more simplified solution especially for large scaled models.

Micro-modeling is used generally to understand the local behavior of masonry infills. Inelastic properties of both unit and mortar and some mechanical properties as Young's modulus, Poisson's ratio are taken into account in detailed micro-modeling. On the other hand, each joint on infill wall is consisting of mortar and the two interface surfaces for simplified micro-modeling method. Infill consisting of elastic blocks interconnected with fracture tracks at the joints [11].

The main difference between macro model and micro model is the local failure modes. Macro model do not consider the effects of all prospective local failure modes on the behavior of the infill while micro model is taken into account all the failure modes.

As a result about the modelling approaches of infill walls, there are two main different methods have been used. Micro model based on the finite element techniques while macro model is the equivalent strut method. Macro modeling is not capable of giving any further information about the failure mechanism of the frame and wall-frame interaction.

The main reason of using the equivalent strut method which is known as a part of macro modelling, is computational simplicity based on the physical understanding of the behavior of the infills. The following section presents a brief review about Equivalent Strut Model which is the most widely used approach on infill design and calculations.

A. *Equivalent Strut Model*

Numerous analytical investigations about infill walls in steel or reinforced concrete frames have been achieved over the few decades. The initial studies about the response of the composite infilled frames were conducted by Polyakov [13], Holmes [14], Smith and Carter [15], Klingner and Bertero [16] with experimental and analytical studies in order to understand linear behavior and complex disposition of infilled frames [17]. However, very wide experimental [18], [15], [19]-[22] and analytical researches [23]-[27] have been conducted in literature [28].

Polyakov is one of the leading people in this regard observed that the stress transmission between infill and frame elements are only occurs in the compression zone based on elastic theory [13]. According to Holmes study, infill wall can be simplified using equivalent diagonal struts which width of the strut is suggested as 1/3 of the diagonal length [14]. Smith and Smith-Carter developed the diagonal strut approach as two pin-connected diagonal struts made of the same material and thickness as the infill [15], [18].

Different concepts were proposed based on equivalent strut method considering frame/infill interaction. [29], [30]. Mainstone [29] proposed an empirical equation about strut width to model infill walls subjected to monotonic lateral loads using the equivalent strut approach. This empirical equation was developed by Mainstone&Weeks [31] subsequently, included in FEMA 274, FEMA 306, FEMA 356, Turkish Seismic Code-2007 [32]-[34], [3] and widely used nowadays. The equation considers initial stiffness and ultimate strength and stiffening and strengthening effect of the masonry infill.

A 1974 study by Kadir [30] indicated that the dimensions of the strut are affected by the adjacent columns and beam and proposed a formula to define diagonal strut dimensions. Mehrabi *et al*. [20] suggested that different levels of infill and circumambient frame strength as predictors for damage initiation for various story drift.

Some researchers proposed multiple strut models to illustrate the behavior of the infilled frames. Crisafulli [35] studied the effects of various multiple strut models on structural response of the infill walls in R.C. frames to obtain the stiffness of the structure and investigate the behavior of surrounding frame. The lateral stiffness of the structure has smaller values for two and three strut infill models. Nowadays, one equivalent diagonal strut model extensively used to model infills because of simple and reasonable procedure to characterize the effect of the masonry infills on surrounding frame.

1) Failure mechanism for infill panels and the stiffness and strength of the strut.

In literature, different strut models were suggested to predict the stiffness and strength of the struts which based on strength assessment and equivalent width calculation.

Liauw and Kwan [23] suggested that the failure mode varies by panel aspect ratio and relative strengths of the frame elements and infill.

In the model by Decanini and Fantin [36] the axial strength of the strut in different failure modes is investigated. The infill struts are taken into account to be ineffectual in tension. However, the combination of both diagonal struts provides seismic load resistance mechanism for x or y direction of loading. According to the test results a hysteresis model for infill panel under monotonic lateral loads has been proposed by Decanini *et al*. [37].

Four main failure modes of the infill walls were defined in literature given below: [38]

1) Shear failure with bed-joint sliding,
2) Cracking because of diagonal tension,
3) Crushing of the infill at corner points,
4) Diagonal compression failure.

Simplified strut models which are compatible with experimental results consider different failure and collapse modes shown in Table I.

TABLE I. FAILURE MODES OF INFILL PANELS WITH REFERENCE TO THE PRESENTED MODELS

Research	Failure mode of the infill			
	Shear (1)	Cracking (2)	Crushing (3)	Compression(4)
FEMA 306 [33]	+	+	+	-
FEMA 356 [34]	+	+	+	-
Turkish Seismic Code [3]	+	+	+	-
Liauw & Kwan [23]	-	-	+	+
Decanini & Fantin [36]	+	+	+	+
Paulay & Priestley [39]	+	+	-	+
Priestley & Calvi [40]	+	+	-	+
Saneineja d&Hobbs [25]	+	+	+	+

NOTE: (1) Shear failure with bed-joint sliding, (2) Cracking because of diagonal tension, (3) Crushing of the infill at corner points, (4) Diagonal compression failure.

2) Determination of the width of the diagonal strut

The rigidity and strength properties to be used so as for the filled walls to be presented in the model are defined. Infill walls that are designed in R.C. frames and the ratio of the diagonal length to the thickness for which is below 30 consider for structural modeling. The walls that include splicing the ratio of which to wall surface does not exceed 10 % may be included in the structure modeling provided that the positions of the splicing do not prevent the formation of diagonal compression strut [3].

In literature many suggestions have been proposed about the width of the strut w in terms of diagonal length d. As a simple conclusion that failure of an infill wall has been calculated by multiplying the compressive strength of infill material to the area of equivalent strut. The axial stiffness of the strut can be determined as:

$$k_m = \frac{E_m\, t\, w}{d} \quad (1)$$

where k_m is axial stiffness of the strut, w is the width of the strut and d is length of the strut, E_m is the modulus of elasticity of masonry and t is the panel thickness shown in Fig. 3. [38].

Stafford Smith (1966) [18] proposed a formula to calculate the width of the diagonal strut based on the relative stiffness named λ_h. The expression of non-dimensional λ_h have also been suggested by Kadir [30], Liauw and Kwan [23], Decanini and Fantin [36], FEMA-306 [33] and Turkish Seismic Code [3] given in Eq. (2).

$$\lambda_h = \sqrt[4]{\frac{E_m\, t\, (Sin\, 2\theta)}{4\, E_f\, I_c\, h_m}} \quad (2)$$

where: E_m is the modulus of elasticity of the masonry infill, E_f is the modulus of elasticity of the frame elements (for concrete on R.C. frames), t is the thickness of the infill, I_c is the moment of inertia of the columns, h_m is the high of the infill and θ is the slope angel of the panel's diagonal.

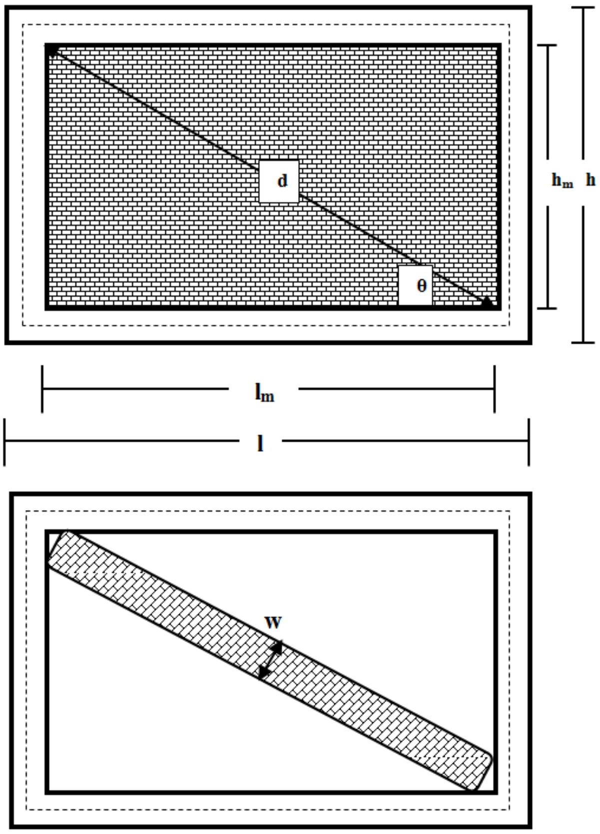

Figure 3. Equivalent strut modelling of masonry infill

TABLE II. EQUATIONS USED FOR STRUT WIDTH (W) CALCULATION

Research	Equivalent Strut Width (w)	Special Remarks	
Holmes[14]	$w = \frac{1}{3}\, d$		
Fema 306[33]	$w = 0.175\, d\, (\lambda_h)^{-0.4}$		
Mainstone [29]	$w = 0.175\, d\, (\lambda_h h)^{-0.4}$		
Liauw & Kwan [23]	$w = \frac{0.95\, Cos\,\theta\, h_m}{\sqrt{\lambda_h}}$	$25^0 < \Theta < 50^0$	
Decanini & Fantin [36]	$w = \left(\frac{k_1}{\lambda_h} + k_2\right) d$	$\lambda_h < 3.14$	$k_1 = 1.300$
			$k_2 = -\,0.178$
		$3.14 < \lambda_h < 7.85$	$k_1 = 0.707$
			$k_2 = 0.010$
		$7.85 < \lambda_h$	$k_1 = 0.470$
			$k_2 = 0.040$
Paulay & Priestley [39]	$w = \frac{1}{4}\, d$		
Priestley & Calvi [40]			
Saneinejad & Hobbs [25]	$w = min\,(w_1\,; w_2)$	$w_1 = \frac{(1-\alpha_c)\alpha_c\, h\frac{\sigma_c}{f_c} + \alpha_b\, l\frac{\tau_b}{f_c}}{Cos\,\theta}$	
		$w_2 = 0.5\, h_m \frac{f_a}{f_c}\frac{1}{Cos\,\theta}$	
Turkish Seismic Code [3]	$w = 0.175\, d\, (\lambda_h h)^{-0.4}$		
Smith & Carter [15]	$w = 0.58\, (\frac{1}{h_m})^{-0.445}\, (\lambda_h h\,)^{0.335\, d\, \left(\frac{1}{h}\right)^{0.064}}$		
Kadir [30]	$w = \frac{\pi}{2}\left(\frac{1}{4\,\lambda_h} + \frac{1}{4\,\lambda_g}\right)$	$\lambda_g = \sqrt[4]{\frac{E\, t\, (Sin\, 2\theta)}{4\, E_f\, I\, h}}$	
Hendry[41]	$w = 0.5\, \sqrt[2]{\alpha_h + \alpha_l}$	$\alpha_h = \frac{\pi}{2}\left(\frac{E\, I\, h_m}{2E_m\, t\, \sin 2\theta}\right)^{1/4}$	
		$\alpha_l = \pi\left(\frac{E_c\, I_c\, l}{2E_m\, t\, \sin 2\theta}\right)^{1/4}$	

A large number of researchers proposed different equations about the width of the strut w. These equations are briefly described in Table II.

On the other hand; there are many developments on modelling of the infill panels in recent years and this paper also reviews the last advances on infill modelling. Total collapse behaviors of reinforced concrete frames have been examined by various experimental programs and as a result failure mode and ductility of the frames depend on the development of big cracks on the infill walls [42]-[44]. However these behaviors can be modelled linear or nonlinear by 3D discrete-finite-element models to investigate the in-plane or out-of-plane behaviors and strength of concrete masonry infills [45]-[48].

IV. CONCLUSIONS

In this paper contribution of infill walls on the seismic performance of framed structures were investigated and an overview of the modelling methods of infill walls in reinforced concrete frames is presented widely.

Various researchers proposed different analytical models to describe the behavior of the frames with infill walls. There are two main different approaches on modelling infill panels have been used. Micro model based on the finite element techniques while macro model is the equivalent strut method. One of the analytical models –macro modelling- has been used widely due to simple and efficient computational process. On the other hand, macro modeling is not capable of giving any further information about the failure mechanism of the frame and wall-frame interaction.

Equivalent strut method based on the determination of the strut width which depends on the aspect ratio and used material and investigation the effect of infill walls on strength and stiffness.

Different strut models have been suggested to illustrate the behavior of the infilled frames. Simplified strut models that are compatible with experimental results consider various failure and collapse modes.

There are many different calculation methods and equations to define the width of the diagonal strut (w) based on the relative stiffness. The equivalent strut width vary between 10 % and 30 % of the strut length based on different equations while the results obtained from flexural model in compliance with some researches [39],

[14], [23], [41]. The Liauw and Kwan model [23] is the most stiff strut model.

The strut width value calculated with respect to Turkish Seismic Code [3] is equal to 11.5% of the strut length is smaller than the results obtained from other equations which are in the range of 23% - 30%.

More attentions need to be desirably paid in the future to the following aspects which are the damage level in infill walls and the effects of openings on the seismic performance of infilled frames. Especially the contribution of the infill panels to the lateral strength and rigidity of entire structure should be considered in national codes particularly in terms of more realistic modelling.

Acknowledgment

This paper was conducted as a part of the PhD thesis named "Investigation of In-plane and Out-of-plane Behaviour of Infilled Frames under Earthquake Loading" of the first author.

References

[1] EU & UNDP (2013): Natural Disaster Risks and Risk Assessment in South East Europe. www.gripweb.org/gripweb/sites/default/files/disaster_risk_profiles/SEE%20DRR%20Risk%20Assessment%20Report-Final.pdf

[2] U. Albayrak, M. Canbaz, and G. Albayrak, "A rapid seismic risk assessment method for existing building stock in urban areas," *Procedia Engineering*, vol. 118, pp. 1242-1249, 2015.

[3] Turkish Republic the Ministry of Public Works and Settlement, Turkish Earthquake Design Code TEC-2007, Ankara, Turkey, 2007.

[4] P. G. Asteris and D. M. Cotsovos, "Numerical investigation of the effect of infill walls on the structural response of RC frames," *The Open Construction and Building Technology Journal*, vol. 6, pp. 164-181, 2012.

[5] G. Mondal and S. K. Jain, "Lateral stiffness of masonry infilled Reinforced Concrete (RC) frames with central opening," *Earthquake Spectra*, vol. 24, no. 3, pp. 701–723, 2008.

[6] R. Davis, P. Krishnan, D. Menon, and A. Prasad, "Effect of infill stiffness on seismic performance of multi-storey RC framed buildings in India," presented at The 13th World Conference on Earthquake Engineering, Vancouver, BC, Canada, 2004.

[7] D. Kakaletsis and C. Karayannis, "Influence of masonry strength and openings on infilled R/C frames under cycling loading," *Journal of Earthquake Engineering*, vol. 12, 2008.

[8] G. Manfredi, P. Ricci, and G. Verderame, "Influence of infill panels and their distribution on seismic behavior of existing reinforced concrete buildings," *Open Construction Building Technolgy Journal*, vol. 6, pp. 236–253, 2012.

[9] K. Mosalam, G. Ayala, R. White, and C. Roth, "Seismic fragility of LRC frames with and without masonry infill walls," *Journal of Earthquake Engineering*, vol. 1, pp. 693–720, 1997.

[10] U. Albayrak, "Investigation of in-plane and out-of-plane behaviour of infilled frames under earthquake loading," PhD. thesis, ESOGU Graduate School of Natural and Applied Science, 2016.

[11] P. B. Lourenço, "Computations on historic masonry structures," *Progress in Structural Engineering and Materials*, vol. 4, pp. 301–319, 2002.

[12] S. Y. Chen, F. Moon, and T. A. Yi, "Macroelement for the nonlinear analysis of in-plane unreinforced masonry piers," *Engineering Structures*, vol. 30, no. 8, pp. 2242–2252, 2008.

[13] S. V. Polyakov, "On the interactions between masonry filler walls and enclosing frame when loaded in the plane on the wall," *Translations in Earthquake Engineering*, Research Institute, Moscow, 1956.

[14] M. Holmes, "Steel frames with brickwork and concrete infilling," *Proceedings of the Institution of Civil Engineers*, pp. 473-478, 1961.

[15] B. S. Smith and C. Carter, "A method of analysis for infilled frames," *Proceedings of the Institution of Civil Engineers*, no. 7218, pp. 31-48, 1969.

[16] R. E. Klingner and V. V. Bertero, "Earthquake resistance of infilled frames," *Journal of Structural Engineering*, vol. 104, no. 6, pp. 973-989, 1978.

[17] E. Rosenblueth, *Design of Earthquake Resistant Structures*, John Wiley & Sons, New York, 1981.

[18] B. S. Smith, "Behavior of the square infilled frames," *Journal of Structural Division*, vol. 92, pp. 381-403, 1966.

[19] A. W. Page, P. W. Kleeman, and M. Dhanasekar, "An in-plane finite element model for brick masonry," in *Proc. A Session Held in Conjunction with Structures Congress New Analysis Techniques for Structural Masonry*, Chicago, Illinois, 1985, pp. 1-18.

[20] A. B. Mehrabi, P. B. Shing, M. Schuller, and J. Noland, "Experimental evaluation of masonry-infilled RC frames," *Journal of Structural Engineering*, vol. 122, no. 3, pp. 228-237, 1966.

[21] S. G. Buonopane and R. N. White, "Pseudodynamic testing of masonry-infilled reinforced concrete frame," *Journal of Structural Engineering*, vol. 125, no. 6, pp. 578-589, 1999.

[22] H. Santhi, G. S. Knight, and K. Muthumani, "Evaluation of seismic performance of gravity load designed reinforced concrete frames," *Journal of Performance of Construction Facilities*, vol. 19, no. 4, pp. 277-282, 2005.

[23] T. C. Liauw and K. H. Kwan, "Nonlinear behaviour of non-integral infilled frames," *Computers and Structures*, vol. 18, pp. 551-560, 1984.

[24] M. Dhanasekar and A. W. Page, "Influence of brick masonry infill properties on the behavior of infilled frames," *Proceedings of the Institution of Civil Engineers*, vol. 2, no. 81, pp. 593-605, 1986.

[25] A. Saneinejad and B. Hobbs, "Inelastic design of infilled frames," *Journal of Structural Engineering*, vol. 121, no. 4, pp. 634-650, 1995.

[26] P. G. Asteris, "Lateral stiffness of brick masonry infilled plane frames," *Journal of Structural Engineering*, vol. 129, no. 8, pp. 1071-1079, 2003.

[27] H. A. Moghaddam, "Lateral load behavior of masonry infilled steel frames with repair and retrofit," *Journal of Structural Engineering*, vol. 130, no. 1, pp. 56-63, 2004.

[28] R. E. Angel, "Behavior of reinforced concrete frames with masonry infill walls," *University of Illinois at Urbana-Champaign*, p. 368, 1994.

[29] R. J. Mainstone, "On the stiffnesses and strengths of infilled frames," *Proceedings of the Institution of Civil Engineers*, pp. 57-90, 1971.

[30] M. R. A. Kadir, "The structural behaviour of masonry infill panels in framed structures," PhD thesis, University of Edinburgh, 1974.

[31] R. J. Mainstone and G. A. Weeks, "The influence of bounding frame on the racking stiffness and strength of brick walls," in *Proc. 2nd International Brick Masonry Conference*, Building Research Establishment, Watford, England, 1970, pp. 165-171.

[32] Federal Emergency Management Agency, NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings, FEMA-274, Applied Technology Council, Washington, DC, 1997.

[33] Federal Emergency Management Agency, Evaluation of Earthquake Damaged Concrete and Masonry wall Buildings: Basic Procedures Manual, FEMA-306, Applied Technology Council, Washington, DC, 1998.

[34] FEMA-356, Prestandard and Commentary for the Seismic Rehabilitation of Buildings, Building Seismic Safety Council, Washington (DC), 2000.

[35] F. J. Crisafulli, "Seismic behaviour of reinforced concrete structures with masonry infills," University of Canterburry, Canterbury, 1997.

[36] L. D. Decanini and G. E. Fantin, "Modelos simplificados de la mamposteria incluida en porticos. Caracteristicas de rigidez y resistencia lateral en estado limite," *Jornadas Argentinas de Ingenieria Estructural*, Buenos Aires, Argentina, vol. 2, pp. 817-836, 1986.

[37] L. Decanini, C. Gavarini, F. Mollaioli, and S. H. Bertoldi, "Modelo simplificado de paneles de mamposteria con aberturas incluidos en marcos de concreto reforzado y metalicos.

Comparacion y calibracion con resultados experimentales y numericos," in *Proc. 9th International Seminar on Earthquake Prognostics*, San José, Costa Rica, 1994. (in Spanish).
[38] L. Liberatore and F. Mollaioli, "Influence of masonry infill modelling on the seismic response of reinforced concrete frames", in *Proc. Fifteenth International Conference on Civil, Structural and Environmental Engineering Computing*, p. 87, 2015.
[39] T. Paulay and M. J. N. Priestley, *Seismic Design of Reinforced Concrete and Masonry Buildings*, John Wiley & Sons. Inc., 1992.
[40] M. J. N. Priestley and G. M. Calvi, "Towards a capacity-design assessment procedure for reinforced concrete frames," *Earthquake Spectra*, vol. 7, no. 3, pp. 413-437, 1991.
[41] A. W. Hendry, *Structural Masonry*, 2_{nd} ed. *Macmillan Press*, 1998.
[42] S. Li, S. Shan, C. Zhai, and L. Xie, "Experimental and numerical study on progressive collapse process of RC frames with full-height infill walls," *Engineering Failure Analysis*, vol. 59, pp. 57-68, 2016.
[43] S. Shan, S. Li, S. Xu, and L. Xie, "Experimental study on the progressive collapse performance of RC frames with infill walls," *Engineering Structures*, vol. 111, pp. 80-92, 2016.
[44] S. H. Basha and H. B. Kaushik, "Behavior and failure mechanisms of masonry-infilled RC frames (in low-rise buildings) subject to lateral loading," *Engineering Structures*, vol. 111, pp. 233-245, 2016.
[45] A. Mohyeddin, H. M. Goldsworthy, and E. F. Gad, "FE modelling of RC frames with masonry infill panels under in-plane and out-of-plane loading," *Engineering Structures*, vol. 51, pp. 73-87, 2013.
[46] X. Chen and Y. Liu, "Numerical study of in-plane behaviour and strength of concrete masonry infills with openings," *Engineering Structures*, vol. 82, pp. 226-235, 2015.
[47] Y. P. Yuen and J. S. Kuang, "Nonlinear seismic responses and lateral force transfer mechanisms of RC frames with different infill configurations," *Engineering Structures*, vol. 91, pp. 125-140, 2015.
[48] E. Martinelli, C. Lima, and G. D. Stefano, "A simplified procedure for Nonlinear Static analysis of masonry infilled RC frames," *Engineering Structures*, vol. 101, pp. 591-608, 2015.

Dr. Uğur Albayrak received his B.Sc.(Civil Engineering) and M.Sc (Structural Engineering) from Eskisehir Osmangazi University (ESOGU) Dept. of Civil Engineering, Turkey. and PhD. from Eskisehir Osmangazi University with the dissertation named "Investigation of In-plane and Out-of-plane Behaviour of Infilled Frames under Earthquake Loading. He is presently working as a research assistant at the same department. His main research interests include design of steel structures, R.C. structures, earthquake resistant design and computer applications in Civil Eng., and having more than 10 publications in national and international journals.

Dr. Eşref Ünlüoğlu received his B.Sc. from Eskisehir State Engineering and Architectural Academy (Civil Engineering); M.Sc. from Yildiz Technical University (Structural Engineering) and PhD. from Anadolu University (Structural Engineering), Turkey. He has been working as Professor at Civil Engineering Department of ESOGU and he is also head of civil engineering department now. His main research interests are steel structures, structural analysis and having more than 30 publications in national and international journals.

Dr. Mizam Doğan received his B.Sc.(Civil Engineering) and M.Sc (Structural Engineering) from Anadolu University and PhD. from Eskisehir Osmangazi University (Structural Engineering), Turkey. He has been working as Associate Professor at Civil Engineering Department of ESOGU and he is also vice chairman of civil engineering department now. His main research interests include earthquake resistant design, R.C. structures, structural analysis, prefabricated buildings, maintenance-rehabilitation of structures and having more than 30 publications in national and international journals.