EXPERIMENTAL STUDY ON DAMAGE REDUCTION SESIMIC RETROFIT TECHNIQUE FOR RC FRAME USING ULTRA HIGH STRENGTH FIBER CONCRETE

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Abstract

According to Japanese current building code, the required structural performance of building is just "not collapse" under severe earthquake. As a characteristic damage state of new RC buildings due to recent earthquakes (the 2011 Tohoku earthquake, the 2016 Kumamoto earthquake) in Japan, structural components have minor damage, but non-structural components such as RC thin walls have severe damage. Once this damage occurs, the building cannot be used continuously as usual after earthquake. Generally, many users in the damaged building will evacuate to a public building, the occupancy level of the building is very high. Therefore "post-earthquake functional use" as structural performance of building under severe earthquake should be focused on recently.

This paper presents experimental test results for 2story-2spans RC frame with thin walls retrofitted by precast Ultra high strength steel Fiber Concrete (UFC) panels to reduce the damage of RC thin walls and improve the structural performance and control collapse mechanism. The precast UFC panels (t=30mm) were simply installed on original RC thin walls (t=60mm) using epoxy resin adhesive. Test result showed maximum story shear force and deformability was upgraded, collapse mechanism was improved from story collapse type (column collapse type) to global collapse type (beam collapse type) by the retrofit technique. Moreover, damage of RC thin walls was reduced by UFC panels.

Introduction

Non-structural walls in RC structure such as thin walls with rectangular section located around center in the span (afterward, center walls) and wing walls contribute to horizontal strength under earthquake, but they are very brittle. As a characteristic damage state of new RC buildings due to recent earthquakes (the 2011 Tohoku earthquake, the 2016 Kumamoto earthquake) in Japan, structural components have minor damage, but non-structural components such as RC thin walls have severe damage. Once this damage occurs, the building cannot be used continuously as usual after earthquake. Generally, many users in the damaged building will evacuate to a public building, the occupancy level of the building is very high. Therefore "post-earthquake functional use" as structural performance of building under severe earthquake should be focused on recently.

This paper presents development of the seismic retrofit technique which not only improve seismic performance of old RC building but reduce damage of non-structural walls. The authors focus on the precast Ultra high strength steel Fiber Concrete (UFC) material[1,2]. In this paper, to show the effectiveness of proposed seismic retrofit technique, RC frame tests will be discussed.

Outline of Loading Test Plan

Specimens are 2 story and 2spans RC frame with non-structural walls such as wing, center, hanging and standing walls assuming typical governmental office building shown in Fig.1. The specimen scale is half size to actual building and this thin wall has only single layer reinforcement shown in Fig. 2. Number of specimen is two, one is non-retrofitted and the other is retrofitted. UFC panels are installed at one side of non-structural walls using epoxy resin adhesive. Thickness of non-structural walls is 60mm. Vertical and horizontal reinforcement in walls is D6 rebar at 100mm interval. Edge reinforcement for center walls is two D10 and one for other walls is two D13. Columns are 350 mm square section with sixteen D16 rebars as longitudinal reinforcement. Beams are 250×350mm section with eight D16 rebars. The shear reinforcement for columns and beams is double D10 rebars at 50 mm interval. Steel type of longitudinal reinforcing rebar is SD345 for columns. Steel type of rebar is SD295, which diameter is smaller than 13 mm. Bar arrangement is shown in Fig.3.

UFC panels are pasted on the non-structural wall face from one side using the epoxy resin adhesive. The high strength non-shirnk mortar is filled in the gaps between beam and UFC panel and the epoxy resin is filled in the other gaps. Three UFC panels are installed at the wall composed of center and standing, hanging wall. Above installed method of UFC panel is shown in Fig.4.
Material test result for steel bar, concrete series (concrete, UFC, non-shrinkage mortar), epoxy resin adhesive is shown in Table.1,2,3

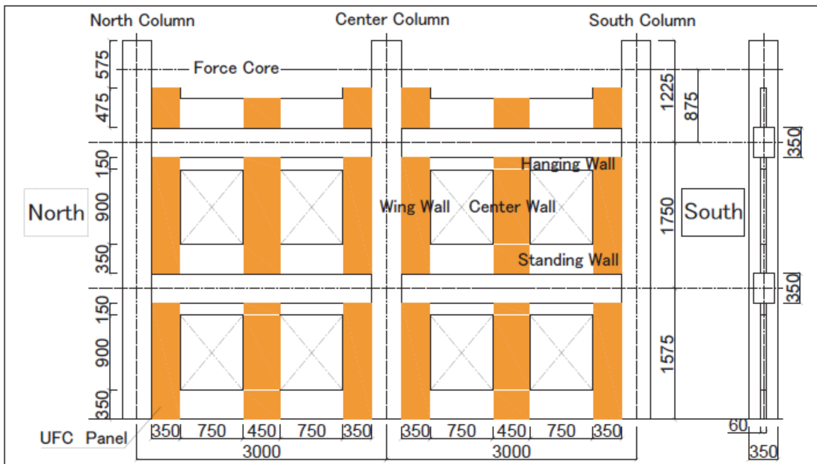


Figure 1. Frame specimen retrofitted by UFC panels

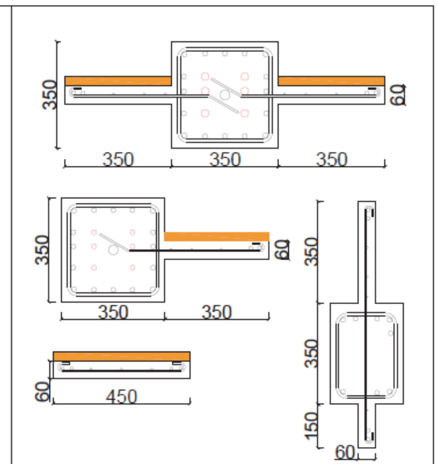


Figure 2. Component section

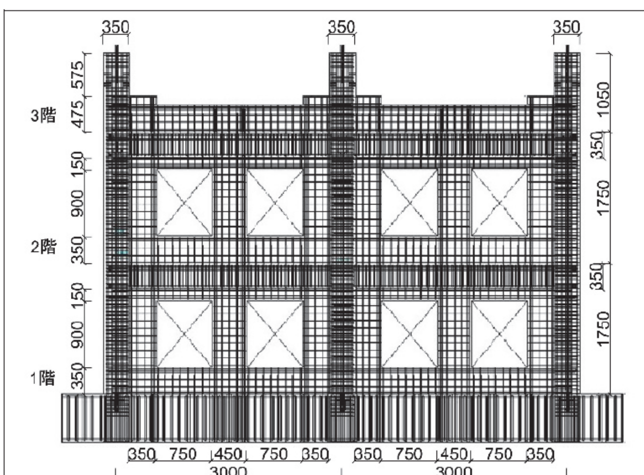


Figure 3. Reinforcement arrangement

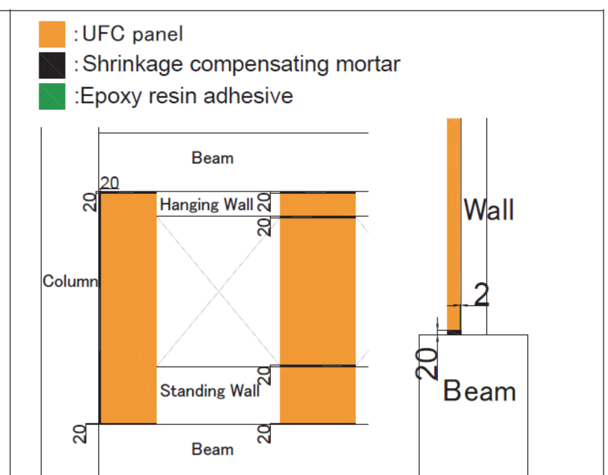


Figure 4. Installed Method of UFC panels

Loading setup and loading path is shown in Fig. 5, 6 respectively. Cyclic loading was implemented using attachment with pin support at both ends to keep horizontal displacement at top of each column on 3rd story. Axial force was applied using un-bonded pc tendon and axial force ratio to column gross section area is 0.075 for outside columns, 0.15 for inside column. Horizontal oil jack was controlled by global drift angle R which is given by horizontal displacement at center of beam in top story divided by total height (=3.325m)

As for measurement plan, flexural and shear deformation for column and beam and shear deformation for wall is measured by displacement transducers shown in Fig.7. The strain at main bars and shear reinforcements for column and beam and reinforcing bars for wall are measured by strain gauges shown in Fig.8 to evaluate critical section of beam, plastic hinge portion and inflexion point of columns.

Table 1. Material Test Result for Reinforcement

Reinforcing bars / Components	Diameter	Grade	Yield strength (N/mm^2)	Young's Modulus (kN/mm^2)
Main bar for beam & column	D16	SD345	391	191
Edge bar for wing, standing and hanging walls	D13	SD295A	338	182
Edge bar for center walls	D10	SD390	402	187
Shear reinforcement	D10	SD295A	350	180
Bar of walls	D6	SD295A	346	185

Table 2. Material Test Result for Concrete, UFC, Mortar

Concrete / Story	Compressive strength (N/mm^2)
Top story	38.2
2nd story	36.8
1st story	39.8

	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)	Young's Modulus (kN/mm^2)
UFC	220	38.3	54.0

	Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Young's Modulus (kN/mm^2)
Non-shrinkage mortar	106	8.86	30.7

Table 3. Material Test Result for Epoxy Resin Adhesive

Epoxy resin adhesive	unit	condition	Tested value	Guaranteed value
Specific gravity (hardened state)	-	25℃	1.7	1.55～1.75
viscosity (mixed state)	mPa・s	25℃	paste	paste
Tensile shear stress	N/mm^2	23℃	16	Over than10
Compressive strength	N/mm^2	23℃	64	Over than 50
Young's Modulus	N/mm^2	23℃	3900	Over than 1000

Test Results

Damage process and backbone curve for retrofitted specimen. Some flexural cracks at wing walls and center walls and beam in each story were observed during R=0.0625% cycle. Above flexural cracks extended and shear crack at standing walls on every story and hanging walls on 2nd story were observed during R=0.125% cycle. Some flexural cracks at outside columns and slight compression failure at top end of center walls on 2nd story were observed during R=0.25% cycle.

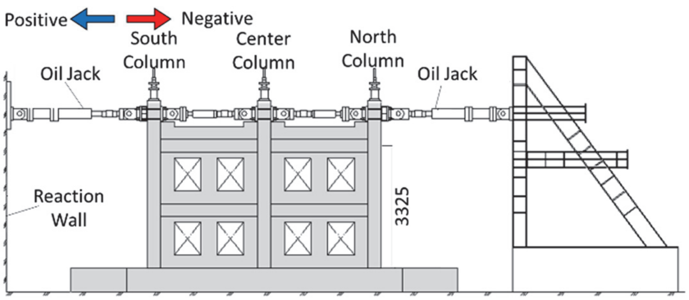


Figure 5. Loading Setup

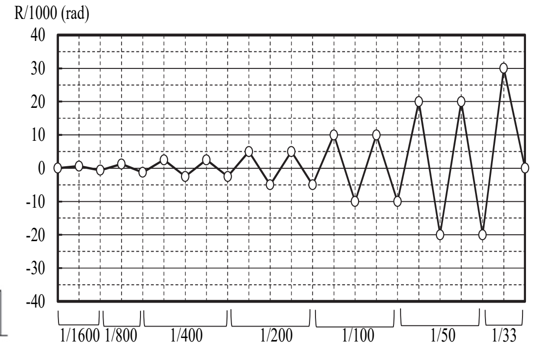


Figure 6. Loading Path

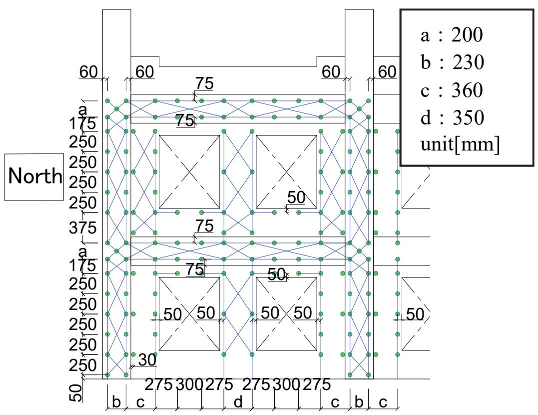


Figure 7. Displacement Transducer Setup

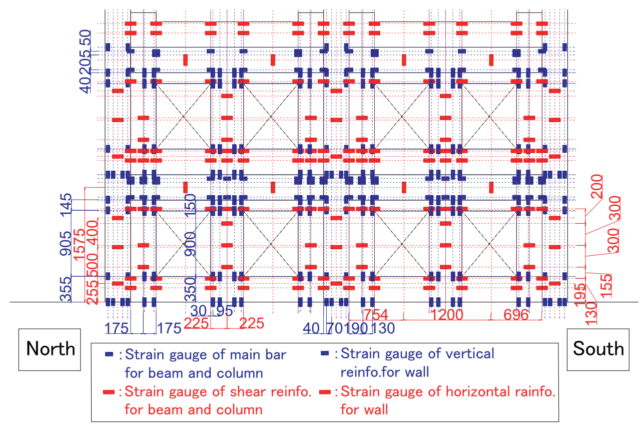


Figure 8. Strain Gauge Setup

Compression failure at both ends of center walls and wing walls on 2nd story were observed during R=0.5% cycle. Some flexural cracks at bottom end of inside column and shear crack at beam-column joint on 2nd and 3rd story were observed during R=0.5%. Shear cracks at every walls (maximum shear crack width at center wall at 1st story is approximately 4.0mm) and flexural crack at UFC panel in 1st story were observed and above compression failure were extended but Any compression failure at any components in 1st story were not observed during R=1.0% cycle shown in Photo 1. Finally, damage concentrated at joint of wing walls and hanging/standing walls on 2nd and 3rd story, at joint of wing walls and standing walls on 1st story, at both ends of every center walls were observed shown in Photo 2.

Backbone curve of each story is shown in Fig.9. When 2nd story drift angle reached at 0.5%, maximum strength was observed and the strength was kept until 1.0%. Regarding the story deformation distribution, 2nd story drift angle is little bit larger than 1st story.

The relationship between base shear (sum of horizontal oil jack) and global drift angle R for non-retrofitted specimen and retrofitted specimen is shown in Fig.10. The retrofitted specimen has larger horizontal strength than non-retrofitted one which rapid strength deterioration was observed at R=0.5%. Fig 11 shows backbone curve which vertical axis is base shear divided by maximum strength to compare both specimens. (a) shows positive side, (b) shows negative side. As above mentioned, from Fig.11 (a), the retrofitted specimen has maximum strength at R=0.5%, kept the strength until R=1.0% and then the strength dropped gradually comparing to the non-retrofitted one. After R=2.0%, the ratio of base shear to maximum strength is almost same. On the other hands, from Fig.11(b), both specimens has maximum strength at R=0.5% and then the strength dropped soon. However the strength deterioration degree of the retrofitted specimen is more gradual than the non-retrofitted one.

Fig 12 shows backbone curve which connected origin to peak points at R=0.5, 1.0, 2.0% respectively. Using the value given from Fig. 12, Fig.13 shows negative stiffness ratio which is negative stiffness after R=0.5% divided by the secant stiffness at R=0.5%. (a), (b) are same as Fig.11. From Fig.13, until R=1.0%, the retrofitted negative stiffness degree is considerably gradual, the value for positive and negative is -0.02 and -0.09 respectively. And until R=+2.0%, degree of the retrofitted specimen for positive side is almost same to the non-retrofitted specimen.

Therefore, this results implies the effect of seismic retrofit is improvement of not only maximum strength, but deformation capacity.

Damage Distribution. Fig.14 shows damage states for the retrofitted specimen and the non-retrofitted specimen at peak of R=0.5, 1.0, 2.0%. Black portion in this figure means spalling of concrete after compression failure.

It is confirmed that shear crack at center walls and wing walls of the retrofitted specimen was reduced comparing to the non-retrofitted specimen at R=0.5%. The cause is assumed that rotational deformation was dominant due to rigid body rotational behavior of center wall with UFC panel and shear deformation component of these walls was controlled.

At R=1.0%, spalling of concrete is observed at walls on 2nd story for both specimens. Spalling of concrete was observed at top end of center walls on 2nd story for the non-retrofitted specimen, and at both ends of center walls on 2nd story for the retrofitted specimen. Regarding the portion of concrete spalling, the portion for retrofitted specimen was observed at end of standing walls and the portion for non-retrofitted specimen was observed at end of wing walls as shown by circle marks in Fig.14. It is assumed that damage distribution was changed by retrofit works, since ultimate flexural strength of column with wing wall and UFC panel was improved and became larger considerably than the strength of beam with walls. This implies damage distribution was controlled by this retrofit technique.

Photo 1. Damage state at R=1.0%

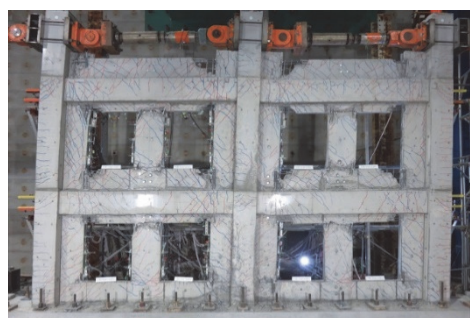


Photo 2. Damage state at R=3.0%

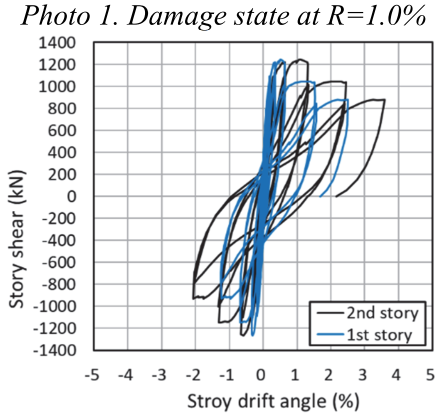


Figure 9. Story Shear and Story Drift Angle Relationships

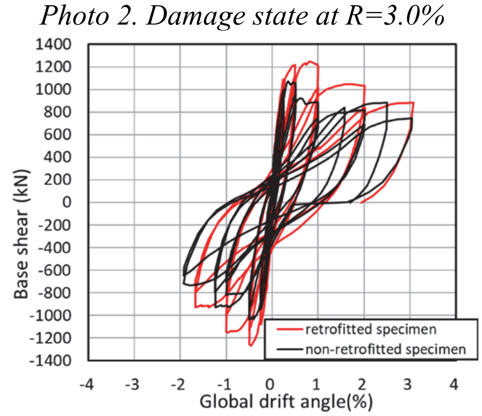
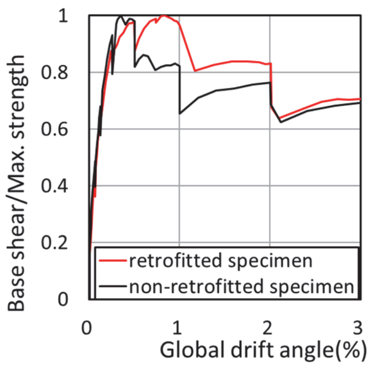
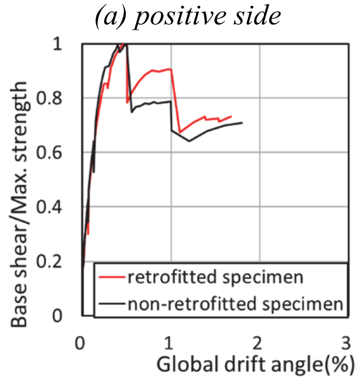


Figure 10. Comparison of Load – Displacement Relationships

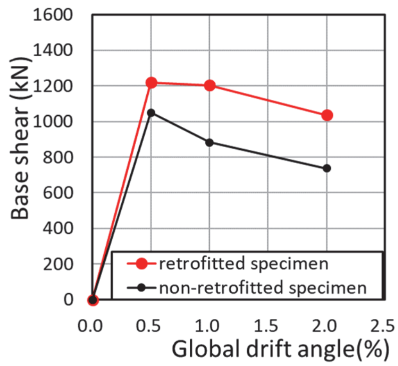


(a) positive side

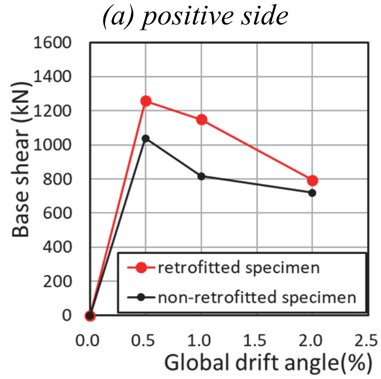


(b) negative side

Figure 11. Backbone Curve for Both Specimens

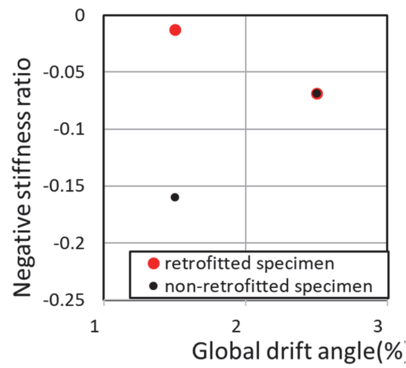


(a) positive side

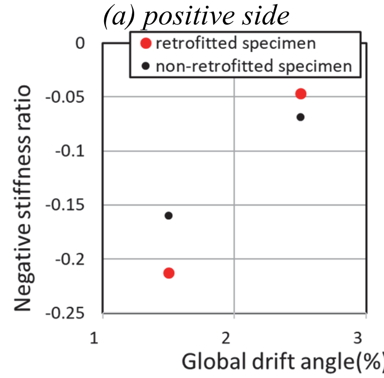


(b) negative side

Figure 12. Simplified Backbone Curve



(a) positive side



(b) negative side

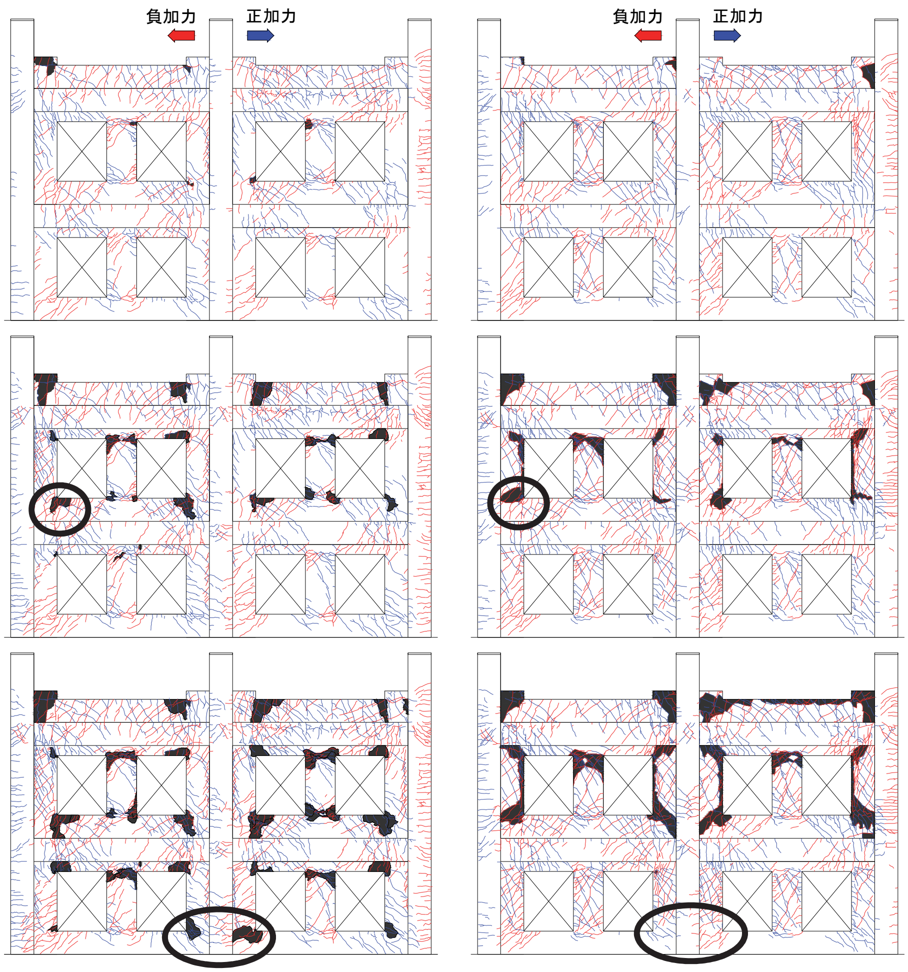
Figure 13. Negative Stiffness ratio After R=0.5%

At R=2.0%, damage observed in the non-retrofitted specimen concentrated at walls on 2nd story. On the other hand, damage for the retrofitted specimen was observed at wing walls and center walls on 1st story. Additionally, the damage portion for retrofitted specimen was also observed at end of wing walls on connected standing wall as shown by circle marks in Fig.14. It is assumed that the end of wing wall on 1st story had plastic hinge, since beam with walls at 2nd story failed in flexure and then the maximum strength deteriorated and inflexion point of column with wing wall at 1st story moved up. Additionally, collapse mechanism was story collapse[3] for the non-retrofitted specimen and global collapse for the retrofitted specimen respectively. This implies collapse mechanism was controlled by this retrofit technique. Therefore, it is confirmed that this retrofit technique using UFC panels can reduce the damage of existing wing walls and center walls and control collapse mechanism at ultimate state.

Reinforcing Bars Yield Distribution. Fig.15 shows yield distribution of each reinforcing bars such as main bar, shear reinforcement of beam and column, edge and other bars of each wall for both specimens. At R=0.5% where both specimens reached maximum story shear force, edge reinforcements at top of center walls on 2nd story yielded for the retrofitted specimen, horizontal reinforcements of center walls on 2nd story yielded for the non-retrofitted specimen. This result is consistent with other result that shear deformation of center walls was controlled by UFC panel as above described. Regarding yield portion of main bar in beam, the portion is at face of wing wall for the retrofitted specimen and at the face of column for the non-retrofitted specimen respectively. This implies the critical section of beam was kept at face of wing walls by UFC panel retrofit. Moreover, the edge bar of 1st story's wing wall on the connected standing wall yielded.

At R=1.0%, main bars of column on 1st story for the retrofitted specimen yielded, it is assumed that the specimen reached global collapse mechanism. On the other hand, any main bars of column on 1st story never yielded for the non-retrofitted specimen.

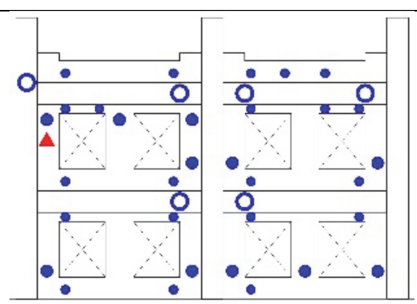
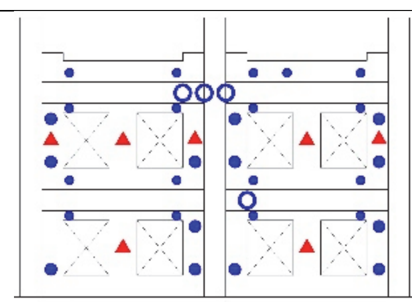
At R=2.0%, shear reinforcement of beam on 3rd story yielded. It is assumed that shear force carried by the beam became large, since critical section of this beam was kept at face of wing wall as above mentioned. Therefore, it is confirmed that yield distribution of reinforcing bars for both specimens was quite different and this retrofit technique using UFC panels can change collapse mechanism.



(a) Retrofitted Specimen *(b) Non-retrofitted Specimen*

(*Top R=1/200 rad., Middle R=1/100 rad., Bottom R=1/50rad.*)

Figure 14. Damage States

R=0.5%		

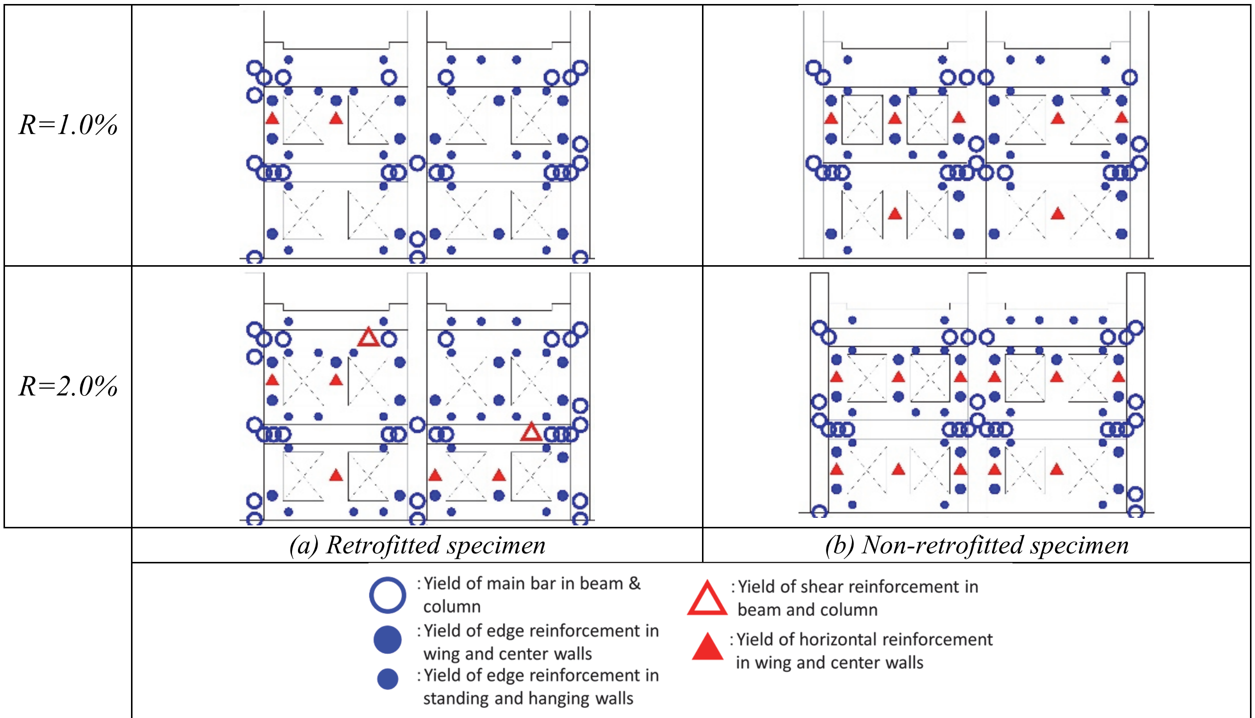


Figure15 Reinforcement Yield Distribution

Conclusions

Experimental test for 2sotry-2span RC frame retrofitted by Precast UFC walls to existing wing walls and center walls was implemented and following seismic retrofit effects were obtained;

- The retrofitted specimen had greater maximum strength than the non-retrofitted specimen, kept the maximum strength until global drift angle R=1.0%, strength deterioration was controlled until 2.0%. This effect is improvement of strength and deformability.
- Damage reduction for existing wing walls and center walls around deformation level at maximum strength was confirmed due to rotational deformation of center wall with UFC panel.
- This retrofit technique changes the collapse mechanism from story collapse to global collapse and excessive concentration of story drift angle was improved.

Acknowledgements

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