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AXIAL-LOAD EFFECT ON RC THIN PANELS USED FOR RETROFITTING OF RC FRAMES

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Keywords

Reinforced Concrete Frame
Axial Load
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Abstract

This paper aims to study the contribution of axial loads applied on reinforced concrete (RC walls to enhance contact at the interface between the beam and the wall in order to prevent massive failure in the surrounding frame with low concrete compressive strength. For this reason, the beams are curved upward in the middle at certain levels before the forming the RC walls. After the construction of the walls, the beams are freed so that the beams can exert axial loads on the walls. Four specimens are used in the experimental study. Three of them are bare RC frames retrofitted by using this technique; the fourth one is the one retrofitted with a regular panel and used as a reference specimen. No increase was observed in load carrying capacities of the specimens with axial loaded panels. However, more energy was dissipated by the specimens with axially loaded panels compared to the reference specimen.

BA ÇERÇEVELERİNİN GÜÇLENDİRİLMESİNDE KULLANILAN BA İNCE PANELLERDE EKSENEL YÜK ETKİSİ

Anahtar Kelimeler

Betonarme Çerçeve
Normal Yük
Deneysel
Güçlendirme
İnce Panel

Öz

Bu çalışma, betonarme duvarlara uygulanan eksenel yüklerin, düşük beton basınç dayanımına sahip çerçevenin ağır hasar görmesini önlemek için kiriş ile duvar arasındaki arayüzdeki teması arttırmaya katkısını araştırmayı amaçlamaktadır. Bu nedenle kirişler, betonarme duvarların yapımından önce belirli seviyelerde ters sehim verilir. Duvarların yapımından sonra kirişler serbest bırakılır, böylece kirişler duvarlara eksenel yükler uygulayabilirler. Deneysel çalışmada dört adet numune kullanılmıştır. Bunlardan üçü, ter sehim işlemi kullanılarak güçlendirilmiş yalın BA çerçevelerdir; Dördüncüsü ise, üzerinde eksenel yükü olmayan ve referans numune olarak kullanılan bir panel ile güçlendirilmiş çerçevedir. Eksenel yüklü panellere sahip numunelerin yük taşıma kapasitelerinde artış gözlenmedi. Bununla birlikte, eksenel yüklü panellere sahip numuneler tarafından referans numuneye kıyasla daha fazla enerji soğrulmuştur.

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1. Introduction

Installing RC shear walls in RC buildings is a frequently applied retrofitting technique. The benefit of usage of shear walls is that these walls are effective in increasing the seismic performance of the structure. Nevertheless, the inadequate contact surface of these walls with the adjacent frame can cause massive shear failures along with undesired soft-story mechanisms at RC structures with low concrete compressive strength.

Much research has been done on shear walls (Erdem, Akyuz, Ersoy and Ozcebe, 2006; Koutas, Pitytzogia, Triantafillou and Bousias, 2014; Vetr, Yarmohamadi and Mohammadikish, 2022; Bastami, Salehi, Ghorbani and Moghadam, 2023; Khademi, Tehranizadeh and Shirkhani, 2023; Liang, Bai, Ma and Jiang, 2023; El-Azizy, Ezzeldin and El-Dakhakhni, 2023; Albutainy and Galal, 2024) and the results show that the connection details between wall edges and beams/columns have major impact on the behavior of the overall structure. Deformation capacities of the walls can be increased by right amount of reinforcement and proper connection of them to beams and columns and so that full continuity between the frame and the wall interfaces increase the load carrying capacity of the frame. The results also state that brittle failure of shear walls or reduction in the ductility of the system can be caused by poor detailing which leads to deficiency of load transfer between old frame and new structural wall.

Considering strengthening of a RC building, there are many studies that show the advantages of adding RC shear walls to the other retrofitting techniques. However, limited experimental researches are currently available on the effectiveness of axial load acting on shear walls in retrofit of a reinforced concrete buildings.

Bastami et al. (2023) performed test on RC shear walls applying lateral load with increasing axial loads. Up to 10% increase in the axial load causes an increase in ductility and lateral resistance; however, beyond that level of axial load causes reduction in ductility. Du, Luo and Sun (2020) tested RC shear walls under two different levels of axial loads and cyclic lateral loads. Axial force decreased ductility, and energy absorption.

The work presented in Teymur and Pala (2018) investigates the effect of axial loads applied on shotcrete panels used for strengthening of RC frames with shotcrete panels. The experimental results state that the axial load exerted on the panel caused an increase in lateral resistance and the energy dissipation of the frames. This experiment was done only for one specific level of cambering.

In this study, four RC bare frames are used. The beams of the three RC bare frames are curved upward in the middle before strengthening with RC thin panels. During this process screw jacks are placed symmetrically at the front and at the back of the frame. When the panels have preserved their full strength, the screws are detached and the beams are freed resulting in an axial force on the panels. The aim of generating in-plane axial force on panels by means of creating upward deflection on the beam is to strengthen the interaction between the beam and the infill panel that helps the shear strength of the panel to increase, therefore, the damage to the frame members would be minimized. The fourth frame is the one retrofitted with a regular panel that is used as a reference specimen. The specimens are tested under displacement reversals with increasing intensity.

2. Method

Experiments has been performed to estimate the impact of axial load on the seismic performance of the frames.

2.1. Material Properties, Geometry and Detailing

Nearly ½ scale, one story, one bay RC frames with low concrete compressive strength were tested under constant vertical loads and lateral reversed cyclic loads. The frames are chosen to represent common deficiencies observed in residential buildings in Turkey. Cast-in-situ RC panels are used to form structural walls in the vulnerable frames.

Reverse deflection levels and concrete compressive strengths are summarized in Table 1 and other construction details are given below.

The columns are 20 cm by 25 cm and beam is 20 cm by 32.5 cm, as shown in Figure 1. The dimensions of the frames are 152.5 cm in height and 220 cm in width. The dimensions of the panels are 120 cm in height and 170 cm in width as shown in Figure 1. Dimensions and reinforcement detail of the frames are presented in Figure 2. Main reinforcement of the frame is 16 mm steel bars which have average yield stress of 270 MPa.

RC panel consists of a wire mesh of ϕ6 mm steel bars and it has a 6 mm thickness given in Figure 2 having a yield stress of 320 MPa.

The reverse deflection amount is between L/500 and L/(500/3) of the clear span length (L) of the frame are stated for each specimen in Table 1. The concrete compressive strengths of frames and the panels are also stated in Table1. Magnitudes of the reverse deflection are chosen below a certain level so that, during the process the cracks that will occur on the beam and the columns will be limited to small-scale so that no restoring will be required. According to the calculations made; longitudinal reinforcements, that are at the middle of the beam, yield at the reverse deflection levels which are larger than L/(500/3).

Table 1. Reverse Deflection Levels

Specimen Name	Reverse Deflection Amount	Concrete Compressive Strength (MPa)	
		Frame	Panel
R	0	10	25
SP1	L/500	10	25
SP2	L/(500/2)	10	25
SP3	L/(500/3)	10	25

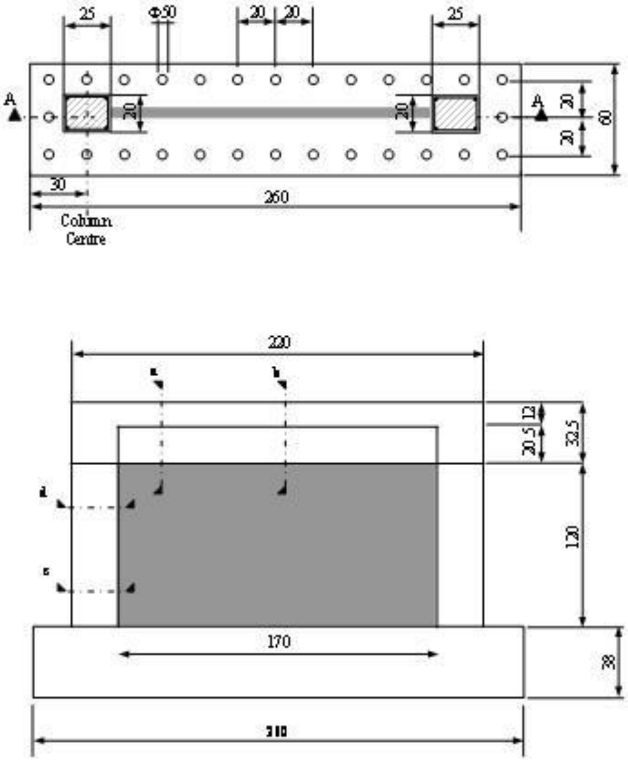


Figure 1. Dimension of the specimens

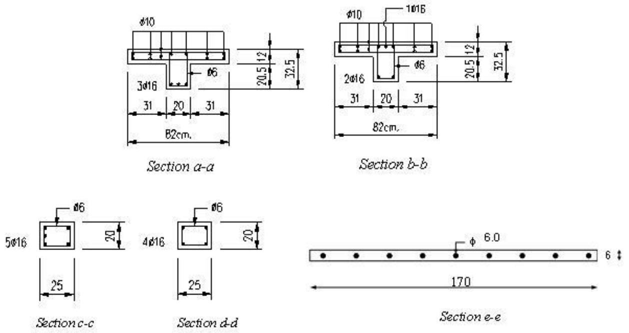


Figure 2. Detailed configuration of the reinforcement in frames and the panels

The wire mesh is connected to all four edges to the frame with anchorages. The details of the connection are shown in Figure 3. 20 cm part of the anchorages are buried in the panel and the rest is buried in the beam and the columns.

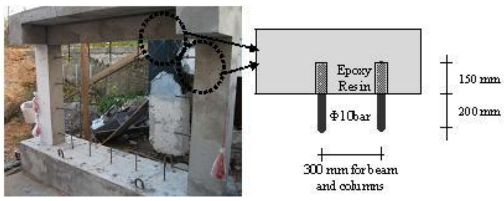


Figure 3. Details of anchorages

The beams of *SP1*, *SP2* and *SP3* are curved upward in the middle before the construction of the panels. This is done by using screw jacks that are placed symmetrically at the front and at the back of the frame. Throughout the process, deflection of the beam is measured with a displacement transducer simultaneously.

Bending cracks have occurred during the reverse deflection process at the middle of the beams of the specimens. The widths of the cracks are 0.4, 1.2, 1.6 mm for *SP1*, *SP2* and *SP3*, respectively. The bending cracks occurred at the columns were less than 0.1 mm.

The main reinforcement of the beams did not yield at *SP1*, *SP2.* However, at *SP3* the ones at the middle of the beam had yielded.

2.2. Test Setup and Load Protocol

Test-setup is shown in Figure 4. A hydraulic jack is used to apply a certain level of axial loads on the columns. Target displacement levels are applied by two MTS 250 kN-capacity hydraulic actuators. The lateral load pattern is given in Figure 5.

Figure 4. Test setup

Displacement reversals with increasing intensity were applied thrice for both pushing and pulling cycles to the specimens to simulate the effect of seismic action. The characteristic of the displacement reversals is recapped in Figure 5.

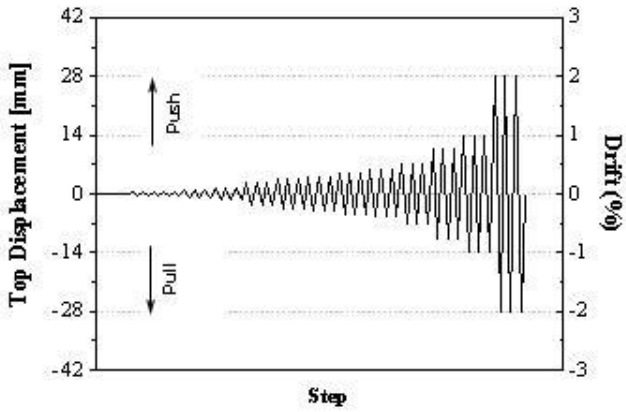


Figure 5. General load pattern

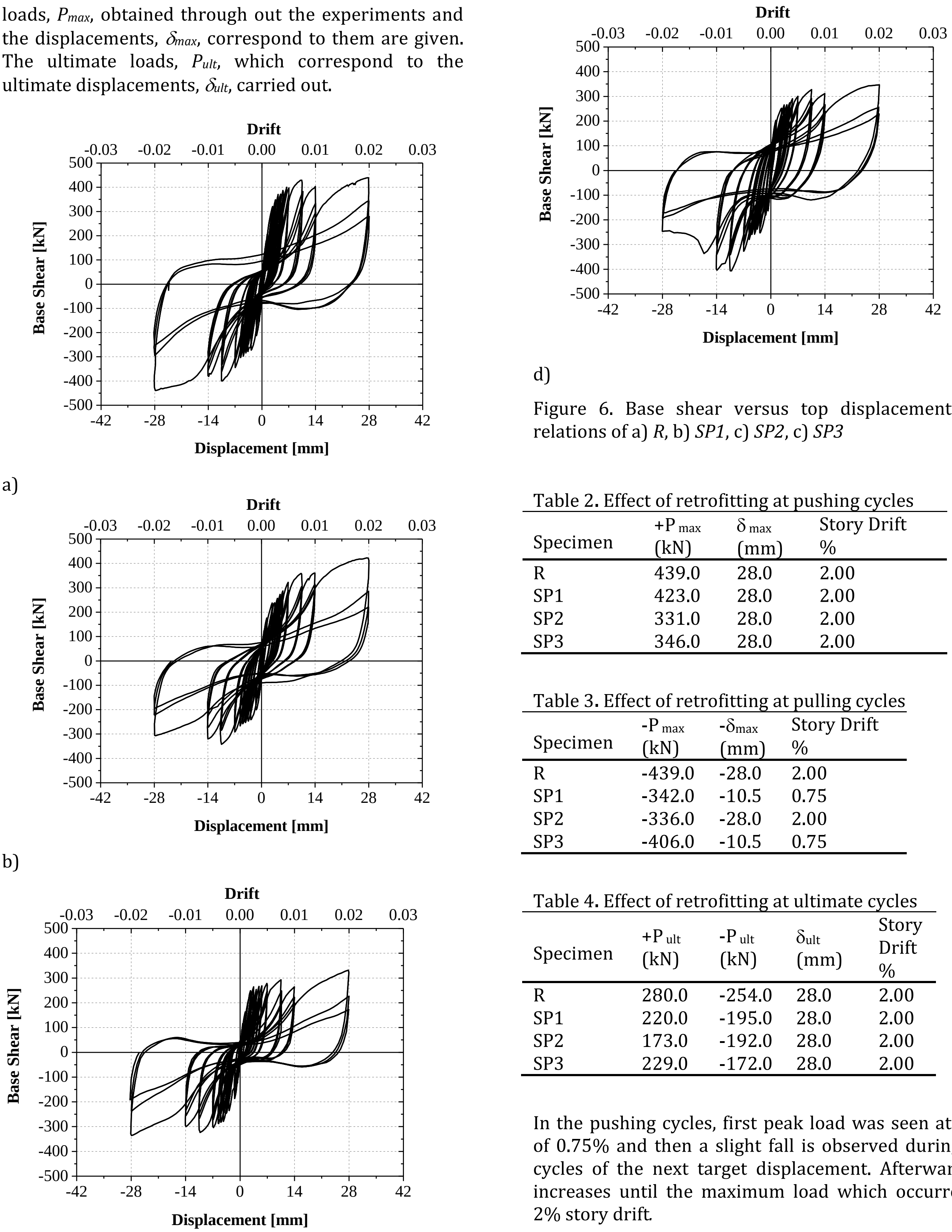
Displacement transducers are used to collect data at critical region. Strain gauges were attached to main reinforcement of both the columns and the beam, and several points on the panels.

3. Experimental Results

The test results of the specimens are discussed here comparing ultimate load carrying capacities, failure modes, initial stiffnesses, and energy dissipation capacities.

3.1. Lateral load carrying capacity

Figure 6 show the base shear versus top displacement relations for specimens *R*, *SP1*, *SP2* and *SP3*, while Table 2 through Table 4 summarises the maximum loads, P_{max}, obtained through out the experiments and the displacements, δ_{max}, correspond to them are given. The ultimate loads, P_{ult}, which correspond to the ultimate displacements, δ_{ult}, carried out.



a)

b)

c)

d)

Figure 6. Base shear versus top displacement-drift relations of a) *R*, b) *SP1*, c) *SP2*, c) *SP3*

Table 2. Effect of retrofitting at pushing cycles

Specimen	$+P_{max}$ (kN)	δ_{max} (mm)	Story Drift %
R	439.0	28.0	2.00
SP1	423.0	28.0	2.00
SP2	331.0	28.0	2.00
SP3	346.0	28.0	2.00

Table 3. Effect of retrofitting at pulling cycles

Specimen	$-P_{max}$ (kN)	$-\delta_{max}$ (mm)	Story Drift %
R	-439.0	-28.0	2.00
SP1	-342.0	-10.5	0.75
SP2	-336.0	-28.0	2.00
SP3	-406.0	-10.5	0.75

Table 4. Effect of retrofitting at ultimate cycles

Specimen	$+P_{ult}$ (kN)	$-P_{ult}$ (kN)	δ_{ult} (mm)	Story Drift %
R	280.0	-254.0	28.0	2.00
SP1	220.0	-195.0	28.0	2.00
SP2	173.0	-192.0	28.0	2.00
SP3	229.0	-172.0	28.0	2.00

In the pushing cycles, first peak load was seen at drift of 0.75% and then a slight fall is observed during the cycles of the next target displacement. Afterwards it increases until the maximum load which occurred at 2% story drift.

In the pulling cycles, reference frame and SP2 are exhibiting the similar behaviour as they performed in the pushing cycles. However, in SP1 and SP3, maximum loads have occurred at drift of 0.75% and afterwards strength degradations are observed. Strength degradations are observed after the shear cracks occurred on windward column, at the region between 1/3 and 1/2 of the column height. In addition, in SP3 concrete spalling is observed at the top end of the leeward column and anchorages are pulled away by the panel from the upper side of the windward column.

No increase was observed in load carrying capacities of the specimens with axial loaded panels compared with the reference specimen.

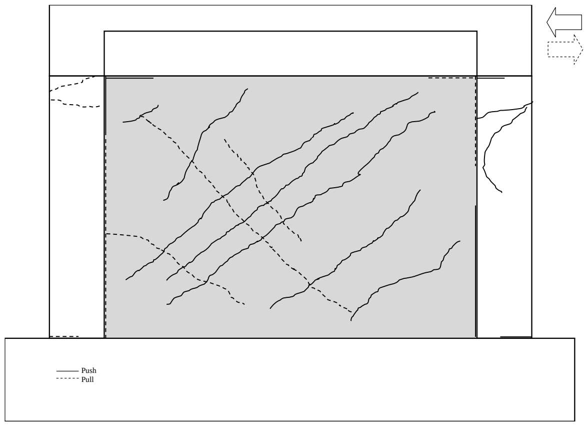
3.2. Failure modes

Figure 7 show crack patterns of all the specimens that have occurred during the tests.

At the drift of 0.03%, the detachment of the panel from the frame members has started and this is observed at all specimens. The separations between the panel and the columns occurred at bottom right and top left of the panel in pushing cycles. In pulling cycles, it is observed at top right and bottom left of the panel. When the target displacement has increased, the detachment of the panel from the columns are slowly increased. In all specimens, their widths reach to 3.5 mm at final steps of the tests.

At the drift of 0.03%, first shear crack is observed at top part of the windward column in all specimens. A distinguishable strength reduction of the frame has been observed while severe increases in widths of the shear cracks are observed at top part of the columns at the last loading cycles. A conclusion can be made that the axial load applied on the panels, do not have an impact on the damage mode of the frames. Actually, since the frames have low concrete compressive strength and have weak columns, this kind of behaviour are to be expected.

Members of the frames exhibit similar behaviours and failure modes. However more shear cracks were noted on panels. The widths of the cracks vary between 0.4-1.5 mm. After a while later, the inclined cracks joins with the cracks that formed along the anchorages of the beam and the columns. This can indicate that the axial loads imposed by the beams can cause the contiguity between the beam and the panel to work together for a longer time. Especially increased number of parallel inclined cracks at the panel of *SP1* compared with the reference specimen's is a good example of this. Despite the fact that the columns had large shear cracks, the panels continued to resist lateral loads and they presented more ductile behaviour when exposed to axial loads.



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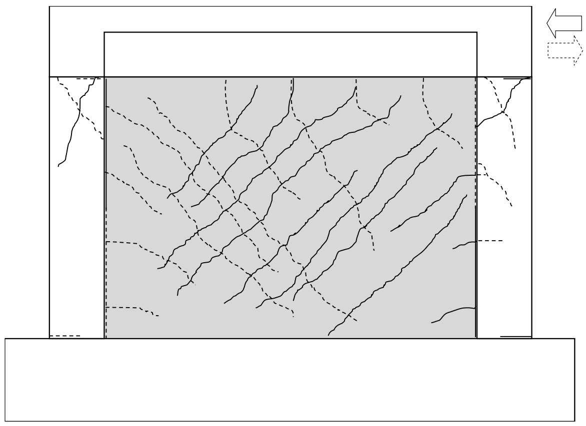

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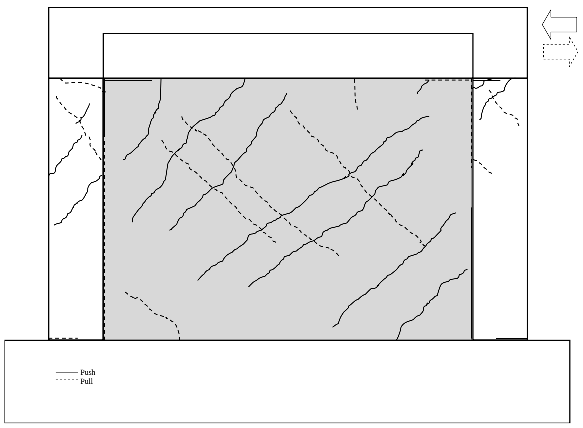

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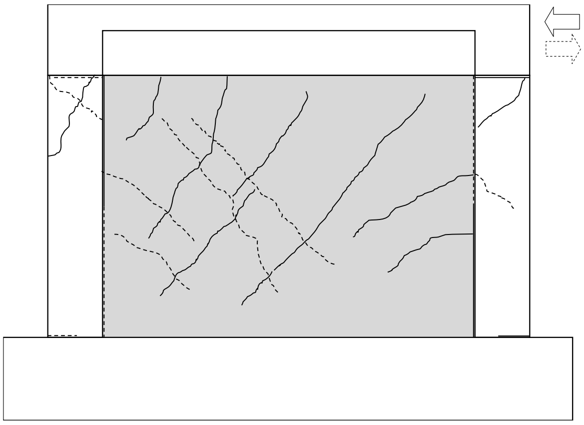
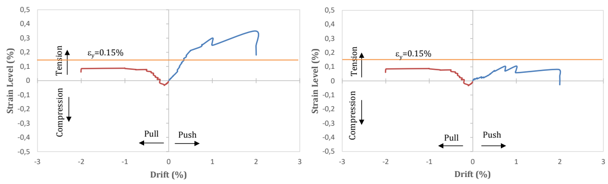


d)

Figure 7. The cumulative crack patterns of a) *R*, b) *SP1*, c) *SP2* d) *SP3*

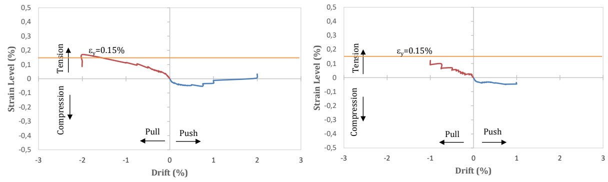
Strains of longitudinal reinforcement versus the story drifts are drawn for the top section of both columns given in Figures 8 and 9. Maximum and minimum strain values that correspond to the drift levels are only shown in the following figures. Figures 8 (a) and 9 (a) shows that the longitudinal reinforcement in the reference frame yields. However, there is practically no yielding in the reinforcements of the other specimens as seen in the figures. Even if the strains of the reinforcement of SP2 shown in Figure 8(c) reaches yielding which occurs at the last cycles of the largest drift, no significant yield deformation has been observed.



a) Reference b) SP1

c) SP2 d) SP3

Figure 8. Longitudinal reinforcement strains versus the story drifts for the windward column



a) Reference b) SP1

c) SP2 d) SP3

Figure 9. Longitudinal reinforcement strains versus the story drifts for the windward column

3.3 Lateral stiffnesses

The lateral stiffness of the frames increased by 30% and 40% for *SP1* and *SP3*, respectively, compared with the reference specimen's. While for *SP2*, it decreased by 30%. The author estimates the reason why lateral stiffness of *SP2* is less than the reference frame's, as the lack of adhesion between infill panel edges and surrounding frames.

3.4 Cumulative energy dissipation

The specimens with the axial-loaded panels' energy dissipation have increased by 5% in SP1 and by 35% in SP3 at 1% story drift level compared with the reference specimen, as shown in Figure 10. There is a 15% decrease occurred at SP2. Examining the damage of the panels of the specimens at this drift level, the number of inclined cracks on the panel of SP2 are less than SP1 and SP3 and they did not join with the cracks that formed along the anchorages of the beam and the columns. Increase of energy dissipation by 10% for SP3 was observed at 2% story drift level. There is a 10% and 25% decrease occurred at SP1 and SP2, respectively. Examining the damage of the frame, the shear cracks are much more severe at SP1 and SP2 compared to SP3. This shows that anchorage of infill panel of SP3 to the beam was firmly provided by means of axial load thanks to reverse deflection process.

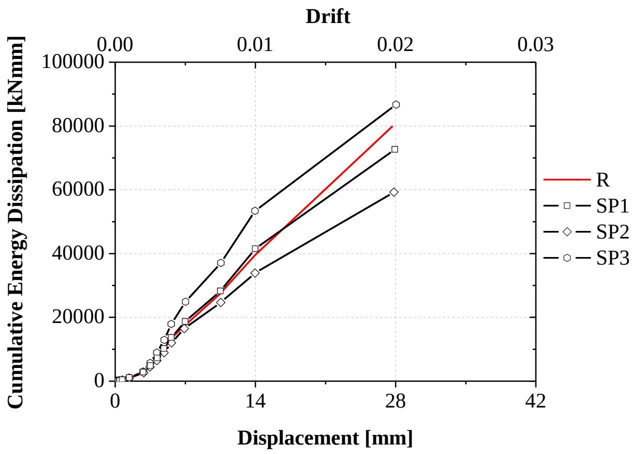


Figure 10. Cumulative energy capacities

4. Conclusion

In this experimental study, a reverse deflection technique was used to retrofit RC frames with low concrete compressive with RC thin panels. The idea was to increase interaction between the beam and the infill panel that helps the shear strength of the panel to increase, therefore, the damage to the frame members would be minimized. The experimental results of the frames compared with the reference frame are summarized below:

Seismic performance of the frames was not improved by using this reverse deflection technique.

The initial stiffnesses of the frames are increased by 30%-40%.

Cumulative energy dissipations of the specimens with the axial-loaded panels are increased by 5%- 35% at 1% story drift level but decreased by 10%-25% and 2% story drift level.

Due to lack of inelastic deformation capacities of RC beam and columns, the axial load exerted on the panels does not have an impact on the seismic performance of the frame. Failure mode of the frame was governed by the diagonal shear cracks and concrete crushing of the frames. It is recommended that before the construction of the panels, the columns and beam-column joints are needed to be strengthened as well.

Even though the frames of all three specimens is damaged heavily, the panel continued to carry the lateral loads.

The disadvantage of the reverse deflection process is that it is not very clear how much load is exerted by the beam on the panel. So, it is hard to estimate the level of axial load applied on the panels.

This paper tried to determine the effect of axial load on RC panels. It has been demonstrated that although the axial force acting on the panel does not have any impact on the dominant mechanism of failure, it improves the initial stiffness and the energy dissipation capacity of the frame. Increasing research on application of axial load on RC panels with different methods and their use in design is important for introducing advanced retrofitting techniques and increasing their practical applications. It is recommended to test different methods for applying axial loads on RC panels in future studies.

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Contribution of Researchers

Literature review, methodology, preparation of the research project, preparation of the test specimens, analysis of the test data and writing of the paper is all done by the author.

Conflict of Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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