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Infill Walls in an Existing Reinforced Concrete Building During Seismic Motion

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Abstract: Earthquake is a challenging occasion for the buildings located in seismic zone. There are many studies in order to examine the behavior of the building during earthquake and prevent the damages and losses caused by earthquake. Studies on infill walls are very popular even it is believed they are used as only the architectural elements. Even though it is known that they affect the structural behavior of the building, they are neglected considering that they have lost their load bearing capacity at the beginning of the earthquake. It is aimed in this paper to show that all of the infill walls are not in damage state even if seismic motion totally complete. According the results, while the inner infill walls has no damage, the outer ones up to Xth floor on X direction and Yth floor on Y direction lost their capacity.

Keywords: infill walls, earthquake, nonlinear dynamic analysis

1. INTRODUCTION

Earthquake has been one of the most dangerous natural event for long years. However, increasing of population and urbanization led to make the earthquake more effective on loss of life and goods. Turkey has dramatically suffered from seismic motions because it locates in active seismic zone and most buildings in Turkey have been built without taking sufficient engineering knowledge and superintendence. In order to minimize negative effects after earthquake, many studies have been conducted. How influential existence of the infill walls has become one of the most discussed studies among civil engineering researchers. In many regulations, neglecting its effect on the dynamic behavior of the building, it is recommended to be used only for separating architectural areas and to be included in the numerical model only as a vertical load [1]. It is stated that the reason for this is that the infill walls will be damaged and lose their effect in the initial phase of the earthquake duration.

Studies on the frame with infill walls started in 1950s. It is found that taking into account of infill walls provides the frames more stiffness, more lateral load carrying capacity [2]. Mehrabi et al. stated after and detailed experiment that by rising vertical load on the infill walls, the frame with infill walls could carry %25 more lateral load [3]. It is found in another study that if axial load of the infill walls does not exceed their capacity, infill walls can provide the frame more stiffness than bare frame [4]. Including infill walls to numeric model causes %67 decline in fundamental period and also greater maximum base shear force [5]. It also is investigated that the effect of openings on infill walls on the dynamic behaviour of the frames [6]. Albayrak et al. compared the seismic performance of an existing building and found that the infill walls prevented to collapse by giving the extra load bearing capacity to an old and structurally weak building [7]. In addition to all of these contribution, ignoring infill walls is able to lead to dramatically negative results such as short column failure and soft storey mechanism [8].

Besides previous analytical and experimental studies about the effects of infill walls, the field investigations after earthquake proves that not all of infill walls are damaged in buildings and continue to make important impact on the performance of buildings. The photos taken after the Wechuan Earthquake for determination the failure type of buildings by Zhao et al. shows that infill walls even in some damaged buildings are still standing on [9]. The same views of infill walls can be found after Van Earthquake which hugely influenced the people [10]. In an investigation after Gorkha Earthquake in Nepal is stated that the non-structural damages occurred mostly in low-rise buildings and also the failure of infill walls enabled people to stay in safe. It is also shown in this paper that there are most of building with undamaged infill walls [11]. It is clearly seen in the Fig.1 that even if some of infill walls cracked, most of the infill wall could resist the strong ground motion [12].

In the light of these researches, the objectives of this study can be expressed as to show that not all of infill walls have damages when the ground motion ended, the first time of the damages occurred to infill walls and how many infill walls will be damaged at the time of maximum top displacement reached.

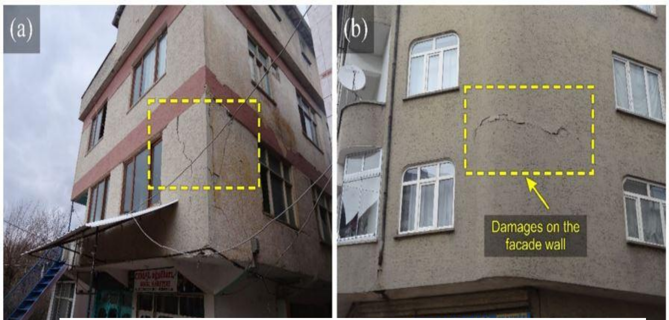

Fig. 1. Infill walls states after Sivrice earthquake in 2020

2. METODOLOGY

In this paper, an existing and still in use reinforced concrete (RC) building from Turkey is used by implementing nonlinear dynamic analysis for testing of the objective. The illustration of the building is given in Fig. 2. X direction of the building is accepted as the short side of the plan and the Y direction is along the long side of the plan. The building has 7seven story and 3-meter height between each floor. It is known that the building built in 1989 by the rules of TEC in 1975 [13]. Therefore, it is considerably appropriate to represent current RC building stock both in Turkey and also other earthquake-endangered regions.

Structural properties used in the analysis are given in Table I. While each beam has the same dimension, 20 by 50 cm, all columns are 50 by 30 cm. The material types for concrete and steel are C14 and S220 respectively. On the other hand, the reinforcement details for each member are also shown obviously in Table I.

The state of infill walls is observed by using of nonlinear dynamic analysis which is the best way to obtain more correct consequences. The SAP 2000 v.20.1.1 package program is preferred to model and analyze [14]. The ground motion used in analysis is selected as Duzce Earthquake from Turkey with 7.1 magnitude. The time histories are demonstrated in Fig. 3.

Fig. 2. Investigated Building

Member	Material		Section Characteristics		
	Concrete	Steel	Cross Section (cm)	Reinforcement	
				Longitudinal	Stirrup
Beams	C 14	S 220	20x50	2 Φ 18	Φ 8 / 250
Columns	C 14	S 220	50x30	8 Φ 16	Φ 8 / 250

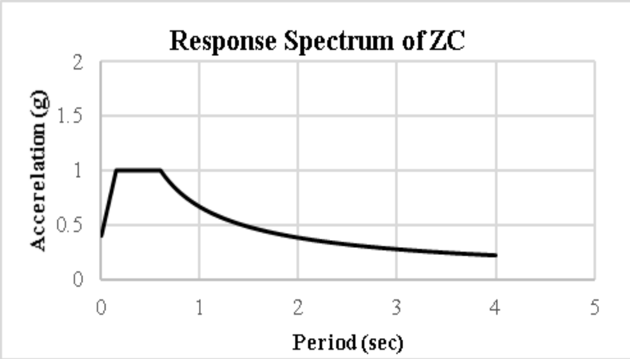

TABLE I. STRUCTURAL PROPERTIES

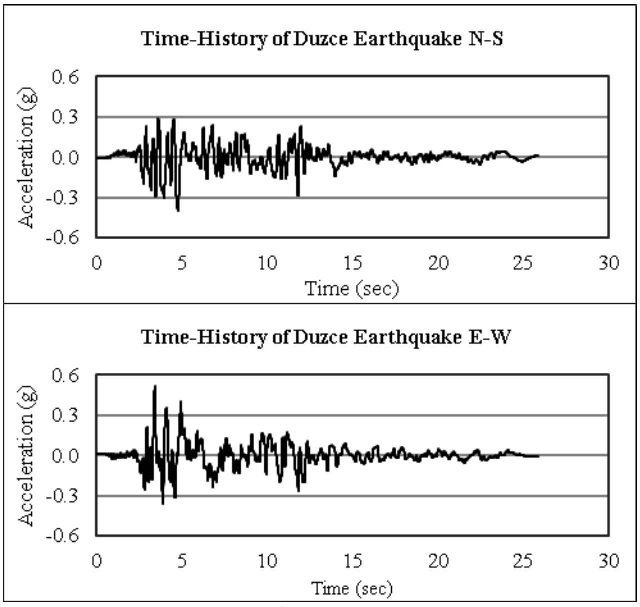

Fig. 3. Time histories of Duzce Earthquake in 1999.

These time histories need to be scaled to account impact of the soil type. Scaling was done via SeismoMATCH package program considering as the soil class ZC defined in TEC-2007 [15-16]. The response spectrum graph of the ZC soil class and the scaling are shown in the Fig 4 and Fig. 5.

In modelling part of the building, it was followed that procedure. Firstly, by using frame elements for beam and column members and then the assigning shell elements for slabs, geometric idealization of the building was done. After effective bending stiffness of frame elements was determined and entered, the plastic hinges were automatically defined at both ends of each frame member to allow the element to behave nonlinearly. After these assignments, taking %30 of dead loads and whole of live loads, vertical nonlinear static analysis was introduced in the program as an initial condition of nonlinear time history analysis. And then, for nonlinear time history analysis, the time histories were added on X and Y direction as an acceleration with %5 damping ratio for both. Finally, equivalent strut element by utilizing moment releases at both ends were included to each span diagonally in order to symbolize the behaviour of infill walls in RC frame.

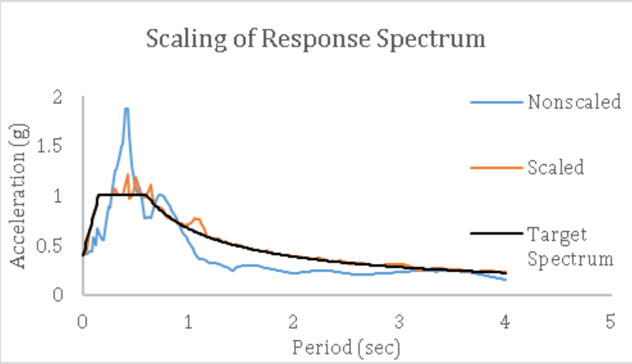

Fig. 5. Scaling of acceleration

There are several modelling techniques for infill walls, but in this paper the approach of Ersin was chosen. He proposed an equation to find effective width of the equivalent struts [17]. It is possible to determine effective parameters by

$$(EA)_{wall} = E.t.\alpha.L_d.\beta.\gamma$$

The parameters of (1) can be expressed as E is the elasticity modulus of infill material, t is the thickness, L_d is the diagonal length of equivalent strut, α, β, γ are coefficient of the definition of equivalent strut's efficient width compared to its length, opening ratio and other effects respectively.

Elasticity modulus of infill walls for this study were chosen 6000 MPa. While thickness of outdoor walls was 20 cm, indoor walls was 10 cm. The coefficient α was selected as 0.37 constantly for each. Window opening (β= 0.5) for outdoor walls i.e. β= 0.8 and door opening for infill walls were selected. γ was 1, which means that there was perfect interaction between infill and frame. These values were taken from the paper of [17-18]. Eventually, for the purpose of determination the damage state in infill walls, force controlled hinges were defined to the middle of the all diagonal equivalent strut. 500 kN and 350 kN axial load bearing capacities were determined for outer and inner infill walls respectively [18].

The 3-D numerical model from SAP 2000 v20.1.1 is illustrated in Fig. 6 after all geometric and material assignment.

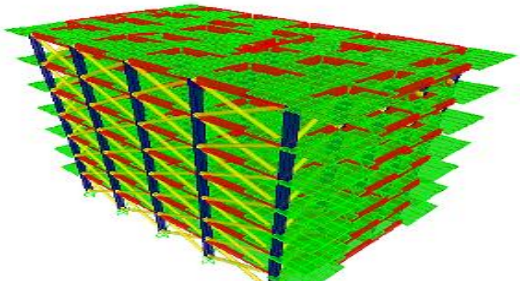

Fig. 6. 3- D model of the building

3. Results & Discussion

In the study in which the damage conditions of the infill walls were investigated, modal analysis results are given first. According to the Table II, the first mode is along X direction which is the weak direction of the building and period of this mode is 0,47 seconds with %81 participation ratio for U_x. The period of the second mode is 0.40 seconds along Y direction with %85 mass participation ratio for U_y. The third period is 0, 31 for torsion mode shape.

Moreover, it can be seen in Fig. 7 the deformed shaped and the hinges states of the building. Also, the basic outputs of dynamic analysis are given with from Fig. 8 to Fig.12 by being shown on the maximum value for each. Fig. 6 shows the change in base shear force with time along X direction. Fig. 7 displays change in the base shear force with time along Y direction. The top displacement outputs are demonstrated by Fig. 8 and 9 for X and Y direction respectively. According to these results, while the maximum base shear force was 12571 kN for X direction, 13759 kN for Y direction. Top floor of the building could displace utmost almost 7 cm along X direction and approximately 5 cm along Y direction. Additionally, when Fig 3. And dynamic outputs are compared mutually, it can be said that while the earthquake was more effective within first 7 seconds on Y direction, on X direction the effectiveness of seismic motion lasted longer.

Mode	Period (sec)	Mass Participation Ratio		
		U_X	U_Y	R_Z
1	0,47	0,81	0	0
2	0,4	0	0,83	0
3	0,32	0	0	0,85

TABLE II. Results of Modal Analysis

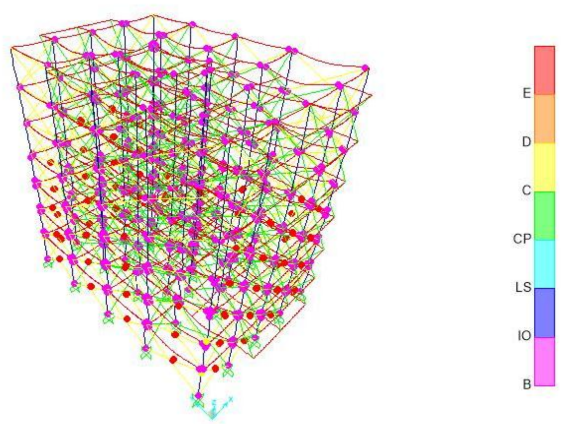

Fig. 7. Final deformed shaped of the building in 3-D

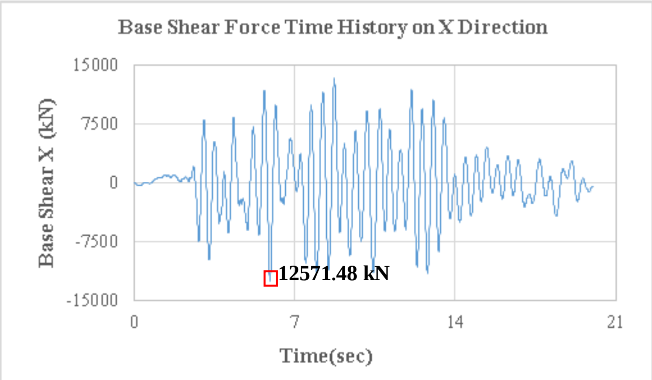

Fig. 8. Base shear forces along X direction during Duzce earthquake

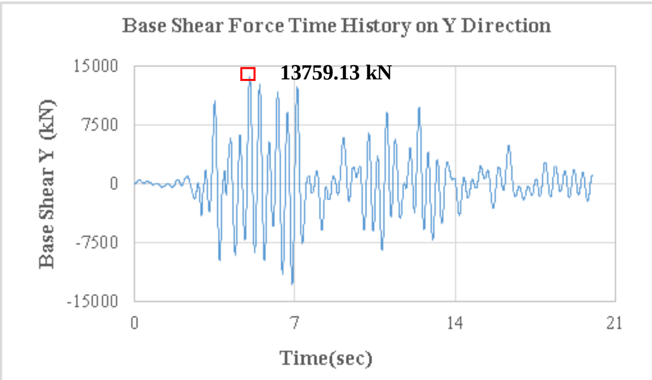

Fig. 9. Base shear forces along Y direction during Duzce earthquake

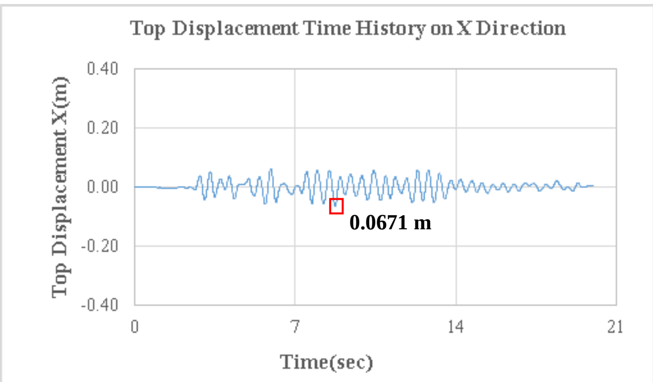

Fig. 10. Top displacements along X direction during Duzce earthquake

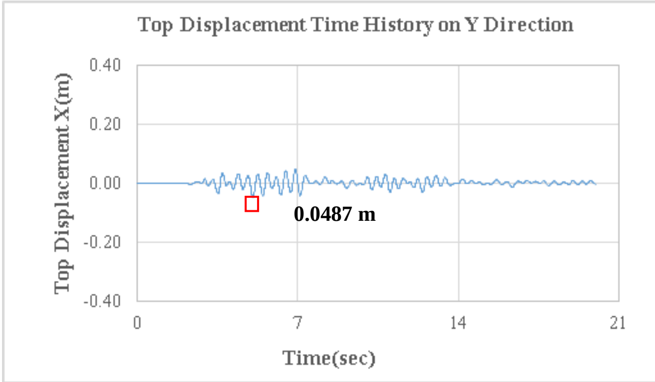

Fig. 11. Top displacements along Y direction during Duzce earthquake

The outer infill walls were examined and compared when the first damage occurred, the maximum peak point was reached and the earthquake ended.

The critical times mentioned in previous sentence are named as condition 1, condition 2 and condition 3 in Table III. As shown in the table, along X direction the first damaged occurred at 2.85 seconds when the top displacement value was 3.7 cm. On the other hand, along Y direction first collapse in an infill wall was found at 3.49 seconds when the top floor displaced 3 cm. After those times, the number of damaged infill walls increased second by second until the time when uppermost top displacement emerged. As seen in the table, whilst %66 of outer infill walls along long side of the building exceeded the axial load earing capacity at 8.74th seconds when the maximum top displacement occurred on X direction, only %43 of those on Y direction damaged at 5.04th seconds when time of top displacement value was maximum along Y direction. Up to the end of earthquake there was no more damage shown in outer infill walls for both directions. During the whole seismic motion duration, it was not observed any damage in the inner infill walls along X and Y directions. Most of the inner walls had less than half of axial load capacity. Only %8 of them was able to pass 175 kN, %50 of capacity. To give an example of the state of outer and inner infill during earthquake, Fig. 12 and Fig. 13 show the graphs of change in axial load of an outer infill wall (OIW) versus base shear force and top displacement in turn. Also Fig. 14 and Fig. 15 displayed the relationship between change in axial load of an inner wall (IIW) and base shear force and top displacement respectively. In those figures the infill walls were selected because they had the maximum axial load demand during the motion.
From these consequences, it can be inferred that when earthquake motion is effective and has greater acceleration, damage to the infill walls begins to lose its contribution to load bearing. Additionally, increase in number of infill walls is in correlation with the rise the top displacement and base shear force since infill walls has positive effects on the stiffness of the building. Observing no extra infill walls damage for both directions between condition 2 and 3 shows that the undamaged infill walls

are able to continue to contribute on the dynamic behaviour even after the maximum top displacement occurred. It is also deduced that the inner infill walls have less risk in terms of having damaged as long as they place close to center of rigidity and are designed according to project.

In Fig. A and Fig. B display the sides of the building that received the highest number of damaged outer infill wall at the end of the earthquake along both directions. It is obviously clear that there were not failed infill wall in the top three floor along X direction. Along Y direction, the number of floor having undamaged outer infill walls was two. In addition, to exemplify of the inner infill walls state, the failure shape of a frame with inner infill wall at the time earthquake finished is given by Fig. C.

TABLE III. OUTER INFILL WALLS DAMAGE STATE

		Condition 1	Condition 2	Condition 3
X Direction	Time (sec)	2.85	8.74	20
	Total OIW*	56	56	56
	Damaged OIW	1	37	37
Y Direction	Time	3.49	5.04	20
	Total OIW	56	56	56
	Damaged OIW	1	24	24

*Outer Infill Walls

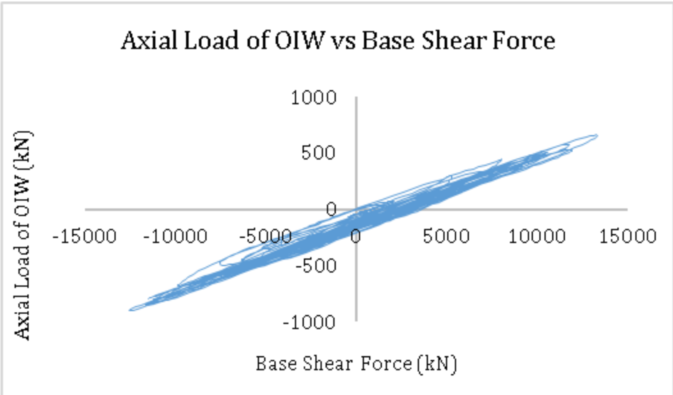

Fig. 12. Axial load of an outer infill wall (OIW) which has tha maximum demand and base shear force relationship

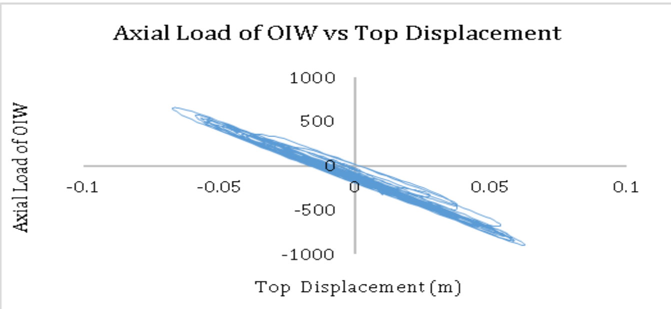

Fig. 13. Axial load of an outer infill wall (OIW) which has tha maximum demand and top displacement relationship

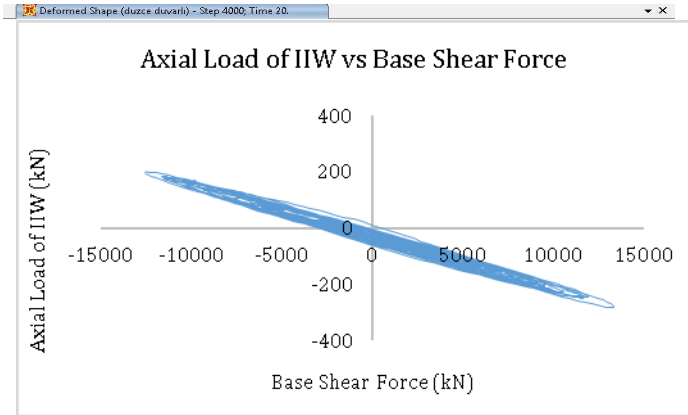

Fig. 14. Axial load of an inner infill wall (IIW) which has tha maximum demand and base shear force relationship

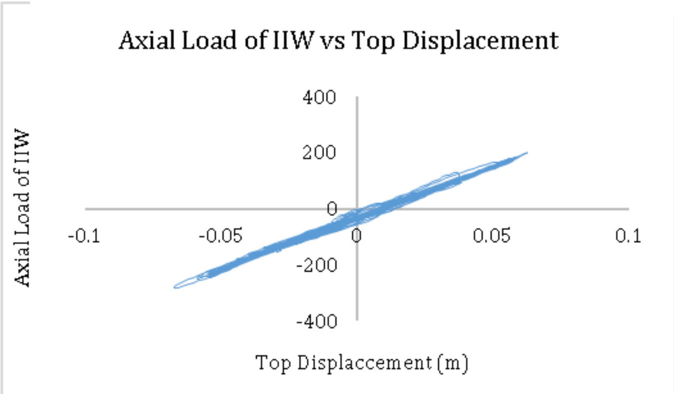

Fig. 15. Axial load of an inner infill wall (IIW) which has tha maximum demand top displacement relationship

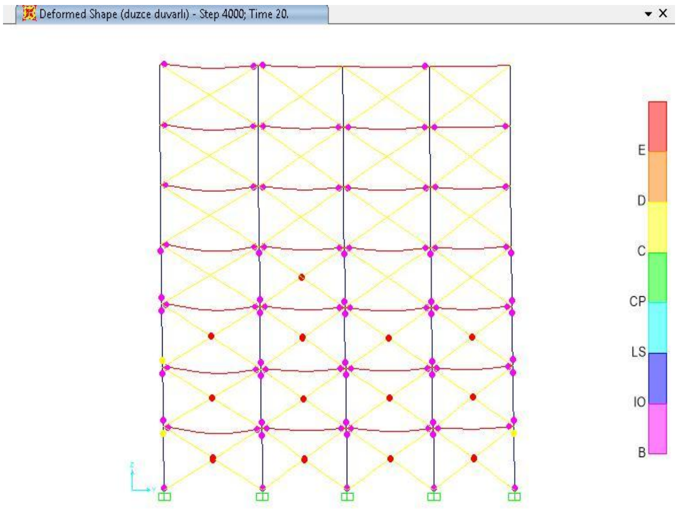

Fig. 16. Outer infill walls damage states along Y direction at the end of ground motion

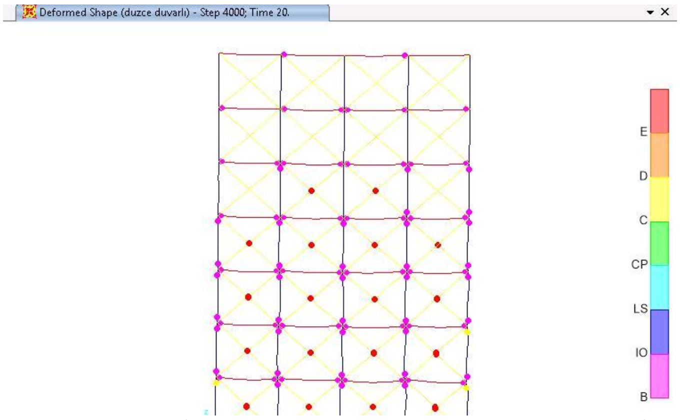

Fig. 17. Outer infill walls damage states along X direction at the end of ground motion

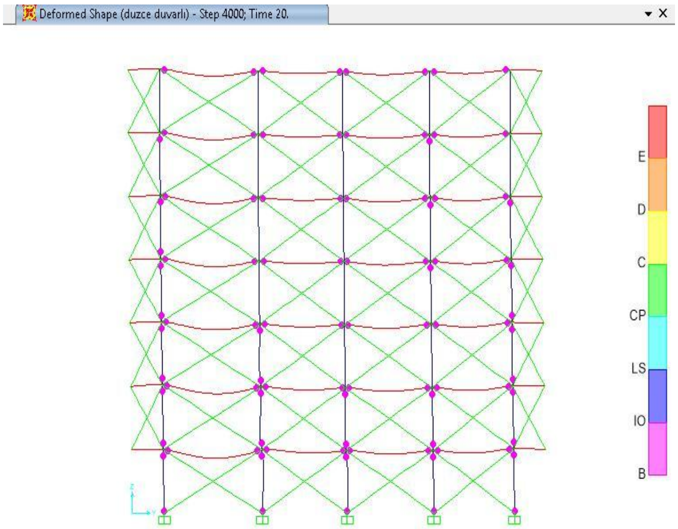

Fig. 18. Inner infill walls damage states along Y direction at the end of ground motion

5. CONCLUSIONS

1-) Contrary to common opinion, it is emphasized in this study that all of the infill walls do not lose their bearing at the beginning of the earthquake. 19 of 56 outer infill walls were still standing without damage on X direction, this number went up to 32 considering the outer infill walls along Y direction at the end of earthquake.
2-) First damage emergence was found at the very early period of the earthquake. At 2.85th seconds for X, 3.49th for Y direction, axial load on a infill wall located the outer side of the building passed over its capacity.
3-) From the relationships graphs, it is seen that the damage in infill wall perfectly correlated by the base shear force and top displacement.
3-) After the time maximum displacement occurred for both sides, it is not observed remarkable infill wall failure.
4-) It is clear seen that inner infill walls have less danger in terms of damage occurrence. In this building, only %8 of inner walls was able to exceed half of axial load capacity.

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