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Earthquake Response of Masonry Infilled Frames

F. Demir
Süleyman Demirel University, Department of Civil Engineering, Isparta 32260, Turkey

M. Sivri
Süleyman Demirel University,Vocation School of Higher Education, Afyon 03950, Turkey

ABSTRACT: In this study, effects of nonstructural masonry infills on the earthquake response of reinforced concrete structure are investigated by considering reinforced concrete structures with different configuration of masonry infills to examine the effects of irregular infill masonry structural performance. The diagonal strut model is adopted for modeling masonry infill. Numerical analysis is performed and results are presented in comparison with the experimental data and the effects of irregular configuration of masonry infill on the performance of the structure are studied.

. Results of the analysis are given by comparing experimental data.

Keywords : Infilled frame, irregularity, masonry, dynamic analysis.

ÖZET: Bu çalışmada taşıyıcı olmayan dolgu duvarların betonarme yapıların deprem davranışına olan etkileri konu edilmektedir. Bu amaçla, dolgu duvarların performansının belirlenmesi için değişik dolgu duvarlı biçimli betonarme bir yapı incelenmektedir. Dolgu duvarın modellenmesi için çapraz eleman kullanılmaktadır. Elde edilen sayısal sonuçlar, dolgu duvarların yapının yatay rijitliğini etkilediği göstermektedir. İnceleme sonuçları deney sonuçları ile karşılaştırılarak verilmektedir.

Introduction

The infill masonry is seldom included in numerical analysis of structural system, because masonry panels are generally considered as structural elements of secondary importance, which introduce some unwanted analytical complexities without having pronounced effect on the structural performance. However, the significant effects of the infilled masonry on the structural responses of frames have been realized by many researcher (Harpal, Paul and Sastry,1998, Hong, Guo-Wei and Yong, 2002, Sahota and Riddington, 2001, Nollet and Smith, 1998). It yields that the presence of nonstructural masonry infills can effect the seismic behavior of framed building to at large extend.

These effects are generally positive: masonry infills can dramatically increase global stiffness and strength of the structure. On the other hand, potentially negative effects may occur such as torsional effects induced by in plan-irregularities, soft-storey effects induced irregularities in elevation and short-column effects due to openings.

The objective of this study is to investigate the response of reinforced concrete structure subjected to ground motion to assess structural damage by focusing on the effects of infill masonry on the structural performance. In this study, Düzce and Erzincan earthquake records are applied to simulate ground motion.

Effects of Masonry Infills on the Analysis

Masonry infills are found in most existing concrete frame building systems. This type of infills is common in our country where seismicity is prime importance. These masonry infills which constructed after completing of concrete frames are considered as non-structural elements. Although they are designed to perform architectural functions, masonry infills do resist lateral forces with substantial structural action. In addition to this infills have a considerable strength and stiffness and they have significant effect on the seismic response of the structural system. There is a general agreement among researchers that infilled frames have greater strength as compared to frames without infills. On the other hand, the presence of the infill also increases the lateral stiffness considerably. Due to the change in stiffness and mass in the structural system, the dynamic characteristics change as well. Recent earthquakes Erzincan, Düzce and İzmit showed that infills have an important effect on the resistance and stiffness of buildings.

However, the effects of the infills on the building under seismic loading is very complex and complicated. Since the behavior of the structural systems is highly nonlinear it is very difficult to predict it by analytical methods unless the analytical models are supported using experimental data. These effects of the infills on the analysis must be considered together with high degree of uncertainty related to the behavior, namely (Penelis and Kappos, 1997);

- the variability of their mechanical properties, and therefore the low reliability in their strength and stiffness;
- their wedging condition, that is how tightly they are connected to the surrounding frame;
- the potential modification of their integrity during the use of the building;
- the non-uniform degree of their damage during the earthquake.

In general, the presence of masonry infills affects the seismic behavior of the building as follow (Dowrick, 1987, Tassios, 1984)

- The stiffness of the building is increased, the fundamental period is decreased and therefore the base shear due to seismic action is increased.
- The distribution of the lateral stiffness of the structure in plan and elevation is modified.
- Part of seismic action is carried by the infills, thus relieving the structural system.
- The ability of the building to dissipate energy is substantially increased.

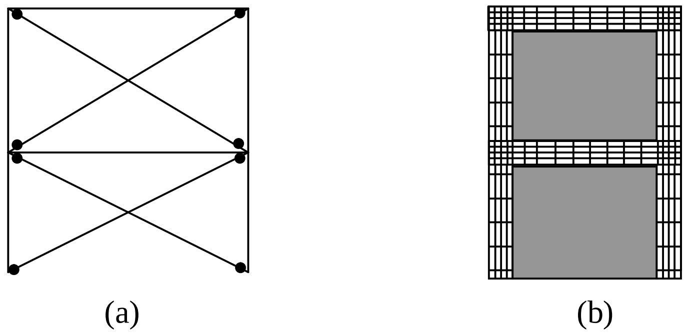


Figure 1. Models for masonry. (a) Diagonal strut model, (b) continuum model

Modeling of Masonry Infill

In conventional analysis of infilled frame systems, the masonry infill is modelled using either equivalent strut model in Figure 1(a) or a refined continuum model in Figure 1 (b). The former is simple and computationally attractive but is theoretically weak. First, identifying the equivalent nonlinear stiffness of the infill masonry using diagonal struts is not straightforward, especially when there exist some openings, such as doors or windows, in the wall. Furthermore, it is also not possible to predicted the damaged area of masonry either. The latter method based on continuum model can provide an accurate computational representation of both material and geometry aspects, if the properties and the sources of nonlinearity of the masonry carefully defined (Hao, Ma and Lu, 2002).

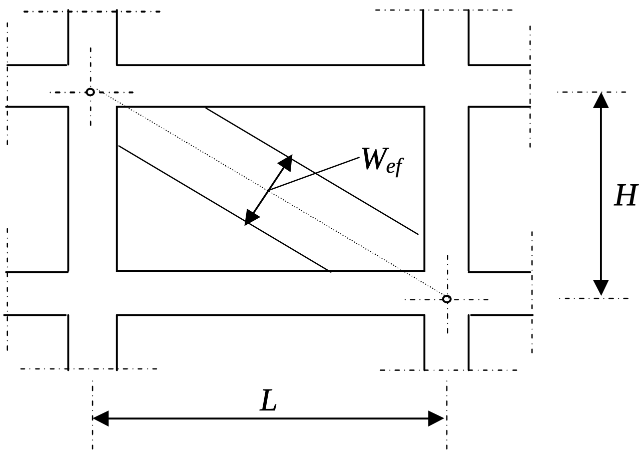


Figure 2. Compression diagonal model for estimation of the infill stiffness.

In Figure 1 the elastic in-plane stiffness of a solid unreinforced masonry infill is represented with an equivalent diagonal compression strut of width W_{ef}. The width is given by

$$W_{ef} = 0.175\left(l_h H\right)^{-0.4}\sqrt{H^2 + L^2} \tag{1}$$

where

$$l_h = \sqrt[4]{\frac{E_i\, t \sin 2q}{4 E_c\, I_c\, H_i}} \tag{2}$$

H and L are the height and length of the frame, E_c, and E_i are the elastic moduli of the column and of the infill panel, t is the thickness of the infill panel, q is the angle defining diagonal strut, I_c is the modulus of inertia of the column and H_i is the height of the infill panel.

In the present paper adopting diagonal strut model, the numerical analysis is carried out by considering as specific frame to investigate its earthquake response.

Numerical Example

The structure which is investigated experimentally by Negro and Colombo, (1997) has been selected for numerical example. The general layout of four-storey reinforced concrete structure is shown in Figure 3.

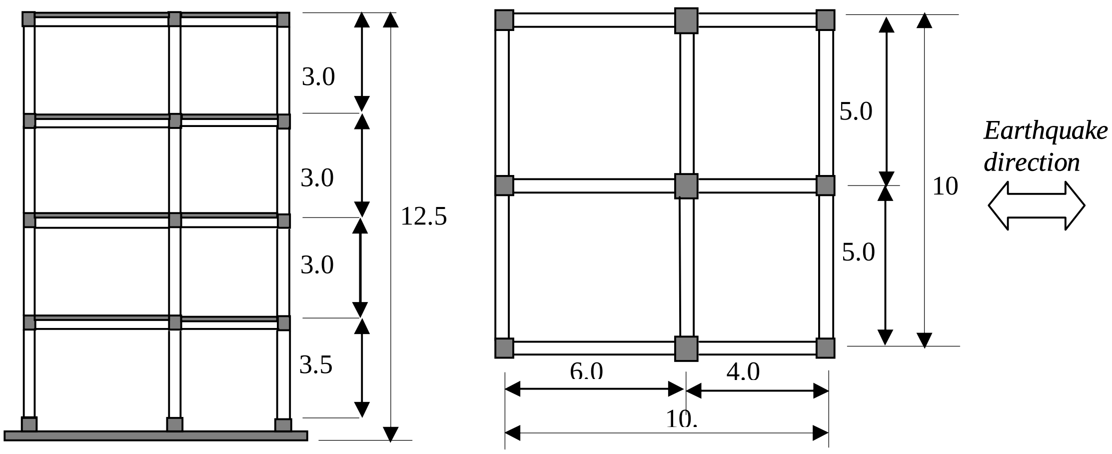
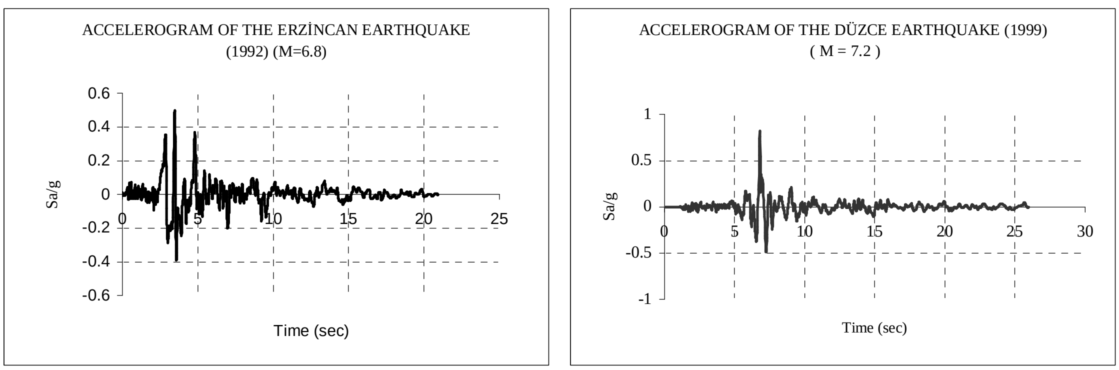


Figure 3. Elevation and layout of the building (dimensions in metres)

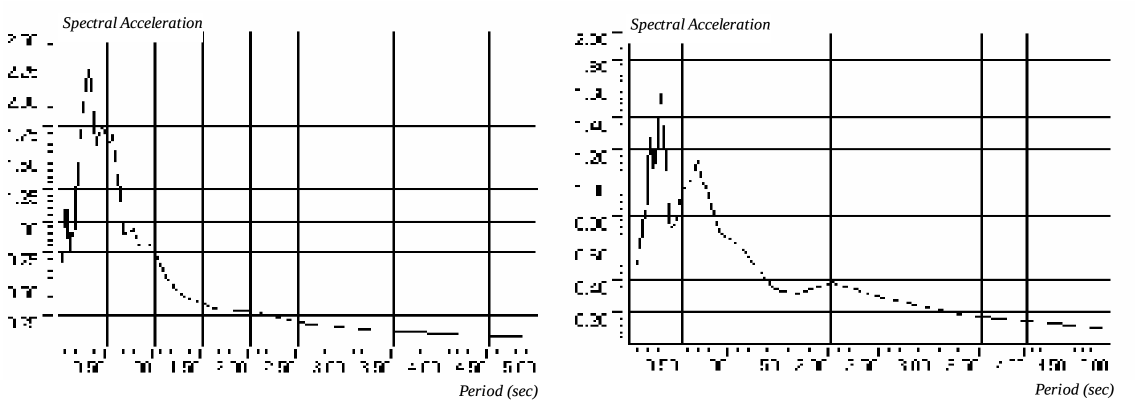


(a) (b)

Figure 4. Accelerogram records of (a) Düzce and (b) Erzincan

The building is 10 m long, 10 m wide and 12.5 m high. In the analysis typical loads (additional dead load 2 kN/m^2 and live load 2 kN/m^2) are taken into account. The concrete is assumed to be C25.

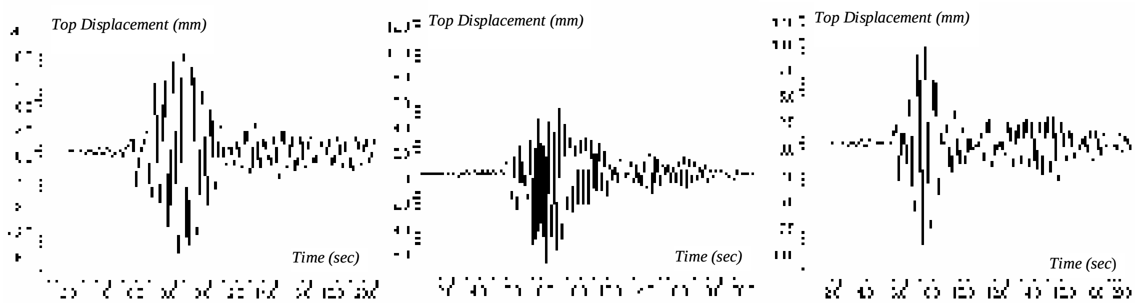
Calculated elastic response spectrum for Düzce and Erzincan Earthquake are given in Figure 5.



(a) (b)

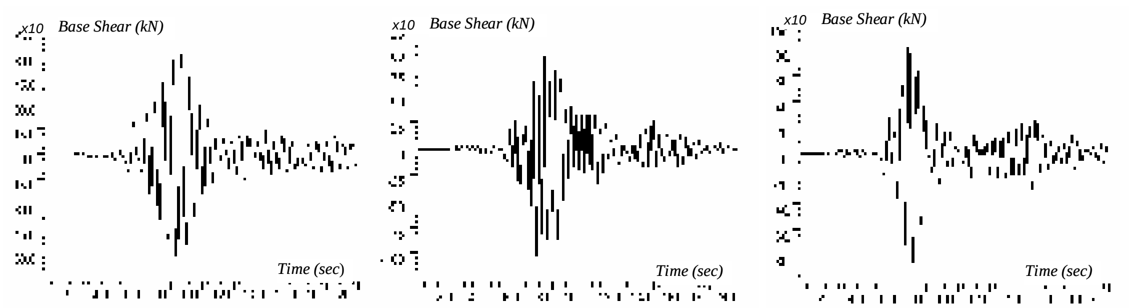
Figure 5. Elastic response specta for a)Düzce Earthquake b)Erzincan Earthquake

Düzce and Erzincan earthquake records given in Figure 4 are applied to the structural system of the building in Figure 3 and for time histories analysis is carried out. The corresponding elastic response spectrum are depicted in Figure 5.



(a) (b) (c)

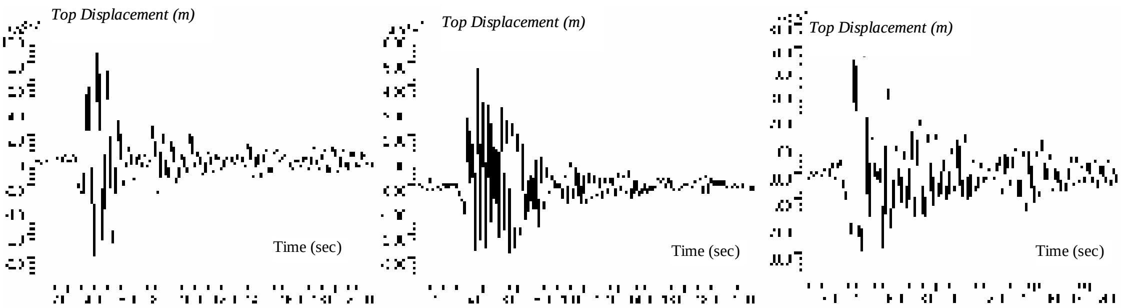
Figure 6. Time histories of the top displacement of building under Düzce Earthquake a) bare frame, b) infilled frame and c) soft-storey frame



(a) (b) (c)

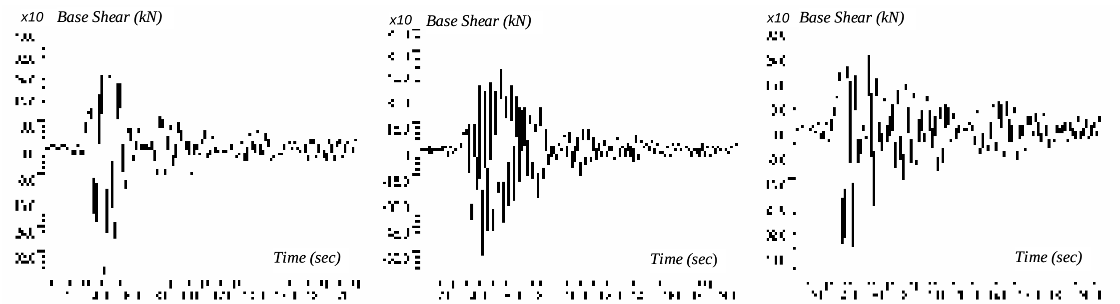
Figure 7. Time histories of the base shear under Düzce Earthquake a) bare frame, b) infilled frame and c) soft-storey frame

Three cases are considered, namely : (a) frame having no infills (bare frame), (b) frame with infills (infilled frame) and frame no infills in the ground floor only and infills in all other floors (soft story frame). Computed top displacement and base shear in cases of bare, uniformly infilled and soft storey frames for Düzce Earthquake are given in Figure 6, 7 for Erzincan Earthquake are given in Figure 8, 9 respectively. In the analysis infill panels are placed at all storey of the external frames and thickness of infills of 190 mm was is assumed as reported by Negro, Colombo 1997.



(a) (b) (c)

Figure 8 Time histories of the top displacement under Erzincan Earthquake a) bare frame, b) infilled frame and c) soft-storey frame



(a) (b) (c)

Figure 9. Time histories of the base shear under Erzincan Earthquake a) bare frame, b) infilled frame and c) soft-storey frame

Table1. Periods of the building in the earthquake excitation direction

Structure	Experimental results (Negro, Colombo 1997) Period (sec)	This Study Period (sec)
Bare frame	0.5618	0.5596
Infilled frame	0.3030	0.3329
Soft story frame	0.6024	0.4614

Table 2. Summary of results for Erzincan and Düzce Earthquakes

Structure	Düzce		Erzincan	
	Max top displacement (mm)	Max. Base shear (kN)	Max top displacement (mm)	Max. Base shear (kN)
Bare frame	16.8	627	9.9	384
Infilled frame	7.6	1030	4.7	638
Soft story frame	11.0	892	5.1	425

The results of the elastic analysis are obtained and present in tables. The comparison of the results obtained from the analysis having different infill configurations given in Table 2 is particularly meaningful, because most of the design codes neglect the changes due to the presence of the infills. As Table 1 yields, the maximum top displacement for the bare frame is about 17 mm for Düzce Earthquake and is 10 mm for Erzincan Earthquake. The maximum top displacements of uniformly infilled frame of two earthquakes are smaller more than 2.2 times due to the increase in the lateral stiffness. Displacements of floor levels are given in Figure 10. As it seen, the lateral stiffness of the soft story frame is large compared to the other two cases when the first floor is considered. Figure 10 shows once more the weak point of the soft-story frame

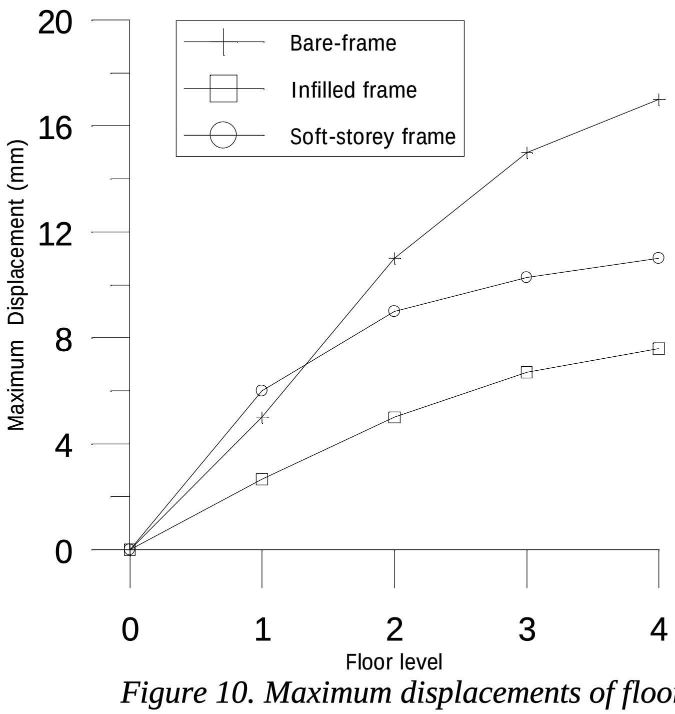


Figure 10. Maximum displacements of floor level

As table 2 the maximum base shear for the soft storey structure is larger than that of the bare frame. The maximum base shears of the two earthquakes obtained for infilled frame are almost 60% larger than that of the bare frame.

As the figures show that the effects of the infills appear to be beneficial, because they correspond to smaller values with respect to those of the bare frame, provided that the infills become in fact and no damage comes into being.

Results

The results of elastic analysis show that the presence of nonstructural masonry infills ca modify the global seismic behavior of framed buildings to a large extend. The stability and integrity of reinforced concrete frames are enhanced with masonry infills. Presence of masonry infill also alters displacements and base shear of the frame. Irregular distributions of masonry infills in elevation can result in unacceptably elastic displacement in the soft storey frame. The analysis of the infilled structure demonstrated that a regular distribution of infills may results in a globally irregular behavior of the frame. Therefore, a safe design procedure should ,in general, neglect the influence of the nonstructural masonry panels.

The comparison of experimental and analysis results demonstrated that the behavior of irregular infilled structure can be predicted by means of simplified diagonal models. Relatively simple and accurate approach can be obtained by using this type models for including the effects oof the infills.

References

Dowrick, D.J., 1987, Earthquake Resistant Design for Engineers and Architects, John Wiley & Sons, New York.

Harpal singh, Paul, D.K., Sastry, V.V., 1998, Inelastic Dynamic Response of Reinforced Concrete Infilled Frames, *Computers and Structures*, Vol.69, pp. 685-693.

Hong hao, Guo-Wei M., Yong L., 2002, Damage Assessment of Masonry Infilled RC Frames Subjected to Blasting Induced Ground Excitations, *Engineering Structure*, Vol.24, No.6, pp.671-838.

Negro, P., Colombo, A.,1997, Irregularities Induced by Nonstructural Masonry Panels in Framed Buildings, *Engineering Structures*, Vol. 17, No.7, pp.576-585.

Nollet, M.J., Smith, B.S., 1998, Stiffened-Story Wall-Frame Tall Building Structure, *Computers and Structure*, Vol. 66, No. 2-3, pp.225-240.

Penelis, G.G., Kappos, A.J., Earthquake-Resistant Concrete Structure, & E FN Spon, An imprint of Chapman & Hall, London.

Sahota, M.K., Riddington, J.R., 2001, Experimental Investigation into Using Lead to Reduce Vertical Load Transfer in Infilled Frames, *Engineering Structure*, No 23, pp.94-101.

Tassios, T.P., 1984, Masonry Infill and R/C Walls Under Cyclic Actions, CIB Symposium on Wall Structure, Invited State– of-the Art Report, Warsaw.