



# Earthquake Vulnerability Assessment of RC Structures with Variable Infill Wall Properties

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## Abstract

The infill walls are often used to the aim of dividing the residential area to provide the architectural requirements according to purpose of use in residential RC structures. Although there is conflict about the infill walls occur a RC structure less vulnerable to earthquake impacts, the beneficial influence of the infill walls on dynamic and static behaviors of RC structures is generally thought. Therefore, understanding the contribution of the infill wall to structural behavior of RC structures is very significant in terms of the structural safety. This study investigates the influence of infill wall having variable mechanical properties as compressive strength and thickness on structural behavior and earthquakes performance of low-rise residential RC structures. In the study, the selected RC structures for earthquake vulnerability assessment are existing residential buildings. The nonlinear static analyzes are carried out for each direction by considering architectural plan of each of RC structure to determine influence of infill wall having variable properties on the structural and earthquake behavior. The target displacements, fundamental periods and relative drift ratio of each story of each RC structures are determined from analysis results. The analyzes are also made for the bare-frame cases of RC structures and are compared with behavior of infilled frames of them. When the results obtained in the this study are evaluated, the existing infill walls and differences in the its mechanical properties significantly affected earthquake vulnerability the RC structures, positively.

**Keywords:** RC structures, Earthquake vulnerability, Infill wall, Structural behavior

## Değişken Dolgu Duvar Özellikli Betonarme Yapıların Deprem Güvenliklerinin Değerlendirilmesi

### Öz

Betonarme yapılarda dolgu duvarlar genellikle yapının mimari gereksinimlerinden dolayı bölme elemanları olarak kullanılmaktadır. Dolgu duvarların deprem etkisine karşı daha zayıf olduğuna dair bir fikir birliği olmamasına rağmen yapının deprem davranışını genellikle olumlu etkilediği düşünülmektedir. Bu nedenle dolgu duvarların betonarme yapıların yapısal davranışına katkısının anlaşılması çok önemlidir. Bu çalışmada dolgu duvarın basınç dayanımı ve kalınlığı gibi mekanik özelliklerinin yapıların deprem davranışa ve performansına olan etkisi incelenmektedir. Bu amaçla, farklı yapısal özellikler sahip konut türü mevcut betonarme binalar seçilmiştir. Değişken özelliklere sahip dolgu duvarlı mevcut betonarme yapıların yapısal ve deprem davranışını incelemek için mimari planları da dikkate alınarak DBYBHY (2007) esaslarına göre her iki yatay doğrultuda doğrusal olmayan analizleri yapılmıştır. Analiz sonuçlarından her bir betonarme binaya ait hedef yerdeğiştirmeler, doğal titreşim periyotları ve görel kat öteleme değerleri belirlenmiştir. Dolgu duvarlı ve dolgu duvarsız çerçeve sistemlerin incelenmesi yapılmış ve karşılaştırılmıştır. Yapılan çalışmanın sonucunda dolgu duvarlar betonarme yapıların deprem performansına olumlu katkısı sağladığı ve duvarın basınç dayanımı ile kalınlığının yapısal davranış önemli ölçüde etkilediği görülmüştür.

**Anahtar Kelimeler:** Betonarme yapılar, Deprem güvenliği, Dolgu duvar, Yapısal davranış

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## 1. Introduction

Considering the loss of life and property, one of the most significantly natural disasters affecting mankind since its existence is earthquakes. For this reason, the largest and most important need of the time is to build safe structures against the earthquake forces. The elements that are commonly used as partitions in the frame systems of RC structures are the infill walls by considering the structural and architectural requirement in many part of the world. Therefore, understanding the seismic behavior of RC structures with wall during the earthquake and influence of factors affecting the earthquake performance of RC structures is very important.

In recent years, the structural behavior and design of frames with infill wall has been extensively investigated by many researchers. A comprehensive review of the study on frames with infill wall was reported through the mid-1980's by researches (Moghaddam & Dowling, 1997). Some experimental studies in the past have aimed to evaluate behavior of frames with infill wall to obtain formulations of limit strength and equivalent rigidity (Klingner & Bertero, 1978; Bertero & Brokken, 1983; Mander & Nair, 1994; Madan et al., 1997). The influence of infilled frames on the seismic behavior of RC frames has been investigated (Uva et al., 2012), pointing out some problems about the precision to the material parameters and the selection of the modelling. Chrysostomou and Asteris (2012) outlined the in-plane behavior and failure modes of infilled frames and provided simplified methods to predict these modes. The influence on the fundamental period of infilled frame with wall contribution to lateral rigidity of RC structures were evaluated (Ricci et al., 2011) and the contribution of frames with infill wall has been realized on the structural responses of frames by many researchers (Reinhorn, 1997; Nollet & Smith, 1998; Shota & Riddington, 2001; Pujol & Fick, 2010; Sattar & Liel, 2010; Hermanns et al., 2014; Korkmaz et al., 2015; Bas et al., 2017; Kaçım, 2017; Dilmaç et al., 2018). Similarly, some studies have been made to determine on seismic response of buildings with and without masonry infill wall using experimental evaluation, energy-based approach, probabilistic assessment or shaking-table test with the aim of improve effective strengthening techniques to develop their performance and prevent collapse (Dolsek & Fajfar, 2008; Penna et al., 2014; Sattar & Liel, 2016; Furtano et al., 2016; Merter et al., 2017; Tekeli & Aydın, 2017; Banavent-Climent et al., 2018; Peng & Guner, 2018; Dilmaç et al., 2018).

The single or multiple equivalent compressive diagonal strut assumption for the simulating the structural behavior of infill wall is defined to be sufficient in investigating the response of infilled frames of RC structures.

However, many method has been developed to investigate influence of nonlinear behavior of infill walls by the researches (Perera, 2005; Samoil'a, 2012; Dilmaç & Demir, 2019; Kareem & Guneyisi, 2018).

In the design and analysis of infilled frames with wall should properly consider the highly nonlinear behavior of structural system during the lateral forces. A study of design principles about the frames with infill wall has been occurred by Kaushik et al. (2006). The comprehensive studies on analytical modeling techniques of infilled frame structures was carried out by Crisafulli et al. (2000).

In the present study, the nonlinear analyzes are carried out by considering architectural plan of each RC structure to determine influence of infill wall having variable properties on the structural and earthquake behavior. The influence of infill walls having different compressive strength and variable thickness is examined on damage levels of load-carrying components and its impact on earthquake performance. The earthquake performance analysis of the RC structures are carried out by considering requirements of the Turkish Earthquake Code (TEC) (2007) and were analyzed by using the SAP2000 software program (CSI, 2002).

## 2. Single-strut model and plastic hinge model of infill wall

The single equivalent compressive diagonal strut assumption was used in the modeling of infill walls as show in Figure 1. Since attempts to model the behavior of building with the infill wall, theoretical findings and experimental observations have shown that a equivalent diagonal strut with mechanical properties and appropriate geometric can likely provide a solution to the uncertainties (Asteris et al., 2012).

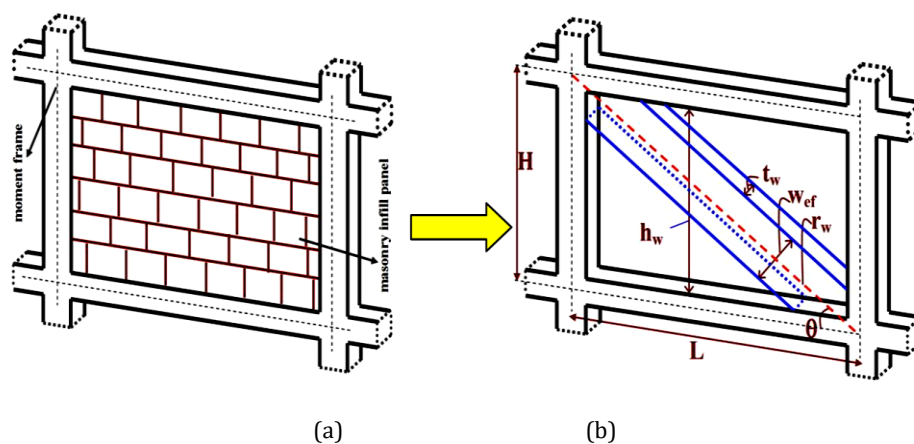


Figure 1: Modelling of infill wall as a diagonal struts

The width of infill wall ( $w_{ef}$ ), stiffness factor ( $\lambda_w$ ), elastic modulus of concrete ( $E_c$ ) and the masonry infill wall ( $E_m$ ) are considered by taken into account following equations as suggested in FEMA-356 (2000).

$$w_{ef} = 0.175(\lambda_w \cdot H)^{0.4} \cdot r_w \quad (1)$$

$$\lambda_w = \left( \frac{E_m t_w \sin 2\theta}{4E_c I_c h_w} \right) \quad (2)$$

$$\theta = \tan^{-1} \left( \frac{h_w}{L_w} \right) \quad (3)$$

$$E_c = 5000 \cdot f_{co}^{0.5} \quad (4)$$

$$E_m = 550 \cdot f_m \quad (5)$$

where H is height of story,  $t_w$  is thickness that considered as constant; 200 mm,  $\theta$  is angle of diagonal to horizontal in degrees is given in Eq. (3),  $h_w$  is height of wall, L is length of span of equivalent diagonal,  $f_{co}$  is the compressive strength of concrete in MPa. The  $f_m$  is the compressive strength of infill wall.

$$K_1 = \frac{G_w L_w t_w}{h_w} \quad (6)$$

$$K_2 = \frac{E_m a_w t_w}{r_w} \quad (7)$$

$$0.005 K_1 \leq K_3 \leq 0.1 K_1 \quad (8)$$

$$F_y = f_{tp} t_w L_w \quad (9)$$

$$S_y = \frac{F_y}{K_1} \quad (10)$$

$$F_m = 1.3 F_y, \quad 0 \leq F_r \leq 0.1 F_y \quad (11)$$

$$S_m = S_y + \frac{F_m - F_y}{K_2}, \quad S_r = S_m + \frac{F_m - F_r}{K_3} \quad (12)$$

where  $G_w$  is the shear modulus of the infill wall and is considered as equal to  $0.4E_m$  (Kakaletsis et al., 2011; Calerec et al., 2011; Uva et al., 2012). The yield load ( $F_y$ ) of the infill wall, the yield shortening ( $S_y$ ) of the infill wall, the maximum compression strength of the infill wall ( $F_m$ ) and the shortening ( $S_m$ ) at the  $F_m$  point and the axial shortening ( $S_r$ ) in case of mechanism were calculated by given equations.

The infill wall model of nonlinear behavior was defined by assigned axial load hinges on diagonal strut that features are defined (Panagiotakos & Fardis, 1996). The model is consist of three stages. The first state ( $K_1$ ) was defined (Fardis, 1996) the initial sliding behavior and the second stage ( $K_2$ ) shows the behavior of the infill wall after it has left the frame. The attenuation behavior of the infill wall was modelled at the last stage ( $K_3$ ) and was calculated given below. The force-displacement relation for the diagonal strut representing the infill wall is illustrated in Figure 2.

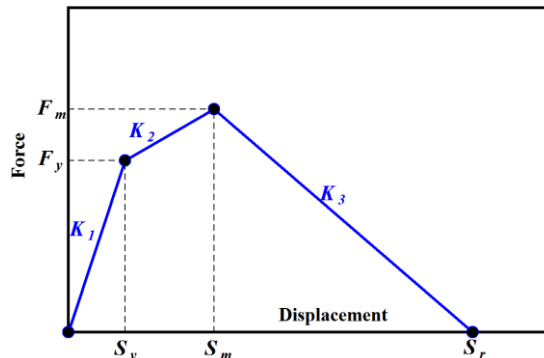


Figure 2: The force-displacement relationships of the compressive diagonal struts (Fardis, 1996)

### 3. Description of existing RC structures

The selected existing RC structures for analyzes have located in high-hazard zones in Turkey. The selected each existing RC structure are two variants of two, three, four and five-storey plane RC frame. The selected RC structures do not have a soft story, short columns, plan irregularities, vertical and plan irregularities of frames. The frames with infill wall and bare case of RC structures were modelled and analyzed with Sap2000 software program (CSI, 2002) by taken into account their architectural properties and project information. The structural behavior and earthquake performance of existing mid-rise RC structures were examined using nonlinear static procedure recommended by TEC (2007). The location of the infill walls in architectural plan was assigned for nonlinear analyzes. The some plans and 3D views of structures were given in Figure 3. In the modelling and the analyzes are also made for the bare-frame cases of RC structures to compare with behavior of infilled frames of them.

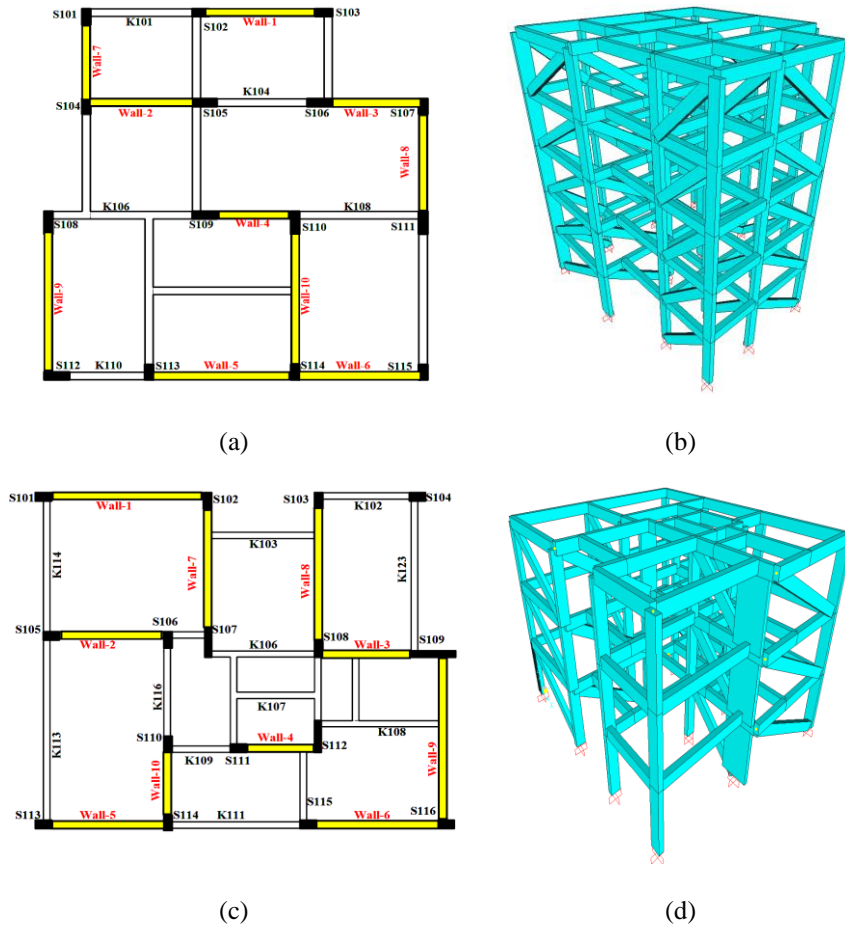


Figure 3: Plans and 3D views of some existing RC structures

### 4. Determination of analyzes parameters

In this study, the existing residential RC structures were modelled and analyzed according to different infill wall configurations that are walls having different value of compressive strength ( $f_m$ ) and thickness ( $t_w$ ). The nonlinear static analyzes were occurred for different values of the  $f_m$  and  $t_w$  of the infill walls.

The influence of  $f_m$  and  $t_w$  were investigated structural behavior and earthquake performance of RC structures. In order to better evaluate the influence of mechanical properties of walls on the structural behavior, strength of the concrete and steel were chosen low in the analyzes. The mean compressive strength of the concrete amounts to 10 MPa and the mean yield strength of steel amounts 220 MPa, respectively. In the analyzes, the  $f_m$  values were considered as 2.1 MPa, 4.1 MPa and 6.2 MPa by a factor as specified as poor, fair, good of wall condition that this classification was chosen by recommended in FEMA-273 (1997). In addition, in order to better investigate the influence of these parameters,  $f_m = 14$  MPa value was also analyzed. The pushover analyzes of existing RC structures was occurred according to each  $f_m$  values and each  $t_w$  values configurations. The configurations are given in Table 1. The case of the bare framed RC structures was encoded as Cs-0.

Table 1: The configurations of considered  $f_m$  and  $t_w$

Case (Cs)	Cs-1a	Cs-1b	Cs-1c	Cs-1d	Cs-2a	Cs-2b	Cs-2c	Cs-2d	Cs-3a	Cs-3b	Cs-3c	Cs-3d
$t_w$ (mm)	80	80	80	80	140	140	140	140	200	200	200	200
$f_m$ (MPa)	2	4	6	14	2	4	6	14	2	4	6	14

## 5. Analyzes results

The earthquake vulnerability assessment of RC structures can be largely determined accurately by determining the behavior under the seismic forces impacts. Therefore, pre-determination and evaluation of some important structural parameters about the provide sufficient database about the seismicity and safety of RC structures. Some of these parameters and possibly the most important ones are structure fundamental period, story displacements, damage levels of load-carrying elements and relationship of lateral load capacity and displacements. These parameters are important that are directly related to each other. In this study, the influence of the  $f_m$  and  $t_w$  on the structural parameters mentioned above is investigated by considering the analyzes results of different configurations of the  $f_m$  and  $t_w$  values.

The fundamental period of RC structure is an significant factor that contains many structural properties and it is directly related to rigidity of the RC structure. In the earthquake assessment, seismic demand of the structure is determined according to fundamental period. It is also know that the infill wall has an important state among the parameters affecting the rigidity of the structure. The results from the analyzes, the influence of the  $f_m$  and  $t_w$  changes on the period and target displacement can be observed for selected RC structures in Table 2 and Table 3, respectively.

It is know that fundamental period of structures directly influences the target displacement level. In the analyzes, the effect of the compressive strength of the wall is greater than the effect of weight on fundamental period of structures. However, when the thickness of the infill wall increases, the weight of the structure will increase. Therefore, it is not possible to directly express the effect of the parameter  $f_m$  and  $t_w$  on the structure safety over the period. It is clear that the increase the target displacement causes the roof drift differences between storey levels. Therefore, it is usual to expect an increase in the damage levels of load-carrying elements. When the values given in Table 3 are evaluated, it is seen that increase both  $f_m$  and  $t_w$  values of the infill wall affect the fundamental period and target displacement, positively. However, it is clear that compressive strength is slightly more effective that the thickness of infill wall factor.

The storey displacement or relative drift ratio occurring at the story levels of the structures under the earthquake loads are the most effective factor determining the damage levels of the structural load-carrying elements of the RC structure. Therefore, the relative drift and displacement changes along the height of the RC structures is a important way of the demonstrating the behavior of the load-carrying components in each storey. The relative drift were displayed in Figure 4 for each storey level of the RC structures. In cases where the thickness of infill wall is constant, it is seen in Figure 4 that the compressive strength varies. In addition, the influence of the thickness of infill wall change on the relative drift between the storey levels is given in Figure 5.

The relative drift ratios of each storey level of RC structures corresponding to the determined target displacement were obtained by the results of the pushover analyzes. The influence of relative drift ratio on each parameter appears to be significant while compressive strength and thickness of the infill wall are compares with each other. This influence is more clearly seen on the first story of the RC structures. Accordingly, it is seen that the damages to occur due to storey drift in RC structures under lateral loads are formed in the load-carrying components located on the first storey level.

To determine the earthquake behavior and performance of RC structures, the damage state of columns and beams under the impact of the lateral loads is obtained from seismic analyzes results. Three damage states are defined in TEC (2007) as minimum damage limit (MN), safety limit (SL) and collapse limit (CL) for load-carrying element. When the Figure 4 and 5 are examined, it is quite normal to occur differences in the damage levels of columns and beams element due to the relative drift ratio differences. Therefore, the earthquake performance of RC structures has changed as a results of the analyzes according to the mechanical properties of infill walls considered. The column and beams damage are given in Table 4 for merely one direction (-x) of 4-storey existing RC structures.

Table 2: The cracked fundamental period of RC structures

ID/n→	TRZ/2		ANF/3		ISR/4		STS/5	
	T (s)		T (s)		T (s)		T (s)	
Cases	T(X)	T(Y)	T(X)	T(Y)	T(X)	T(Y)	T(X)	T(Y)
Cs-0	0.514	0.529	0.787	0.674	0.916	0.899	0.814	0.903
Cs-1a	0.381	0.409	0.601	0.452	0.769	0.748	0.712	0.789
Cs-1b	0.379	0.405	0.584	0.448	0.752	0.734	0.689	0.782
Cs-1c	0.355	0.376	0.561	0.435	0.723	0.702	0.68	0.76
Cs-1d	0.316	0.332	0.526	0.419	0.673	0.651	0.639	0.726
Cs-2a	0.367	0.371	0.589	0.434	0.729	0.701	0.692	0.773
Cs-2b	0.349	0.369	0.578	0.43	0.711	0.684	0.673	0.758
Cs-2c	0.322	0.348	0.552	0.421	0.684	0.649	0.641	0.741
Cs-2d	0.287	0.299	0.519	0.399	0.626	0.601	0.561	0.689
Cs-3a	0.335	0.358	0.567	0.429	0.695	0.669	0.648	0.749
Cs-3b	0.311	0.336	0.558	0.424	0.674	0.638	0.639	0.727
Cs-3c	0.299	0.311	0.532	0.412	0.629	0.621	0.596	0.695
Cs-3d	0.261	0.271	0.485	0.387	0.559	0.537	0.55	0.639

Table 3: The target displacement of RC structures

ID/n→	TRZ/2		ANF/3		ISR/4		STS/5	
	dep (m)		dep (m)		dep (m)		dep (m)	
Cases	depX	depY	depX	depY	depX	depY	depX	depY
Cs-0	0.092	0.112	0.219	0.174	0.271	0.241	0.231	0.264
Cs-1a	0.058	0.073	0.154	0.105	0.214	0.193	0.199	0.23
Cs-1b	0.052	0.066	0.151	0.1	0.195	0.184	0.186	0.222
Cs-1c	0.038	0.042	0.142	0.093	0.183	0.177	0.179	0.215
Cs-1d	0.026	0.031	0.127	0.081	0.169	0.164	0.161	0.201
Cs-2a	0.054	0.061	0.142	0.102	0.198	0.179	0.172	0.216
Cs-2b	0.039	0.045	0.138	0.098	0.189	0.166	0.169	0.208
Cs-2c	0.034	0.041	0.125	0.085	0.176	0.159	0.158	0.202
Cs-2d	0.024	0.036	0.103	0.072	0.152	0.147	0.146	0.186
Cs-3a	0.049	0.058	0.134	0.097	0.183	0.164	0.166	0.209
Cs-3b	0.034	0.039	0.129	0.092	0.172	0.159	0.157	0.202
Cs-3c	0.029	0.035	0.114	0.081	0.158	0.144	0.149	0.189
Cs-3d	0.021	0.026	0.091	0.064	0.135	0.126	0.139	0.174

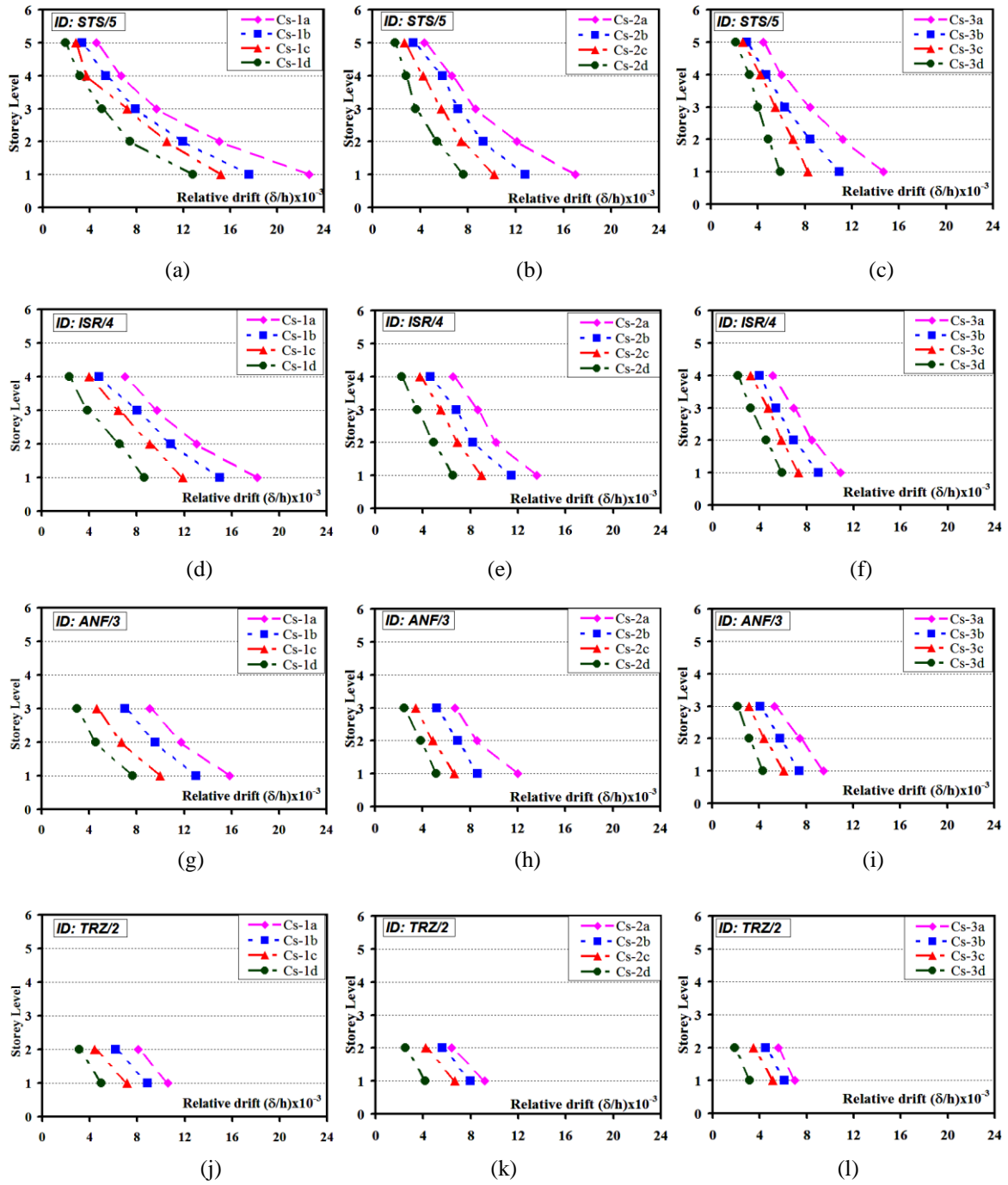


Figure 4: The influence of compressive strength of infill walls on relative drift ratio

Table 4: The column and beams damage levels for ISR/4

**ID: ISR/4**  
**Area of floor : 122 m<sup>2</sup>**  
**Number of stories : 4**

	Cs-0	Cs-1a	Cs-1b	Cs-1c	Cs-1d	Cs-2a	Cs-2b	Cs-2c	Cs-2d	Cs-3a	Cs-3b	Cs-3c	Cs-3d
S101 (60x25)	CL	SL	SL	MN	MN	SL	MN	MN	-	SL	MN	MN	-
S102 (25x60)	CL	CL	CL	SL	SL	CL	CL	SL	SL	CL	CL	MN	MN
S103 (25x60)	CL	CL	CL	SL	SL	CL	SL	SL	MN	SL	SL	SL	MN
S104 (60x25)	CL	SL	SL	SL	MN	SL	MN	MN	MN	MN	MN	MN	-
S105 (60x25)	CL	SL	SL	SL	MN	SL	SL	MN	-	SL	SL	MN	-
S106 (25x60)	CL	CL	CL	SL	SL	CL	SL	SL	SL	SL	SL	SL	MN
S107 (25x60)	CL	CL	CL	SL	SL	CL	CL	SL	SL	SL	SL	MN	MN
S108 (60x25)	CL	SL	SL	MN	MN	SL	SL	MN	MN	SL	SL	MN	MN
S109 (60x25)	CL	CL	CL	SL	MN	SL	SL	MN	-	SL	MN	MN	-
S110 (25x60)	CL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	MN	MN
S111 (25x60)	CL	SL	SL	SL	MN	SL	SL	SL	MN	SL	SL	SL	MN
S112 (60x25)	CL	CL	SL	SL	MN	SL	MN	MN	MN	SL	MN	MN	-
K101 (25x50)	SL	SL	SL	SL	MN	SL	SL	SL	MN	SL	SL	SL	MN
K102 (25x50)	CL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
K103 (25x50)	SL	SL	SL	SL	SL	SL	SL	SL	MN	SL	SL	SL	MN
K104 (25x50)	CL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
K105 (25x50)	CL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
K106 (25x50)	CL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
K107 (25x50)	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
K108 (25x50)	SL	SL	SL	SL	SL	SL	SL	SL	MN	SL	SL	SL	MN
K109 (25x50)	CL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
K110 (25x50)	SL	SL	SL	SL	MN	SL	SL	SL	MN	SL	SL	SL	MN

The lateral load bearing capacities of the existing RC structures are determined by the static pushover analysis that is a nonlinear static analysis under dead and live loads of the structures and under incremental lateral loads. The distribution of the lateral loads is practically the same for bare frame case and infilled frames cases. The pushover curves of existing 2, 3, 4 and 5-storey existing RC structures with infill wall having different  $f_m$  and  $t_w$  values are presented in Figure 5 and 6.

It can be clearly stated that the presence of infill wall strongly decreases the vulnerability of RC structures. Especially, the contribution of the infill wall and its thickness to lateral load bearing capacity of the RC structures can be observed from given Figure 6, clearly. As can be seen from Figure 7, the presence of infill wall appears to have not contributed to the earthquake performance of the RC structures in rare cases. It can be observed clearly that, even though the infill wall contribute significantly to the lateral load bearing of RC structures, the same influence cannot be seen on the ductility of structures. However, in most cases, the contribution of the infill walls to provide of the target earthquake performance of RC structures is observed in Figure 7.



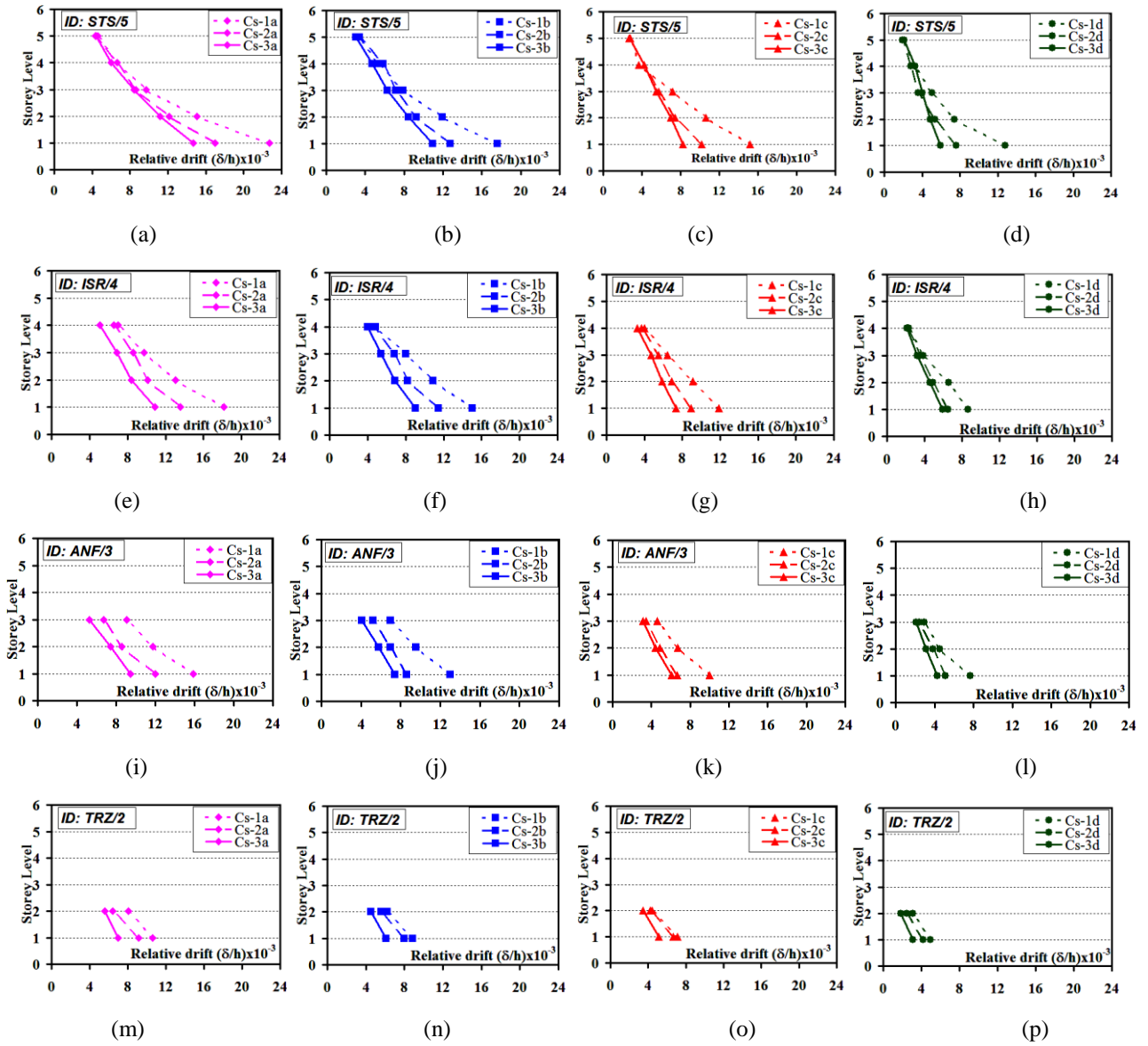


Figure 5: The influence of thickness of infill walls on relative drift ratio

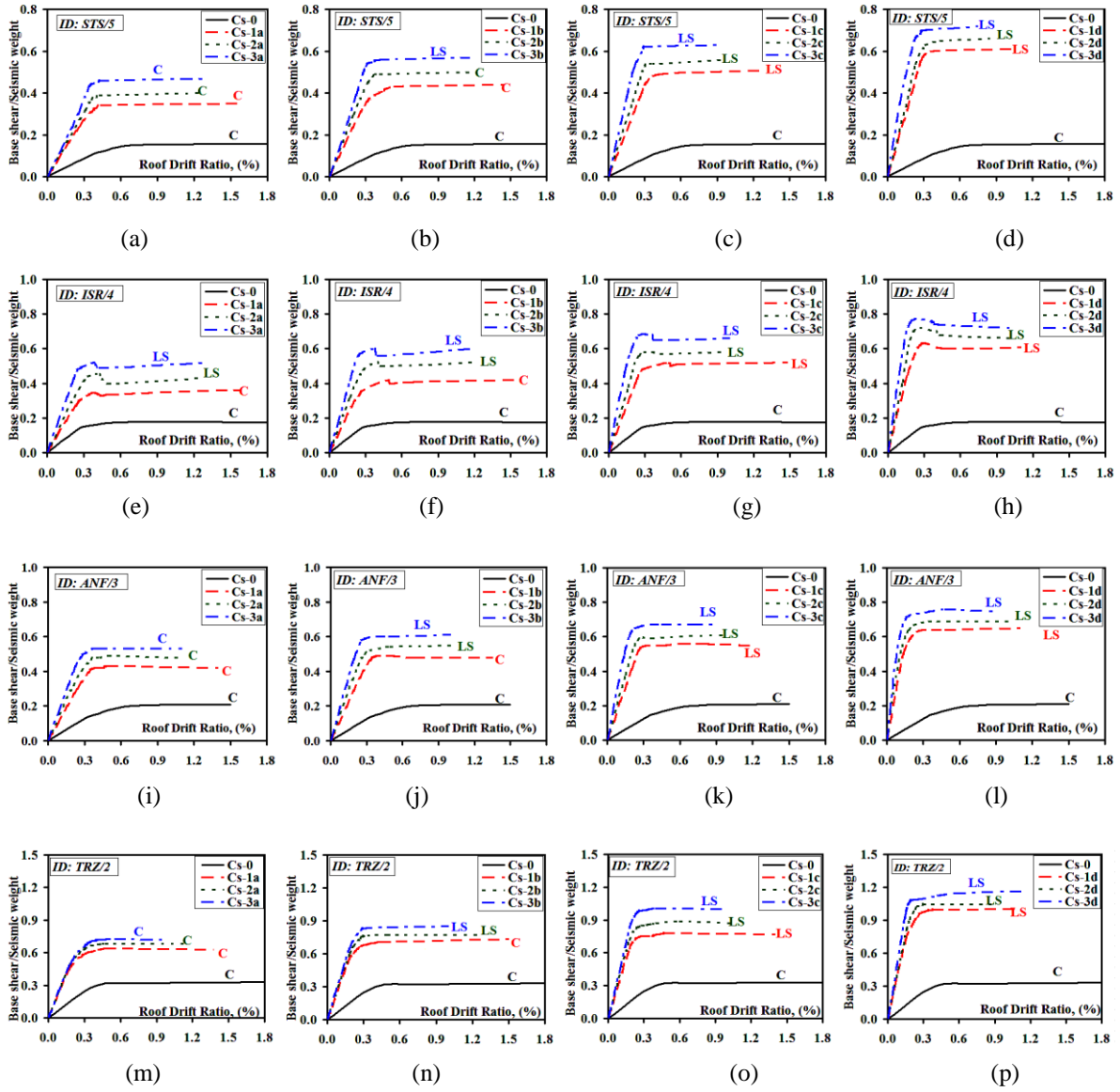


Figure 6: The influence of thickness of infill wall on capacity curves of RC structures

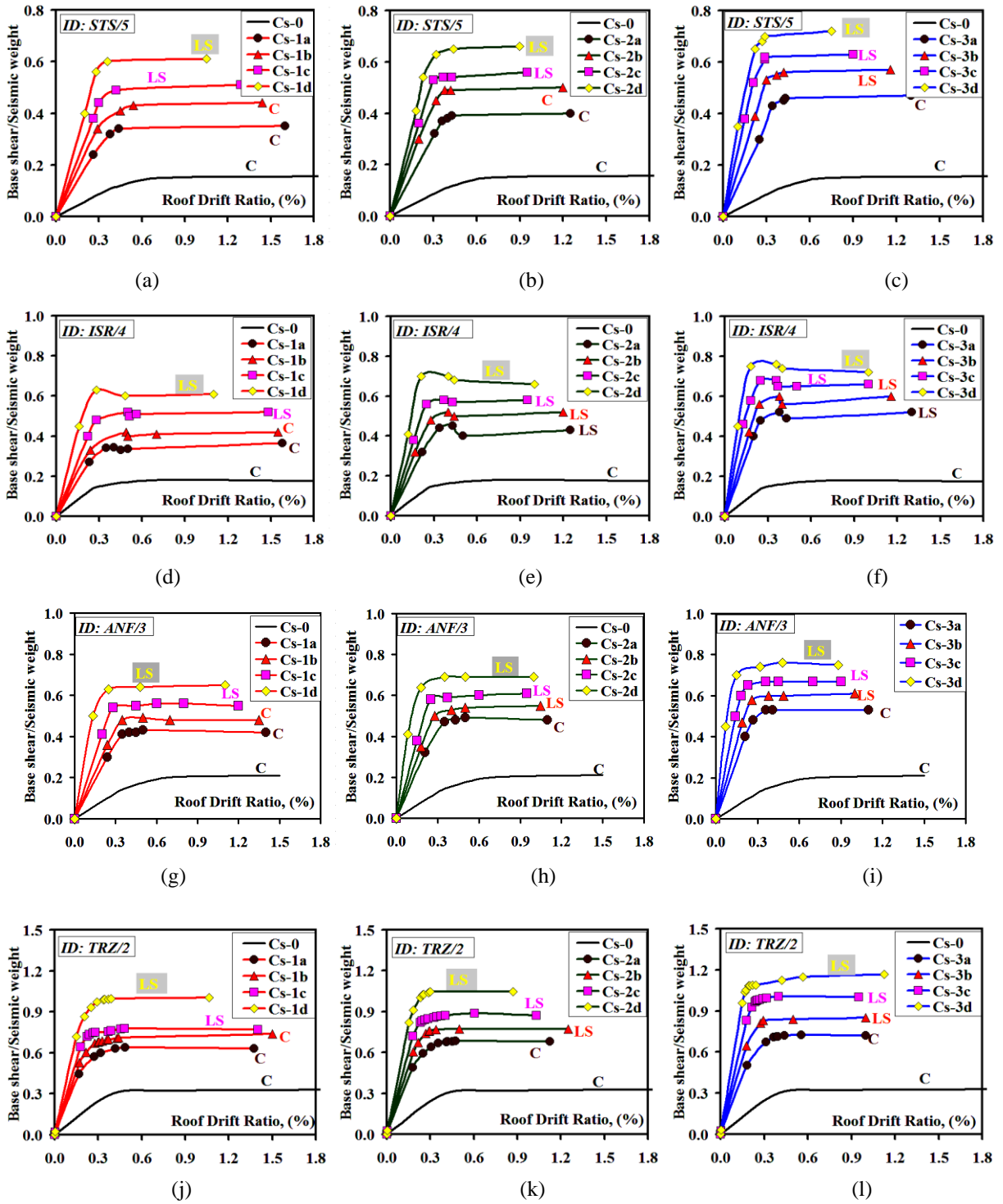


Figure 7: The influence of compressive strength of infill wall on capacity curves of RC structures

As is known that the concrete and steel strengths of the RC elements is highly effective on the structural behavior of RC structures. In the analyzes, the material strengths are selected 10 MPa for concrete, 220 MPa for steel. The aim of selecting low material strength is to examine the influence of compressive strength and thickness of infill wall on structural behavior and earthquake performance. When the Cs-0 case is examined, it is seen that the RC structures do not meet the LS performance level. It is possible to observe that if the strength of material of the RC elements is chosen at the minimum strength level recommended by the TEC (2007), it is most likely provide the LS target performance level of all infilled frames with the infill wall.

In addition, some structural results obtained from the analysis of the existing RC buildings are given in Table 5 and Table 6 for the all cases.

Table 5: Comparison of earthquake performance of existing RC structures according to  $f_m$  values

ID	Perf. Level	Cases												
		Cs-0	Cs-1a	Cs-1b	Cs-1c	Cs-1d	Cs-2a	Cs-2b	Cs-2c	Cs-2d	Cs-3a	Cs-3b	Cs-3c	Cs-3d
TRZ/2	LS	-	-	-	✓	✓	-	✓	✓	✓	-	✓	✓	✓
	C	✓	✓	✓	-	-	✓	-	-	-	✓	-	-	-
ANF/3	LS	-	-	-	✓	✓	-	✓	✓	✓	-	✓	✓	✓
	C	✓	✓	✓	-	-	✓	-	-	-	✓	-	-	-
ISR/4	LS	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	C	✓	✓	✓	-	-	-	-	-	-	-	-	-	-
STS/5	LS	-	-	-	✓	✓	-	-	✓	✓	-	✓	✓	✓
	C	✓	✓	✓	-	-	✓	✓	-	-	✓	-	-	-

Table 6: Comparison of earthquake performance of existing RC structures according to  $t_w$  values

ID	Perf. Level	Cases											
		Cs-1a	Cs-2a	Cs-3a	Cs-1b	Cs-2b	Cs-3b	Cs-1c	Cs-2c	Cs-3c	Cs-1d	Cs-2d	Cs-3d
TRZ/2	LS	-	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓
	C	✓	✓	✓	✓	-	-	-	-	-	-	-	-
ANF/3	LS	-	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓
	C	✓	✓	✓	✓	-	-	-	-	-	-	-	-
ISR/4	LS	-	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓
	C	✓	-	-	✓	-	-	-	-	-	-	-	-
STS/5	LS	-	-	-	-	-	✓	✓	✓	✓	✓	✓	✓
	C	✓	✓	✓	✓	✓	-	-	-	-	-	-	-

## 6. Conclusion

In the scope of the study, the influence of the infill walls having variable value of compressive strength and thickness on the structural behavior and earthquake safety is investigated. For this reason, the type of residential RC structures having different number of stories and structural properties are selected by considering the architecture plans of them. The nonlinear analyzes of the existing RC structures are performed according to the principle of nonlinear elastic method determined by the TEC (2007). The results obtained are summarized below:

The analytical results indicated that presence of infill walls in the RC structure significantly increase the lateral load-carrying capacity of the RC structure. As the thickness or compressive strength of infill walls increases, the value of fundamental period and the target displacement of RC structures decreases.

The increase in compressive strength of infill wall contribute to lateral load-carrying capacity of RC structures is more than the increase in the its thickness. It is understood that load-carrying element of the structures directly affect the earthquake damageability. In additional, the interaction between bare-frame and infilled frame with the wall can lead to a remarkable change in the of the shear force in the load-carrying component. It was observed that the presence of infill wall is very effective on the lateral load-carrying capacity of the existing RC structures.

The column damage in the first story of RC structures according to the nonlinear methods was obtained as "CL" for selected all RC structures by considering the Cs-0. However, ends of columns and beams damage levels varies depending on condition of

thickness or compressive strength of infill wall. Thus, when the contribution of the infill walls to rigidity of the RC structures is considered, it is observed that the damage levels of the columns and beams is decreased.

The compressive strength and thickness of the infill wall were found to be an effective factor in structural behavior and performance of RC structures. In addition, according to the results of the analysis it is understood that the compressive strength of infill wall is more effective parameter than the thickness of wall.

In the analyzes, the earthquake performance levels of bare-framed existing RC structures are obtained as "C" level. However, The performance levels of most of the infilled RC structures are determined as "LS" level. In the case of Cs-1a, Cs-2a and Cs-3a, the performance levels of the existing RC structures could not be obtained as "LS" level. The most important reason of this is the low strength of the concrete and steel considered in the analyzes.

The effect of the compressive strength of the wall is greater than the effect of weight on fundamental period of structures. However, when the thickness of the infill wall increases, the weight of the structure will increase. Therefore, it is not possible to directly express the effect of the parameter  $f_m$  and  $t_w$  on the structure safety over the period. The period decrease caused by the increase in stiffness compensates for the more limited period increase brought about by the weight increase.

It is recommended that the thickness of the infill wall should not be less than 80 mm and the wall strength should not be less than 6 MPA in terms of earthquake safety in the new low-rise residential buildings.

Consequently, in the architectural and engineering design of RC structures, it is observed that the choice of appropriate filling material of wall, proper construction and appropriate location of the infill wall contribute positively to the structural behavior and earthquake performance of RC structures.

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