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Comparison of infill wall effects in reinforced-concrete frames over different parameters

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Abstract

Infill walls are widely used in reinforced-concrete structures and their contribution to the reinforced-concrete frame can be neglected. The amount of infill wall effect was investigated for a reinforced-concrete frame which has three different openings in this study. For this purpose, five different structural models have been created such as completely filled, gap in the corner, double gap and completely bare on the ground floor. Structural analyses were performed in Seismostruct software by using pushover and eigen value analyses for each structural model, respectively. Only the absence of infill wall was selected as a variable. The limit state of three different damages for performance level, period, base shear force, elastic and effective section stiffness's were obtained separately for each structural model. The study revealed once again that the amount of infill wall contributes significantly to the seismic capacity of the building. Considering the contributions of infill walls will make the structural results much more realistic.

1. Introduction

Infill walls are widely used in buildings to fill frame gaps or to separate residences [1,2]. In the current design of such structures, in most cases only the weight of the infill walls is taken into account and other strength parameters are ignored. The structural behavior of such frames is highly dependent on the dynamic properties of the respective laterally and vertically loaded infill walls, such as stiffness, bearing capacity, period and damping level [3-6]. In-plane and out-of-plane damages are common in reinforced concrete structures after earthquakes [7-13]. For these reasons, the infill wall effect is a subject worth examining.

It has been determined by experimental studies that the values obtained as a result of the calculations will not reflect the truth in cases where the infill walls are not placed appropriately and consciously and are not taken into account [14]. In the literature, the effect of the infill wall was investigated on different parameters by both experimental and numerical modeling. The capacity curves of infill walls, story horizontal displacements, relative dispalcements, maximum plastic rotations in stories and the distribution of plasticized sections in the system in regular reinforced-concrete structures were compared by Korkmaz and Uçar [15]. In the study conducted by Akyürek et al. [16], the effects of the infill wall change on the capacity curve of the building, the first natural period, the target target displacements, the damage distribution of the first story columns, and the building performance level in residential type reinforced-concrete buildings with different openings and number of stories were investigated. In the study conducted by Tekin et al. [17], the strengths of the filled and unfilled four-storey three-span planar reinforced-concrete frames were compared with the capacity curves. In the study conducted by Sivri [18], a reinforced concrete structure with different infill wall placements was taken into consideration and the results were compared in order to examine the effect of infill walls and wall layout on the building behavior. In a study by Paripour et al. [19] investigated the effect of infill walls on the risk of progressive collapse in reinforced-concrete (RC) frames. Layadi et al. [20] investigated the infill wall effect experimentally in their study. In this and similar studies, the positive contributions of the infill walls used in reinforced concrete structures to the earthquake behavior of the building have been revealed.

Within the scope of this study, the infill wall effect for a reinforced-concrete frame consisting of three different openings was tried to be revealed by static pushover and eigenvalue analysis on five different structural models. For each structural model, period, seismic capacity, elastic stiffness value and target displacement values for structural performance were obtained separately. Suggestions were made by comparing the results obtained with the study.

2. Material and Method

Within the scope of the study, eigenvalue and static pushover analyzes were performed for the reinforced concrete frame consisting of three different spans. Model analysis is a dynamic analysis method that enables the determination of free vibration periods, frequency values, mass participation rates and mode shapes of the structure [21]. Another method used in generating performance estimates is pushover analysis. This method is a practical way of demonstrating the behavior of a building in the inelastic region. This type of analysis gives the base shear force and the peak displacement capacity curve of the building. To obtain this curve, the lateral forces are monolithically increased until the displacement of the top of the building reaches a predetermined value [22-26]. To obtain the pushover curve, it is necessary to geometrically combine the intersection points on an interaction diagram of the roof displacement values corresponding to the base shear forces under the applied load, raising the structure from zero to unstable. The limit states given in the worldwide used damage estimation Eurocode-8 (Seciton 3) are taken into account in the structural analysis [27,28]. Three different cases are specified for damage cases in the software. These states are considered near collapse (NC), significant damage (SD), and damage limitation (DL). These cases are calculated for all structural models.

Table 1. Limit states in Eurocode 8 (Part 3) [27,28].

Limit State	Description	Return Period (year)	Probability of exceedance (in 50 years)
Limit state of damage limitation (DL)	Only lightly damaged, damage to non-structural components economically repairable	225	0.20
Limit state of significant damage (SD)	Significantly damaged, some residual strength and stiffness, non-structural components damaged, uneconomic to repair	475	0.10
Limit state of near collapse (NC)	Heavily damaged, very low residual strength & stiffness, large permanent drift but still standing	2475	0.02

The behavior of building materials under loads can be determined by using some mathematical models that have an important place in building design and evaluation [29]. For the concrete and steel material, the nonlinear concrete model [30] and steel model [31] were used. The stress-strain relationship of these material models is shown in Figure 1.

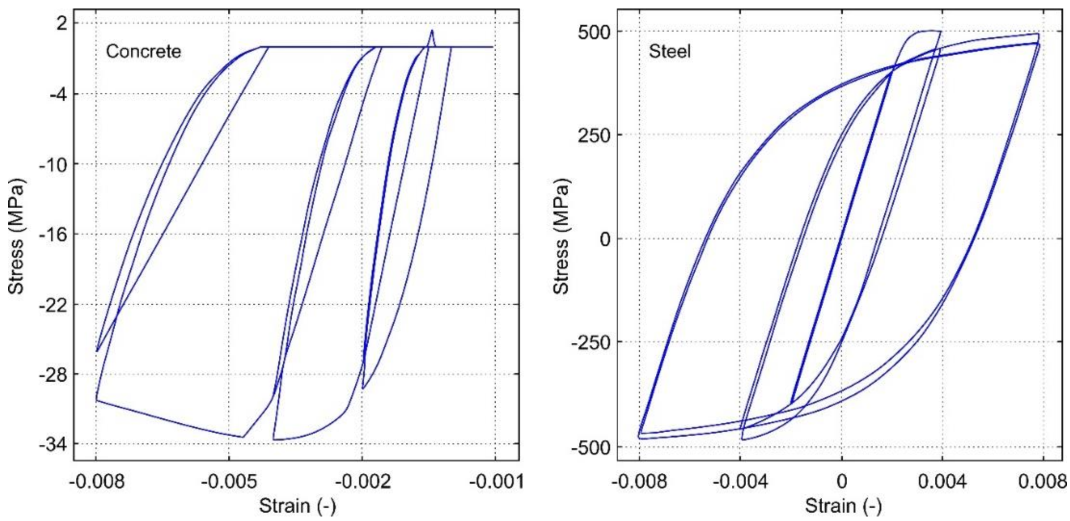

Figure 1. Material models for concrete and steel considered in this study [32]

The story heights were chosen as 2.7 m, being equal to each other. The reference structure model is shown in Figure 2.

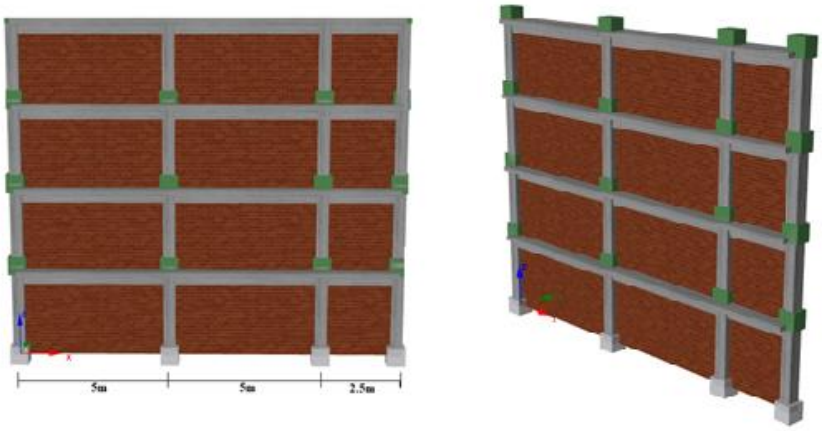

Figure 2. Structural models of the reference building model considered in the study.

The load cases applied in all structural models considered within the scope of this study are shown in Figure 3.

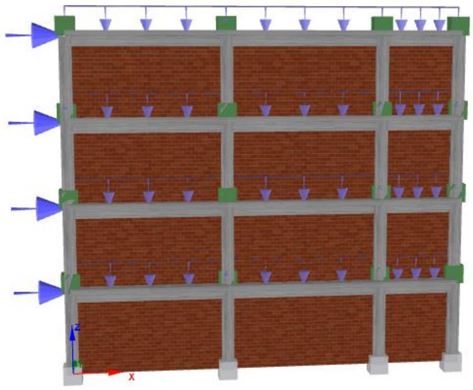

Figure 3. Applied loads

Within the scope of this study, the columns and beams used in the reinforced-concrete frame were created by using the same size and material in all structural models. C25-S420 was taken into consideration for all RC buildings model. In order to reveal the infill wall effect more clearly, no changes were made to these load-bearing elements. The cross-sections of the beams and columns used are given in Figure 4. While the columns were chosen as 40*40 cm, the beams were taken into account as 25*50 cm.

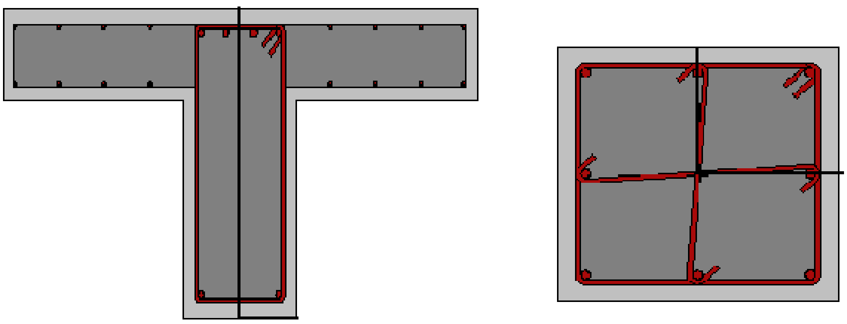

Figure 4. Cross-sections of columns and beams used in the RC frame

Other structural models considered in the study are shown in Figure 5. The reference building was rated as Model 1. The target displacement was chosen as 0.10 m in order to make comparisons in all structural models.

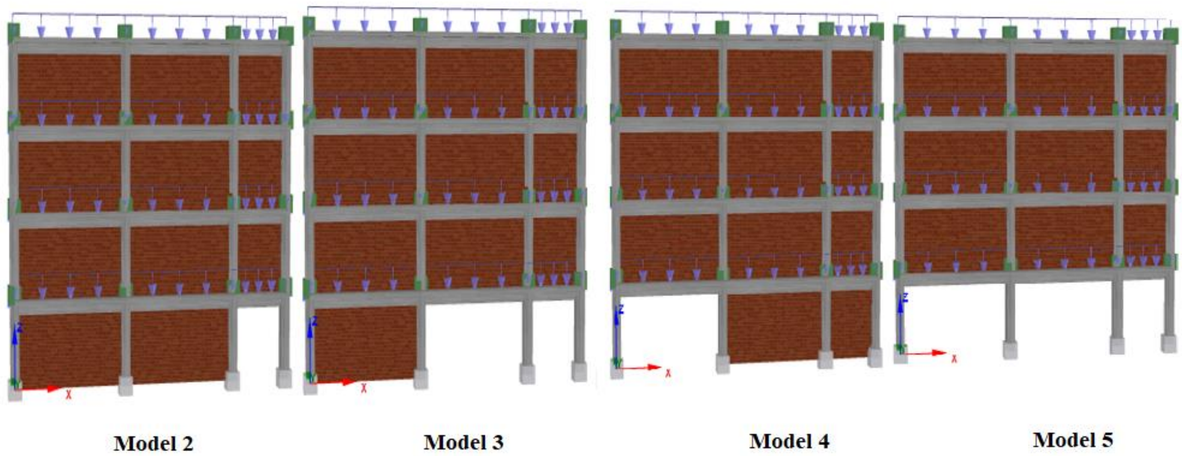

Figure 5. Structural models obtained for the infill wall effect

Within the scope of the study, only the changes of the infill walls on the ground floor were examined. Structural models were created in this context are shown in Table 2.

Table 2. Structural models

Model No	Description
Model 1	Completely filled
Model 2	One gap in the corner
Model 3	Double gap in the left corner
Model 4	Double gap in the right corner
Model 5	Completely bare (No infill)

While making earthquake resistant design and performance evaluation, the natural vibration period of the buildings is an important parameter. The equivalent seismic lateral force is determined using the static design method from a design spectrum that is a function of the fundamental vibration period of a building [33,34]. By using eigenvalue analysis, fundamental natural periods can be obtained. The results were shown in Table 3.

Table 3. The natural periods for structural models

Model	Model 1	Model 2	Model 3	Model 4	Model 5
1	0.199634	0.208785	0.225426	0.228301	0.308856
2	0.069151	0.071214	0.074129	0.074455	0.08129
3	0.06244	0.062441	0.062452	0.062463	0.062476
4	0.05144	0.051469	0.051482	0.051442	0.051485
5	0.047596	0.047619	0.047668	0.047647	0.047815
6	0.044667	0.045209	0.045829	0.045872	0.046776
7	0.036328	0.036436	0.036547	0.036534	0.036694
8	0.033518	0.033533	0.033536	0.033521	0.033539
9	0.022823	0.022823	0.022827	0.02283	0.022834
10	0.022244	0.022293	0.022336	0.022369	0.022555

The stiffness values of reinforced concrete elements differ from the stiffness values estimated under the effect of earthquakes. Therefore, effective cross-sectional stiffness values are used when designing and analyzing such structural elements. In order to determine the performance of reinforced concrete structural systems under earthquake loads, the stiffness of the cracked sections is taken into account. The effective stiffness value of the cracked sections is obtained using the stiffness reduction coefficients predicted from the elastic stiffness value [35-37]. The elastic stiffness (K_elas) and effective stiffness (K_eff) values for the structural models are directly obtained using the stiffness reduction coefficients estimated in the algorithm. All results were shown in Figure 3.

Table 4. Comparison of values obtained values

Model	Base Shear (kN)	Kelas (kN/m)	Keff (kN/m)	DL (m)	SD (m)	NC (m)
Model 1	913.61	193954.2	130170.6	0.003017	0.00387	0.009665
Model 2	881.71	173653.5	117333.4	0.003435	0.004406	0.010996
Model 3	554.87	145838.0	88925.6	0.004605	0.007061	0.015233
Model 4	524.43	143538.4	87404.39	0.007618	0.01079	0.021345
Model 5	396.36	62842.24	44267.62	0.014845	0.019238	0.033857

3. Results and Discussion

In most cases, only the weight of the infill walls is taken into account and other strength parameters are ignored. In the scope of this study, the effect of infill wall for reinforced concrete structures was investigated. Eigenvalue and static pushover analyze were performed for five different structural models. The lowest period was obtained in Model 1, where the reinforced-concrete frame was completely infilled, while the highest period was obtained for the ground story without a completely infilled wall. As the amount of infill wall decreased, the period value became higher. The results obtained for Model 2 and Model 4 show that the period value increases as the infill wall opening increases. The seismic capacities obtained for the reinforced-concrete frame were obtained in full compliance with these values. In the case of a full infill wall, the seismic capacity increased by 2.3 times compared to the case of no infill wall. The seismic capacity decreased as the opening increased in the sections without infill walls. The lowest seismic capacity was obtained for the fully hollow frame model. Completely similar results were obtained for elastic and effective stiffness values. The presence and length of infill walls directly affect these values. With the study, target displacement values were also obtained for the expected performance levels from the building. While the smallest values were obtained for Model 1 with a fully infill wall, the largest values were obtained for Model 5, which is a fully hollow model.

All the result values obtained were fully compatible with each other. The results showed once again that infill walls make very important contributions to the seismic behavior of reinforced concrete frames. Therefore, it is clear that considering the effect of infill walls in the calculations will allow the structural analyzes to be more realistic. In future studies, the type of infill wall material, the use of infill walls with different openings and heights, or the examination of the effects of door and window gaps will also be beneficial.

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Author contributions

Ercan Işık: Conceptualization, Methodology, Software **Mehmet Cihan Aydın:** Data curation, Writing-Original draft preparation, Validation. **Ali Emre Ulu:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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