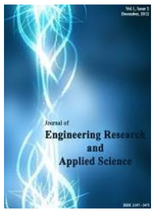
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 7 (2), December 2018, pp 878-885
ISSN 2147-3471 © 2018



Investigation of effect of infilled wall on soft story irregularity

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Accepted 28 August 2018

Abstract
Earthquake is one of the most destructive natural disaster types. Reducing the devastating impact of earthquake impact on structures is an important issue for earthquake engineering. Sufficient rigidity, strength and ductility are expected from structures under earthquake effect. Irregularities that will have a negative effect on the behavior of the structure should be avoided in order to perform the necessary behavior of the structure. The irregularities occurring in the structures are soft story irregularity, weak story irregularity, irregularity in the plan, short column behavior, mass irregularity. The occurrence of these irregularities in the structures makes the earthquake effect more destructive. The removal of the infilled walls on the ground story in the structures image lead to soft story irregularity and weak story irregularity in the structures in order to obtain commercial purposes and aesthetic image. In the earthquakes experienced in the past years, damage caused by soft story irregularities occurred. The loss of life and property in these buildings was very high. In this study, the effect of infilled walls and ground story height on the occuring of soft story irregularities was investigated. 4 different ground story height model was created. In these models, the infilled walls and absence of infilled walls on the ground story were investigated separately.

Keywords: Soft story, infilled wall; pushover analysis; equivalent diagonal compression strut.

1. Introduction

Earthquake is one of the most devastating natural disaster types [1]. Even if the structure is not damaged during the earthquake, or even if it is damaged, it is an important issue for earthquake engineering that the living creatures can escape from the building. [2]. In order to achieve this, the structure must show sufficient ductility, stiffness and strength [3]. In recent years, many studies have been done to achieve these basic criterias [4-7]. According to these studies, regulations are taking many measures. At the beginning of these measures, irregularities are affected by the general architectural structure of the building. These irregularities can be called soft story, weak story, plan irregularities, vertical carrier continuity, mass irregularity, short column behavior. These irregularities cause load distribution and load transmission problems which is undesirable problems in the structure.

In the earthquakes in the past years, many structures have been damaged due to irregularities. One of these irregularities is soft story irregularity. Soft story irregularity arises due to reasons such as increasing the ground story height or removing the ground story infilled walls in order to obtain a commercial or aesthetic image [8]. Even though the infilled wall effect is neglected during the design of the building, the difference of the infilled walls between the stories or the absence of one of the infilled walls in one of the stories decreases the stiffness and adversely affects the earthquake behavior [9]. In recent years, it has been observed that the infilled walls affect the building's natural vibration period, its strength, stiffness, horizontal displacement, and building seismic performance [10-15]. Since the lack of a infilled wall during the earthquake reduces the stiffness on that story. These story more damage is caused to the story which constitutes too much story drift compared to the other stories. As these damages continue, the collapse of the columns occurs without any damage on the upper stories due to the fact that the columns become the mechanism of collapse.

Turkish Building Earthquake Code - 2018 (TBEC - 2018) limited displacement differences between stories in order to prevent soft story irregularities. According

to TBEC – 2018, The case where in each of the two orthogonal earthquake directions, Stiffness

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Irregularity Factor η_{ki}, which is defined as the ratio of the average relative story drift at any i'th story to the average relative story drift at the story immediately above or below, is greater than 2.0. η_{ki} is calculated with (1) formula [16].

$$\eta_{ki} = \frac{(\Delta_i/h_i)_{ort}}{(\Delta_{i+1}/h_{i+1})_{ort}} \leq 2.0 \quad (1)$$


Figure 1. Earthquake damage due to soft story irregularity [17, 18].

2. Material and method

In order to examine the effect of infilled wall and story height on soft story irregularity, 8 reinforced concrete frame models were created in SAP2000 program. The dimensions of story height on the ground stories are variable such as 3 m, 4 m, 5 m and 6 m as seen in Figure 3. Story height on upper story is 3 m. Frame span is 4 m. Concrete class as C30 and steel class as S420 is taken. The column dimensions are 25x50 cm and the beam dimensions are 25x50 cm. As shown in Figure 2, 10ϕ14 longitudinal reinforcement bars in columns and 7ϕ12 longitudinal reinforcement bars in beams were used. 25 kN/m dead load and 15 kN/m live load on the beams was considered. It is assumed that the columns are connected to the story as fixed support.

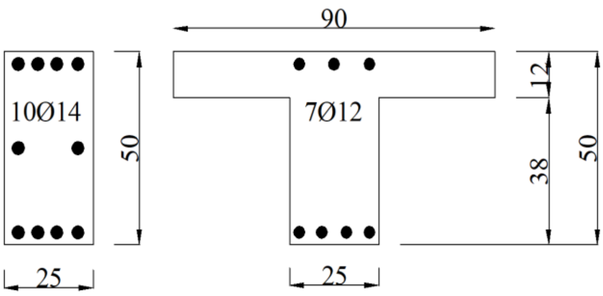

Figure 2. Column and beam dimensions.

As shown in Figure 3 in the frames, different types have been determined with the ground story infilled walls and without the ground story infilled walls. In addition, 8 frame models were created by taking variable ground story height. The modeling of the infilled walls is based on the equivalent diagonal compression strut model in FEMA 356. Equivalent diagonal compression struts are modeled on two ends with hinges. Figure 4 shows a schematic representation of the equivalent diagonal compression strut acceptance.

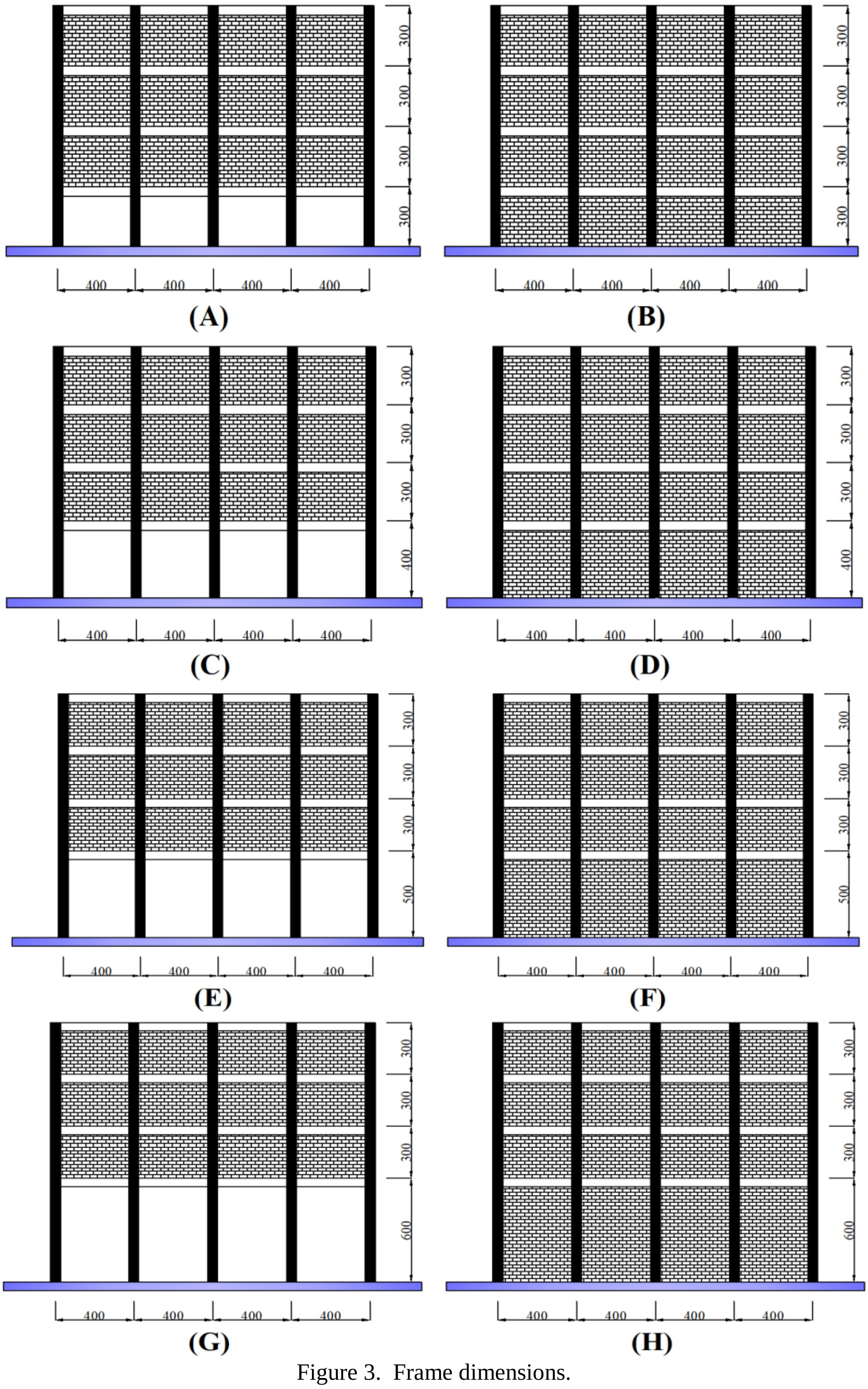

Figure 3. Frame dimensions.

The equivalent diagonal compression strut of width is calculated by the following formula (2) and (3) as defined in FEMA 356.

$$\lambda_1 = \left[\frac{E_{me}.t_{inf}.sin2\theta}{4.E_{fe}.I_{col}.h_{inf}}\right]^{\frac{1}{4}} \quad (2)$$

$$a = 0.175(\lambda_1.h_{col})^{-0.4}.r_{inf} \quad (3)$$

In here,

λ_1 : Coefficient used to determine equivalent width of infilled strut

E_{me} : Expected modulus of elasticity of infilled material

t_{inf} : Thickness of infilled panel and equivalent strut

θ : Angle whose tangent is the infill height-to-length aspect ratio
E_{fe} : Expected modulus of elasticity of frame material
h_{col} : Column height between centerlines of beams
h_{inf} : Height of infilled panel
I_{col} : Moment of inertia of column
L_{inf} : Length of infilled panel
r_{inf} : Diagonal length of infilled panel
a : Equivalent diagonal compression strut of width

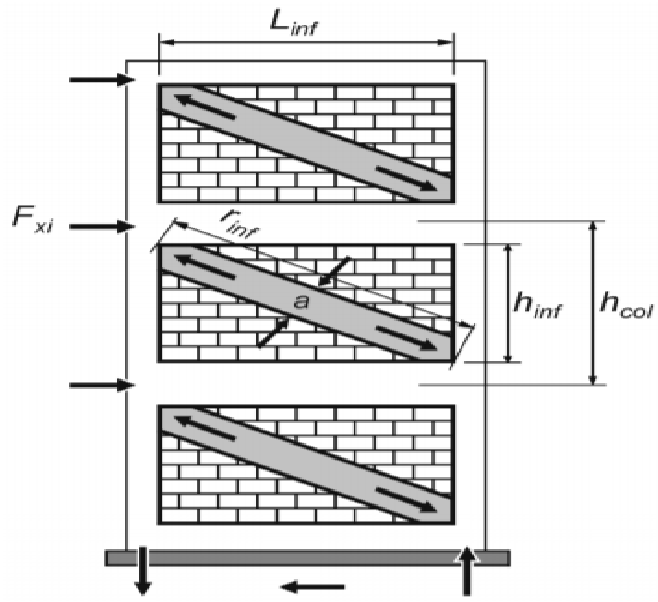

Figure 4. Equivalent diagonal compression strut.

As shown in the formulas (2) and (3), the equivalent diagonal compression strut of width in all frames has changed due to the difference in ground story height in all model. Table 1 shows the equivalent diagonal compression strut of width on the ground stories and upper stories according to each model.

Table 1. Equivalent diagonal compression strut of width.

Type of Frame	Number of Story	Equivalent Diagonal Compression Strut of Width (cm)
A	Ground StoryZemin Kat	-
	1th, 2nd, 3rd Stories	39
B	Ground StoryZemin Kat	39
	1th, 2nd, 3rd Stories	39
C	Ground StoryZemin Kat	-
	1th, 2nd, 3rd Stories	39
D	Ground StoryZemin Kat	40
	1th, 2nd, 3rd Stories	39
E	Ground StoryZemin Kat	-
	1th, 2nd, 3rd Stories	39
F	Ground StoryZemin Kat	43
	1th, 2nd, 3rd Stories	39
G	Ground StoryZemin Kat	-
	1th, 2nd, 3rd Stories	39
H	Ground StoryZemin Kat	46
	1th, 2nd, 3rd Stories	39

Model of equivalent diagonal compression strut with two ends hinge made from S420 steel was created using width given in Table 1. Models were analyzed with pushover method. Pushover analysis is the most commonly used method in the analysis of structures under earthquake load. Pushover analysis is based on the principle of increasing the loading to a target displacement or horizontal loading until the target load value or displacement value is reached. Some elements in the structure may exceed the yield limit during pushover analysis [19]. Figure 5 shows the frame element of the created model in SAP2000.

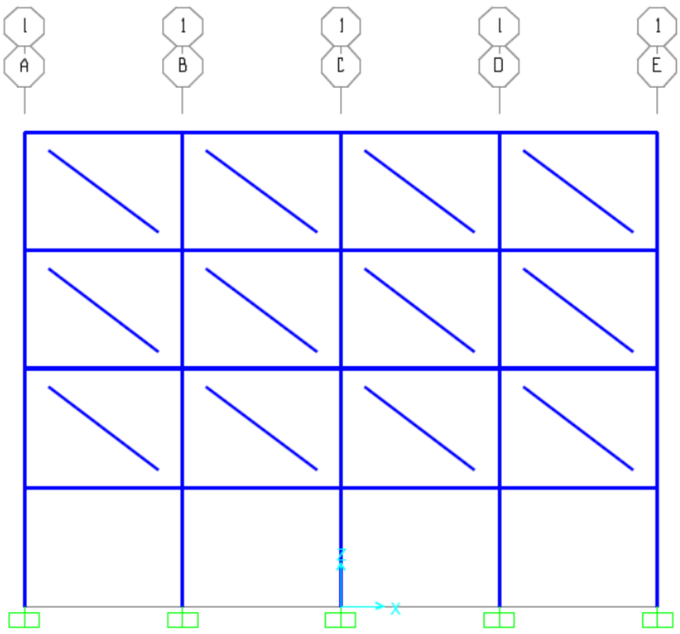

Figure 5. Frame model.

3. Results and discussions

In this study, pushover analysis of 8 different frames were conducted. The equivalent diagonal compression strut is used to see the infilled wall effect in the frames. As a result of the analysis, natural vibration periods obtained in the frames are given in Table 2. As seen in Table 2, the natural vibration period is reduced in the frames with the ground story infilled walls. As it exhibits a more rigid behavior, it makes less horizontal displacement and completes its period in less time. With the increase in the ground story height, an increase is observed in the natural vibration period.

Table 2. Natural vibration period of the frames

Type of Frame	Natural Vibration Period (s)
A	0.21476
B	0.08634
C	0.31888
D	0.09681
E	0.43940
F	0.11013
G	0.57393
H	0.12640

Table 3 shows the soft story irregularity coefficients calculated based on the horizontal displacements of the frames at each level. On the model without ground story infilled wall, as seen in Table 3, there is a soft story irregularity on both the ground story and the story above the ground story. As the ground story height increases, the soft story irregularity coefficient increases in both ground and upper stories. Although there is an increase in soft story irregularity coefficient in direct proportion to the ground story height in the frames with infilled wall, there is not an increase in the coefficient to create soft story irregularity.

The story level-horizontal displacement graph for the frames is given in Figure 6 for each type of frame. When the graphs are examined, it is seen that the horizontal displacement of the frames with infilled walls on the ground story shows a linear increase. However, it is seen that the horizontal displacement on the ground story is too much in the ground story without infilled walls. In addition, it is observed that some frame types have been displaced in contrast to the ground story.

Table 3. Stiffness irregularity coefficient for each type of frame.

Type of Frame	Number of Story	Stiffness Irregularity Coefficient
A	1	267.1640927
	2	17.10377358
	3	0.150141643
	4	-
B	1	1.124822527
	2	1.056852284
	3	1.052881029
	4	-
C	1	584.6881851
	2	-8.765124555
	3	-0.470686767
	4	-
D	1	1.062238319
	2	1.05479345
	3	1.049507793
	4	-
E	1	624.8443689
	2	-7.715355805
	3	-0.762857143
	4	-
F	1	1.277222786
	2	1.090844999
	3	1.034342663
	4	-
G	1	2031.77839
	2	-2.157221207
	3	2.863874346
	4	-
H	1	1.445104047
	2	1.097135654
	3	1.025164232
	4	-

Figure 6. The story level-horizontal displacement graphs

4. Conclusions

The following results were obtained in accordance with the data obtained from the study with the frame models created based on the ground story height and the presence of infilled walls on the ground story:

- Although the increase in the ground story height increases the coefficient of soft story irregularity, soft story irregularity does not occur. The fact that there is no infilled wall in the ground story rather than the ground story height in the soft story irregularity gives more critical results.
- Even if the ground floor height increases, the behavior of the structure is more linear if there is a infilled wall on the ground story.
- In the case where there is no infilled wall on the ground story, plastic hinges begin to form at the bottom and upper end of the ground story columns. The structure goes into a state of collapse mechanism without taking advantage of the other bearing elements.
- Extra safety measures should be taken at the upper and lower end of the ground story columns in buildings with soft story

irregularities. Increasing the cross section of the column at the lower and upper ends, and increasing stirrup spacing are some of these measures.

Soft story irregularity occurs due to the inadequacy of rigidity in the story. Therefore, the shear wall placement on the ground story may increase the stiffness and thus prevent irregularity. Clarification should be made by doing studies in this direction.

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