Examining the Simplified Method for Considering the Infill Wall Effect in "Urban Transformation Law"

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ABSTRACT: A simplified method is investigated in detail given in the recent code namely "Determination of Seismically Vulnerable Buildings" in the context of "Urban Transformation Law", where a single coefficient was defined to consider the effect of masonry infill walls. Column shear forces, inter-story drift ratios, mode shapes and the corresponding periods are the engineering demand parameters considered in this study. Analytical model of a four-story RC building is generated and the effect of infill walls on its seismic response is investigated. The coefficient proposed by the code to consider the effect of infill wall leads to column shear demands that are on the safe side in most of the cases. On the other hand, non-symmetrical arrangement of infill walls can cause torsion in the structure, which increases the shear demands in certain columns. Accordingly, it is suggested to add a further limitation in the application of the simplified method when the infill walls cause torsion in the structural system.

1 INTRODUCTION

Infill walls are generally neglected and not taken into account in the design stage of buildings. But the recent studies show that, masonry infill walls can affect the seismic performance of RC buildings (Tasligedik et al, 2011) considerably. Soft story and/or weak story irregularities, which are partially related with the arrangement of infill walls in the buildings, are some of the main reasons for structural failure in the recent earthquakes in Turkey. Therefore infill walls need to be considered as a structural member. Besides, the infill walls with non-symmetrical arrangement in the plan can cause torsion, which can change the structural response significantly. For these reasons infill walls should be considered in the design and performance assessment of the buildings.

Although masonry infill may increase the overall lateral load capacity, it can alter the structural response and transfer the seismic forces to critical structural components leading to a brittle type of failure (Paulay and Priestley, 1992). This means that masonry infill may cause structural deficiencies. Smith and Coull (1991) presented a design method for infilled frames based on diagonal compression strut elements. They assumed an effective width for the diagonal compression strut as equal to one-tenth of the diagonal length of the infill panel. Smith and Carter (1969) examined multi-story infilled frames under the effect of lateral loading. In the light of their experimental results, authors proposed design graphs and design method based on an equivalent strut concept. First, they focused on the failure mechanism of the infilled frames. Then, the factors that affect the effective width of the diagonal compression strut were examined. Finally, depending on the observed experimental response and the investigated parameters, the design curves are proposed to estimate the equivalent strut width.

In the design stage of the buildings, the design engineer should make certain effort to take into account the effect of infill wall. The geometrical and the mechanical properties of the infill wall units, mortar, plaster, etc. should be identified as precise as possible for realistic estimates, which involves too many uncertainties. Instead, a simplified method can be considered. Such a recommendation was made in the recent code namely "Determination of Seismically Vulnerable Buildings" (2013) in the context of "Urban Transformation Law". According to the related part of the code, it is mentioned that;

"If the condition of $\Sigma A_{kn}/A_p \geq 0.002*N$ satisfies and the maximum drift ratio (δ/h) is less than 0.015 in the direction at which the seismic evaluation of the building will be performed at the critical story, the effect of infill wall can be taken into account by multiplying the calculated earthquake force with a reduction coefficient of 0.75."

Where;

A_p : Plan area of the critical story.

ΣA_{kn}: The total infill wall area in the direction of the evaluation at the critical story; the ratio of openings (doors and windows) on the wall should be less than 5% and the ratio of the diagonal length to the width is to be less than 40, on the story plan area.

(δ/h): Drift ratio

N : Number of the stories

According to this code; only two criteria have been defined for the simplified method to be used; total infill area on the plan and the limitation of the maximum story drift ratio. In this study, the adequacy of recommended simplified method and the criteria for its applicability are examined. It is also studied the adequacy of this recommendation when using different infill wall materials and different methods to determine the mechanical properties for the infill walls. For this study, the structural system of a 4 story office building in Anadolu University was used and the analyses were conducted by using its analytical model.

2 ANALITICAL METHOD

The recent studies emphasize that the easiest and the common way to take into account the infill wall effect in a frame is to model the infill walls as diagonal compression struts as shown in Figure-1. The equivalent compression struts are defined in the analytical model by pin jointed diagonal elements at the ends.

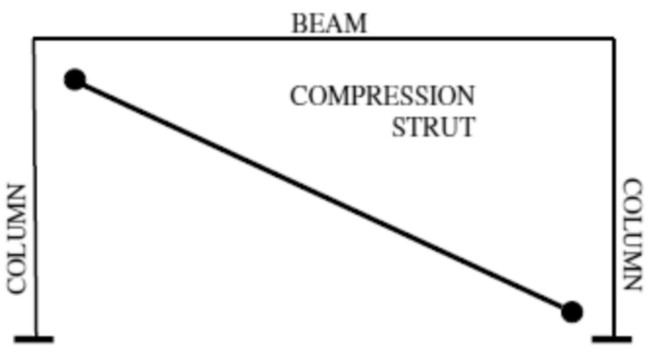

Figure 1. The analytical model of infilled frame

2.1 FEMA Equivalent Compression Strut Method

In this study the equivalent width of the compression struts is obtained according to the formula defined in FEMA-356. It is emphasized that the infill wall and the frame should work together. The equivalent width of the compression struts is calculated with the formula given in Equation 1 and Equation 2. According to these formulas, the equivalent strut width is related with the mechanical and geometrical properties of both the frame members and the infill wall.

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf} \tag{1}$$

$$\lambda_1 = \left[\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}}\right]^{\frac{1}{4}} \tag{2}$$

2.2 Analytical Model of the Building

The building is located in the second seismic zone and the local soil class is Z2 according to Turkish Earthquake Code (TEC). 4-storey building has a symmetrical plan with the dimensions of 12.4m x 18.5m. The floor plan, column sizes and the location of infill walls are shown in Figure 2. All of the infill walls have a 20 cm width. The building was constructed about 30 years ago. The concrete compressive strength is calculated as 13 MPa from the concrete samples taken from the columns at the base floor (Kılınç et al, 2012).

For the elastic modulus of the concrete, the formula recommended in ACI 318M-11 is used (Equation 3). f_c is the compressive strength of concrete in MPa.

$$E_{fe} = 5000\sqrt{f_c} \tag{3}$$

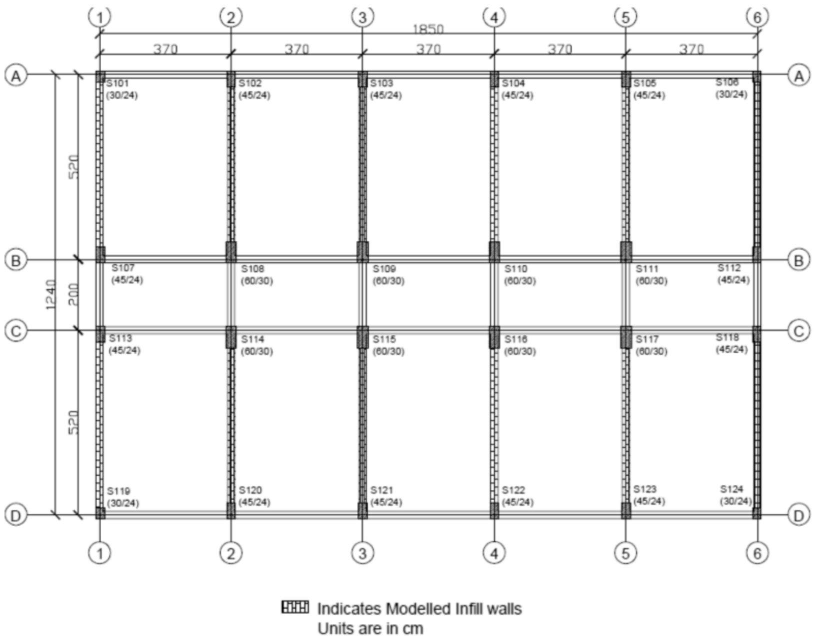

Figure 2. Floor Plan and the Modelled Infill Walls

Accept for the elasticity modulus of the infill wall E_{me}, all the other parameters in Equation 1 and 2 were obtained from the actual measurements taken from the building and the material tests conducted at the laboratory. The elastic modulus of infill wall is related with the compressive strength of the infill wall (FEMA 356 and TEC 2007). The material properties of the infill wall are required to be used in calculating the stiffness properties of the compression struts. In this study, instead of taking samples from the infill wall in building, different infill wall properties are considered to investigate the effect of infill wall on the behavior of structural system. FEMA 356 suggests that the compressive strength of infill wall, f_{me}, shall be taken not more than 6.2 MPa for masonry in good condition, 4.1 MPa for masonry in fair condition and 2.1MPa for masonry in poor condition. In this study for the compressive strength of infill wall, analyses have been performed by using these three boundary values separately. In addition, for the modulus of elasticity of the infill wall, two different approaches are considered; Turkish Earthquake Code (Equation 4) and FEMA 356 (Equation 5) approach.

$$E_{me}=200f_d \quad (4)$$

$$E_{me}=550f_d \quad (5)$$

f_d=Compressive strength of infill wall (MPa)

Firstly, the analytical models of the infilled frame (braced) and bare frame (unbraced) are generated. (Figure 3)

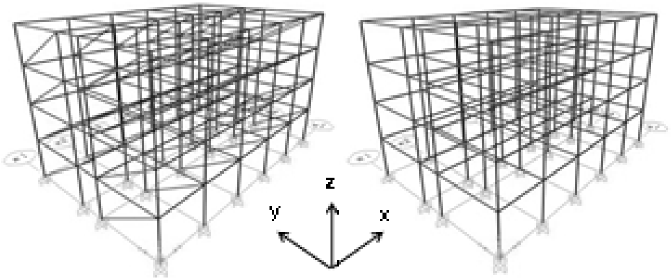

Figure 3. Analytical models of braced and unbraced systems

Then, another model was developed to investigate the torsional effect, which is supposed to take place when the infill wall arrangement is not symmetrical. For representing non symmetrical infill wall arrangement, the equivalent compression struts are modeled just in one axis of the building, which is on the outer side. (Figure 4)

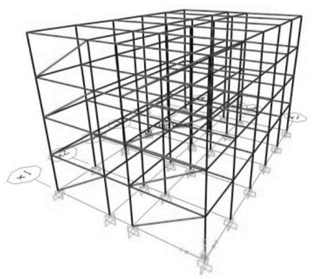

Figure 4. Analytical model of partially braced system

3 ANALYSIS

Linear elastic analysis method has been performed as explained in the recent code of Determination of Seismically Vulnerable Buildings (DSVB). Earthquake forces are calculated in accordance with the method defined for equivalent earthquake force described in Turkish Earthquake Code (TEC) for the first two models. For the last model mode superposition method is used due to irregularities. In order to compare the analyses results of the partially braced and unbraced systems, the mode superposition analysis has been performed also for the unbraced system.

3.1 *Modal analysis results*

In the case of infill walls in poor condition using $f_d = 2.1$ MPa and E_{me}=$200f_d$ (TEC, 2007), the modal analysis results of braced and unbraced systems are presented in Table 1 and Table 2.

Table 1. Modal analysis result of unbraced system

Mod No.	Period(s)	Mass Participation X-direction	Mass Participation Y-direction	∑Mass Participation X-direction	∑Mass Participation Y-direction	Mass Participation Torsional	∑Mass Participation Torsional
1	1.01	0.85	0.00	0.85	0.00	0.18	0.18
2	0.76	0.00	0.00	0.85	0.00	0.24	0.43
3	0.67	0.00	0.80	0.85	0.80	0.39	0.82

Table 2. Modal analysis result of braced system

Mod No.	Period(s)	Mass Participation X-direction	Mass Participation Y-direction	∑Mass Participation X-direction	∑Mass Participation Y-direction	Mass Participation Torsional	∑Mass Participation Torsional
1	1.01	0.85	0.00	0.85	0.00	0.19	0.19
2	0.61	0.00	0.00	0.85	0.00	0.25	0.43
3	0.52	0.00	0.83	0.85	0.83	0.41	0.84

In the direction that the infill walls were modeled (Y-direction), the period reduced from 0,67s to 0,52s. This reduction in period is an expected result due to the increase in rigidity of the building by the compression struts. A reduction is also observed in the period of torsional mode.

3.2 *The criteria of application of simplified method according to DSVB*

For the analytical models, the criteria of application of the simplified method described in DSVB; $\Sigma A_{kn}/A_p \geq 0.002N$ and $(\delta/h) \leq 0.015$ are to be satisfied. It is seen in Figure 5 that the maximum drift ratio is less than %1.5.

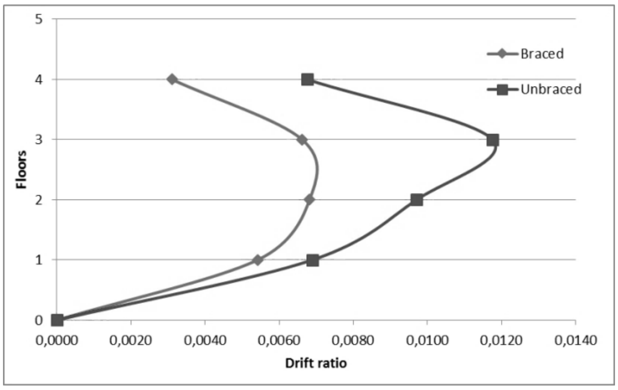

Figure 5. Drift ratio

3.3 *Response spectrum analysis*

In the partially braced model, due to torsional irregularity in the plan, the equivalent seismic load method is not applicable. Mode superposition method was used in this model to determine the earthquake forces. This method is also used for unbraced model to compare the analyses results of the two models. The building is located at Z2 soil class and for this location the corner periods in the design spectrum are T_A=0.15s and T_B=0.40s.

4 ANALYSIS RESULTS

The analyses have been conducted with SAP2000 for 3 different infill walls and 2 different formulas for calculating modulus of elasticity of infill walls. The analyses were performed only in Y-direction along which the infill walls are located. For each case, change in the shear force of the base columns has been investigated.

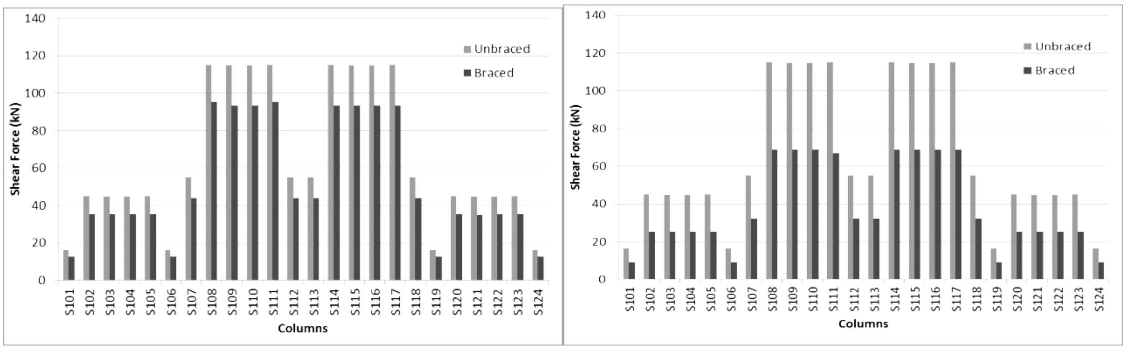

Figure 6.Shear forces in the case $f_d = 2.1$ Mpa and E_{me}=$200f_d$, E_{me}=$550f_d$ respectively

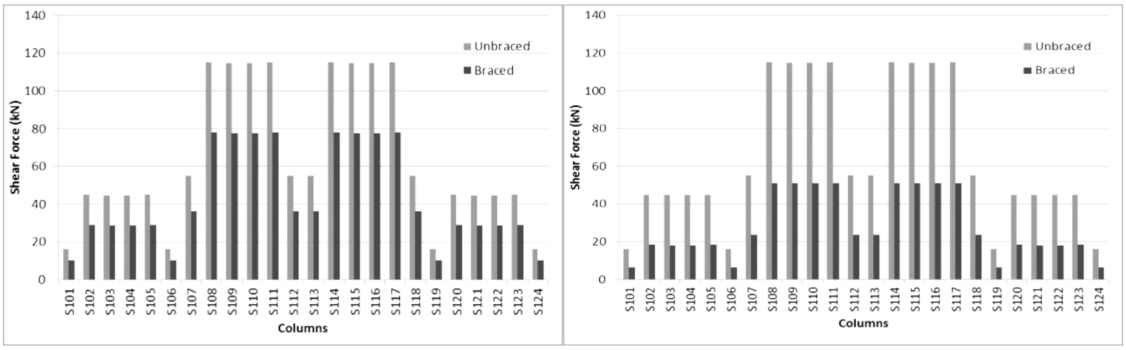

Figure 7.Shear forces in the case $f_d = 4.1$ Mpa and E_{me}=$200f_d$, E_{me}=$550f_d$ respectively

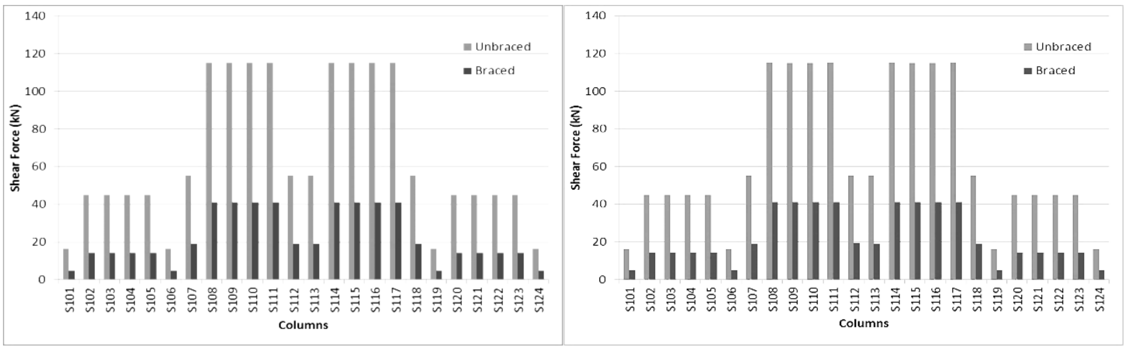

Figure 8.Shear forces in the case $f_d = 6.2$ Mpa and E_{me}=$200f_d$, E_{me}=$550f_d$ respectively

As the strength of infill wall increases the modulus of elasticity increases. Hence, the rigidity of the equivalent compression struts increase as well. Although the period in Y-direction reduced and the total earthquake force increased, the compression struts take some shear forces and the total shear force transferred in the base columns reduced. In addition, the coefficient defined in DSVB to consider the infill wall effect, is examined with the results of each analysis performed with different material properties. For the analysis, this coefficient is calculated by the total shear force in the base columns in braced model divided by the total base shear in braced model. Figure 9 shows the variation in the described coefficient for six different models.

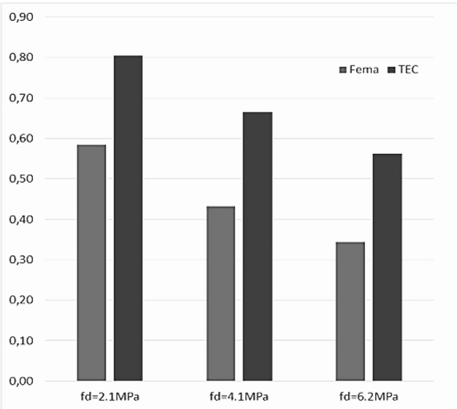

Figure 9. The ratio of the total shear force of columns to the total base shear force of the building

The suggestion of modulus of elasticity in FEMA results lower values than the ones for TEC, which is less thatn 50% for fair and good quality infill walls. As shown in Figure 9, the coefficient of 0.75 described in DSVB is mostly on the safe side, but in poor quality of infill wall, the coefficient is calculated to be slightly more than 0.75.

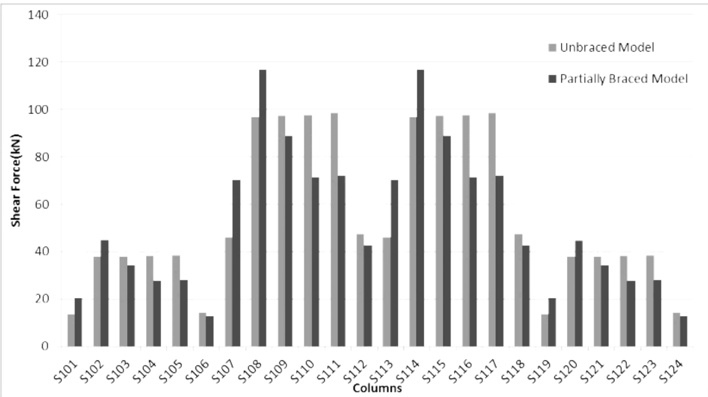

Figure 10. Distribution of column shear forces for torsional case.

In order to consider the effect of infill walls in the case of non-symmetrical arrangement, only several compression struts (partially braced model) were modeled. In this model, torsional mode dominates the overall response of the system. The analyses results obtained from dynamic analyses for the partially braced and the unbraced models are compared. In Figure 10, in the partially braced model, some of the column shear forces are more than the ones for the unbraced case. Especially for the columns on the far side of the compression struts in the partially braced model. This is certainly due to the adverse effect of the torsional response. It is seen that using a reduction coefficient described in DSVB without considering the torsional effect can lead to unrealistic results. When investigating a building that has a non-symmetrical infill wall arrangement, instead of using the simplified method described in DSVB, modelling infill walls in the analytical model, gives more realistic results.

5 CONCLUSIONS

When performing a risk assessment for a RC building, considering the infill wall effect with a simplified method is very practical in predicting the seismic behavior of the building. The simplified method to consider the effect of infill walls described in DSVB is examined. Two models were developed, in the first one infill walls are modelled as compressive struts and in the second one infill walls are not considered as structural members. In addition, another model has been developed to consider the torsional effect caused by the non-symmetrical arrangement of infill walls. The results of this study can be summarized as follows.

- In the case that infill walls are taken into account in analytical model, significant differences are observed both in modal analyses results and distribution of shear forces in the columns.
- As the material quality of infill wall increases, the column shear forces reduce and the shear force taken by infill walls increases. In the development of realistic analytical model, the properties of infill walls should be specified as precise as possible.
- The reduction coefficient of 0.75 recommended in DSVB is mostly on the safe side when the arrangement of infill walls is symmetrical. But for the poor quality of infill wall case, the corresponding reduction coefficient can lead to underestimation in column shear forces.
- In the recommendation by DSVB, only two criteria are defined as the limiting parameter whether to use the reduction coefficient or not. But the non-symmetrical infill wall arrangement can cause torsion, which can increase the seismic shear forces and moments in several columns. Therefore, in the case of a non-symmetrical arrangement of infill walls, application of the reduction coefficient should be revised and increase in the seismic demands of the columns should be taken into account.

6 REFERENCES

Tasligedik AS, Pampanin S, ve Palermo A. "*Damage Mitigation Strategies of 'Non-Structural' Infill Walls: Concept and Numerical-Experimental Validation Program*". Proceedings of the Ninth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Society, Aucland, New Zealand, 14-16 April 2011.

Paulay T, Priestley MJN. *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley & Sons, Inc., 1992.

Smith BS, Coull A. *Tall Building Structures: Analysis and Design*. John Wiley & Sons, Inc., 1991.

Smith BS, Carter C. *"A Method of Analysis for Infilled Frames*". Proceedings of the Institution of Civil Engineers (ICE), Vol. 44, pp.31-48, September 1969.

Riskli Yapıların Tespit Edilmesine İlişkin Esaslar (RYTEİE), (Ek:RG-2/7/2013-28695) EK-2, Çevre ve Şehircilik Bakanlığı, 2013.

FEMA 356 "*Prestandard And Commentary For The Seismic Rehabilitation Of Buildings*". prepared by ASCE for Federal Emergency, Washington D.C., 2000.

Kılınç K, Yalçın M, Tuncan M. "*AÖF TV Yapım Merkezi Müdürlüğü A Blok, Eski İletişim Bilimleri Fakültesi A Blok ve B Blok Binalarına Ait Deney Raporu*", Eskişehir, Kasım 2012.

American Concrete Institute (ACI). Building Code Requirements for Structural Concrete and Commentary, ACI 318M-11, USA, 2011.

Turkish Earthquake Code (TEC) (2007) "*Specification for buildings to be built in seismic zones*". Ministry of Public Works and Settlement, Government of Republic of Turkey