

Characteristics of Shear Wall Retrofit Effect with Different Retrofitting Method

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ABSTRACT: Recently, for more demands of the economical benefits and environmental conservation, many engineers prefer to choose remodeling. In these cases, artificial openings are unavoidable to make house wider, and this will degrade wall strength and stiffness by losing effective wall section and it may cause the weakening of system capacity. So these damaged shear walls need to be retrofitted by additional materials or members.

In this research, four specimens were tested to find out the capacity of the damaged wall and the retrofitted wall. The artificially damaged wall was prestressed by tendons to improve the shear capacity of the wall, and the other walls were retrofitted by adding steel plate at the surface for the same purpose. Consequently, these retrofitted walls showed more capacity in shear and flexural corresponding to strength and stiffness. Especially, the wall with steel plate showed ductile behavior after ultimate strength and the prestressed wall had more stiffness than prototype wall which had no retrofit.

Keywords: retrofit, steel plate, prestressing, shear walls, opening

1. INTRODUCTION

In the case of the remodeling of shear wall system apartment, shear walls are principle element for resisting lateral loads. It is necessary to make the opening at the wall for horizontal expansion. Loss of wall area due to the opening cause the reducing of wall capacity and this may cause the collapse of whole structures. Therefore it is important that the structural system needs

to be improved the lateral resistance and stiffness and performs appropriate seismic behavior.

There are several retrofitting methods for reinforced concrete structures. Recently many engineers prefer to use ductile material such as steel plate. It is used by adhering plate to damaged element. However, this method has the problem that shear or flexural spalling of retrofitting material could occur at the end of the

retrofitting material before the limit stress of the retrofitted element is reached. In order to prevent this problem, loss of integrated behaviour, prestressing retrofitting method was proposed. This retrofitting system applies the stress intentionally to close the diagonal tensile cracks occurred at the web of the wall. Therefore, this retrofitting method might be effective for shear controlled elements.

These two types of retrofitting method have the same object that increasing the member strength. However, these two have shown different behaviour and different developing time of retrofitting effect. Therefore, in this study, we will discuss the strength degradation ratio caused by loss of wall area and effectiveness of different retrofitting effect and behaviour through the test.

2. Experimental Program

2.1 Test Specimens

An objective building of this study was a wall-dominant apartment building which was built in the 1980s in Korea. We assumed that horizontal expansion was accomplished by making openings at the wall which was lying between two houses.

Specimen was 1/2-scale representations of a two-story wall in a Korean apartment building and had a compressive strength of 21MPa assumed for concrete and a yield stress of 400MPa assumed for reinforcement in the design calculations. In order to represent the damage, opening reinforcement was not installed.

The size of openings was 580*1300mm, which was 23% of the wall area. It was determined based on the conservative results of previous studies for appropriate opening area in remodeling project. According to this information, we produced test specimens. The first specimen named Solid was produced as control specimen which had no opening area. CW-RS had openings without retrofitting materials. CW-ST was retrofitted by steel-retrofitting

method and CW-PS was retrofitted using prestressing. Details of the specimens are shown in Fig. 1 and Table 1.

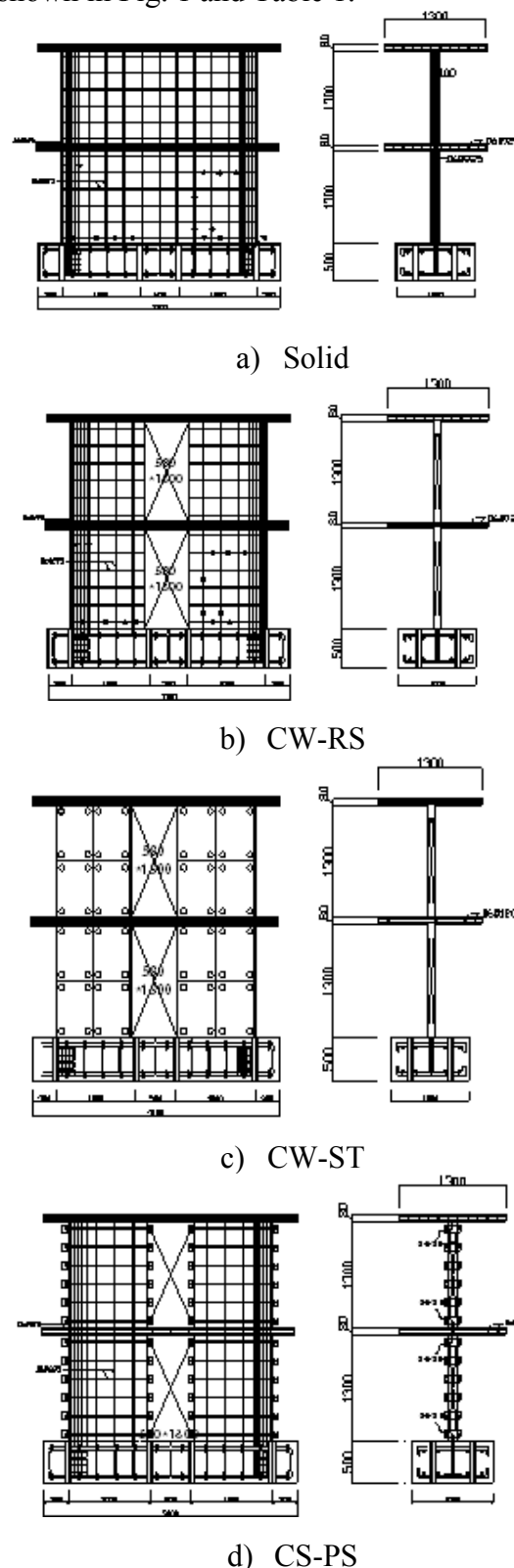


Figure 1 : Details of Specimens
(Unit : mm)

Table I : List of specimens

Specimens	Opening	Opening-Wall ratio	Steel of Wall		Steel of Slab			Steel Panel	Prestress Bar
			Ver	Hor	Ver	Hor			
Solid	x	—	D6@225	D6@225	D6@120	D6@120	21.23		—
CW-RS	o	23% (580mm*1300mm)							
CW-ST								3mm	
CW-PS								—	

Plate thickness of 3mm was chosen for CW-ST retrofitting. By comparing two specimens, CW-RS and Solid, CW-RS required more strength. In order to match the strength of CW-RS to Solid, plate thickness on par with the area of required re-bar proposed in ACI318 was determined. CW-PS had the same retrofitting stress of CW-ST.

2.2 Material test and test set-up

Concrete compressive strength of 21MPa was obtained through the cylindrical test. Based on KSF 2404 specification, test specimens were produced using cylindrical mold and cured. Table 2 represents the result of compressive strength test. In order to find characteristic of reinforcements, coupon tests were planned according to KS B 0801-La specification. Test results were represented in Table 3.

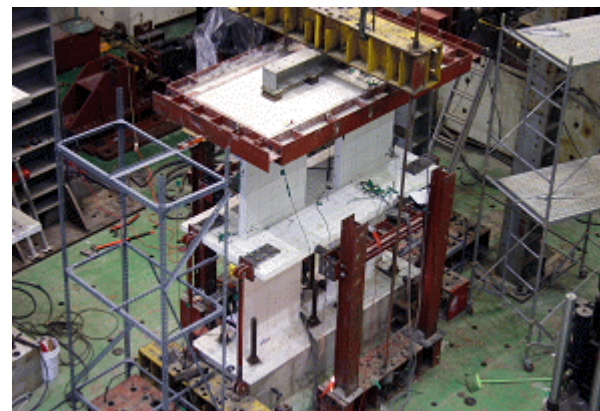
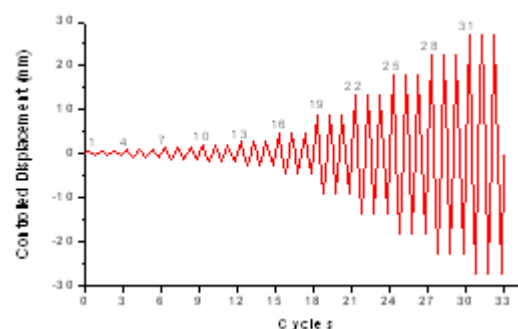
Table II : Material properties of concrete

Materials	Compressive strength (MPa)	Young's modulus (GPa)	Maximum Strain, (ϵ_u)	Poisson's ratio
Concrete	21.23	21.92	0.00171	0.15

Table III : Material properties of steel

Materials	Yield strength (MPa)	Yield Strain, (ϵ_y)	Tensile strength (MPa)	Poisson's ratio
D6	291.19	0.0019	375.01	0.28

A picture of the test setup is shown in Fig. 2. Tests were conducted in the laboratory with three dimensional reaction walls. Two bars were mounted vertically to apply 630kN of constant axial compression during testing.

**Figure 2** : Test Set-Up**Figure 3** : Applied Loading History

This corresponded to approximately 10% of the computed concentric capacity of walls. Displacement controlled lateral load was applied at the top of the wall by a 2000kN hydraulic actuator mounted between the specimen and a reaction wall. In order to prevent lateral buckling of 2nd story slabs, frames were assembled at the edge of slabs. Guide beams and ball zigs were used to minimize out-of-plane movement and simulate the diaphragm effect of a slab. Hinges were installed to allow appropriate slab rotation. In order to measure the lateral

displacement of specimens, LVDTs were mounted to the end of each floor slabs. To measure diagonal deformation of walls, which was shear deformation of walls, other LVDTs were installed at the edge of walls and the center of walls. Lateral displacement control for the test is shown in Fig. 5. Lateral drift was applied as reversed cyclic loads. Each steps of this cyclic loads repeated three times

3. Test Result

3.1 Cracks and Failure mode

Crack patterns at failure of the three specimens are illustrated in Fig 4. Solid, which is a control specimen, showed flexural cracks at the wall edge at the initial cycles. As larger loads applied to the specimen, crack width became larger and these cracks were developed to diagonal tensile cracks at the central part of the wall. Near the final stage of loading, after these diagonal cracks were intersected each other, the width of cracks became wider and spalling of concrete occurred. Finally, the specimen was failed by crushing of concrete at the wall edge.

CW-RS specimen, which had slabs as coupling members, showed initial cracks at displacement of 6mm at the roof observing point. General failure pattern was flexural failure. As larger loads applied to the specimen, cracks were developed to the openings. After that, cracks were dispersed to the whole wall from the edge of the wall. In later cycles, there was no crack dispersion but cracks at lower part of the wall became wider. Tensile failure of the wall's lower

edge was dominant at later cycles of the test, and compressive crush occurred at the opposite side of the wall approximately at the same time.

For the test of CW-ST specimen, which had retrofitted by steel plate, cracks could not be observed because of the steel plate. Removing the steel plate, after the end of the test, we were able to observe the crack patterns. Cracks were concentrated at lower edge of the wall and the failure occurred by the sliding at the wall base contact area. More cracks were observed at the slab-wall connection area because of the stress concentration.

In the case of CW-PS, initial cracks occurred at the wall edge at the roof drift of 10mm. As larger load applied, cracks were developed as diagonal tensile cracks to upper part of the wall and opening. Cracks were developed at the anchorage of the prestressing rod. Near the final stage of the loading, this specimen failed at the wall toe and separated from the footing just like CW-ST specimen. However, cracks at the slab occurred less than those of CW-ST. The reason of this observation was that CW-PS had lower stiffness than CW-ST.

As a result, retrofitted specimens failed by the sliding at the wall-base connection area. It was believed that increased stiffness caused by retrofitting delayed the wall failure.

3.2 Load-displacement relationship

The load-Displacement relationships for all specimens are illustrated in Fig 5. Displacements were measured at the roof slab.

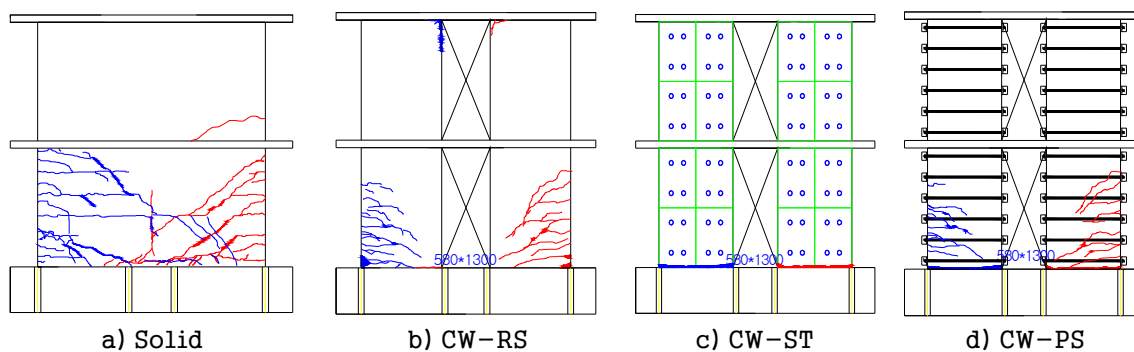


Figure. 4 : Setting for test

In the case Solid, maximum strength was 280kN at the drift of 0.8%. After maximum load was reached, shear cracks were developed and concrete crushing occurred at the wall edge, lower part with decreasing applied load. CW-RS had the maximum strength of 160kN at the drift of 0.6%, and showed ductile behaviour. CW-ST had larger shear strength than CW-RS but its strength decreased 21% compared to Solid. CW-PS had the maximum strength of 192kN at the drift of 0.96% and showed similar behaviour as CW-ST. This value was 69% of the strength of Solid.

In the characteristic of cyclic loop, pinching was observed in Solid, which is the general behaviour of rectangular shape shear wall. CW-RS, CW-ST and CW-PS did not show pinching behaviour. It seems like openings of the wall changed shear controlled behaviour to flexural controlled behaviour.

CW-ST was able to withstand more cycles of loads and the strength decreased gradually in later cycles, since steel plate was more ductile than concrete. CW-PS showed similar behaviour as CW-RS, but it experienced more cycles than CW-RS. It may be caused by the stiffening effect of the prestressing.

3.3 Stiffness Characteristic

Fig. 6 shows that stiffness and stiffness degradation ratio of the specimens. All specimens showed degradation of stiffness as the load cycles increased.

Specifically, by comparing non-retrofitted specimens, Solid showed gentle degradation of stiffness in the beginning, but after diagonal cracks occurred, stiffness of the specimen steeply decreased. However, CW-RS showed very steep degradation of stiffness from the start.

In the case of CW-ST, initial stiffness was less than Solid. At later cycles, CW-ST

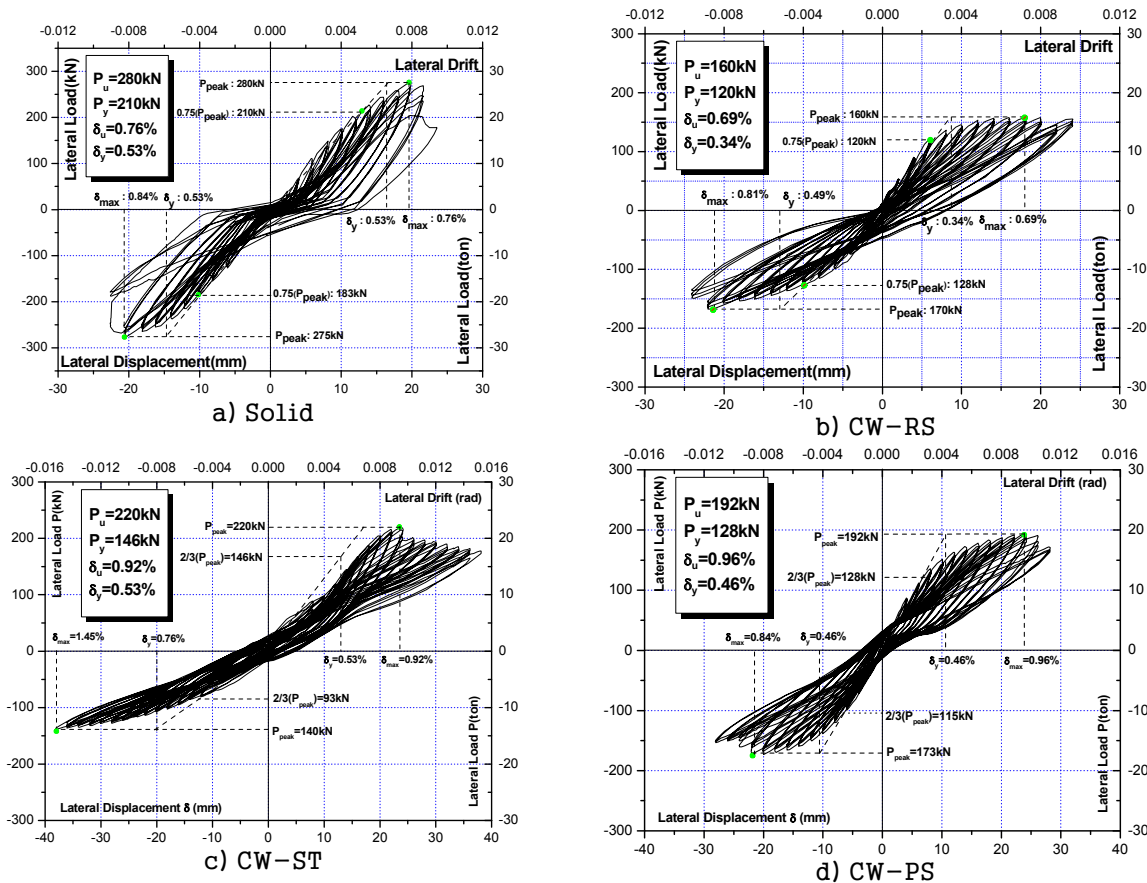


Figure 5: Load-Displacement Relationship

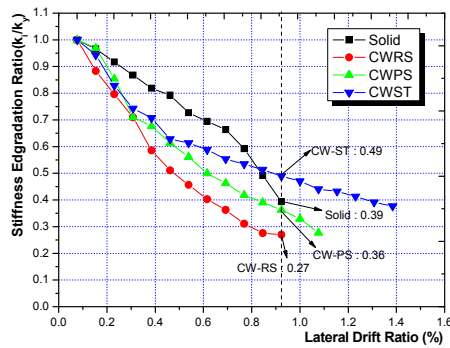
Table IV: Test Results

specimens		P_{CR} (kN)	P_y (kN)	P_u (kN)	δ_y (mm)	δ_u (mm)	μ	θ_y	θ_u	$\frac{P_{u(retrofit)}}{P_{u(non retrofit)}}$	$\frac{P_{u(retrofit)}}{P_{u(Solid)}}$
Solid	Pos	98	186	280	14	20	1.42	0.76	1/185	-	1
	Neg	95	13	275	14	22	1.57	0.84	1/185	-	1
CW-RS	Pos	59	106	160	9	16	1.77	0.61	1/288	1	0.57
	Neg	54	113	170	14	22	1.57	0.84	1/185	1	0.61
CW-ST	Pos	137	146	220	16	24	1.5	0.92	1/162	1.39	0.79
	Neg	110	93	140	20	38	1.9	1.46	1/130	0.82	0.51
CW-PS	Pos	98	128	192	12	25	2.1	0.96	1/216	1.22	0.69
	Neg	85	116	178	12	22	1.83	0.84	1/216	1.04	0.65

P_{CR} : Cracking Load P_y : Yielding Load P_u : Ultimate Load δ_y : Yielding Drift

δ_u : Maximum Drift μ : Ductility ratio $\frac{P_{u(retrofit)}}{P_{u(non retrofit)}}$: Retrofit effectiveness ratio for Solid

$\frac{P_{u(retrofit)}}{P_{u(Solid)}}$: Retrofit effectiveness ratio for CW-RS

**Figure 6 : Stiffness Degradation**

showed more gentle degradation of stiffness. It was believed that steel plate showed the retrofitting effect after the maximum strength of the specimen was reached. CW-PS showed generally higher stiffness and lower degradation rate of the stiffness than CW-RS. At the drift of 0.92%, retrofitted specimens were maintained higher stiffness.

4. Characteristics of Retrofitting Effect

4.1 Strength improvement

By observing the strength of each specimen, retrofitted specimens, CW-ST and CW-PS, showed strength increase of 39% and 22% compared to CW-RS. Specifically,

the strength of CW-ST showed steep increase until the maximum strength was reached. After maximum load stage, the strength of the wall degraded. However, after maximum loads, specimen showed ductile behaviour. The steel plate contributed the wall behaviour after concrete of the wall failed and prevented brittle failure. Unlike CW-ST, CW-PS contributed the wall behaviour from the start by increasing the strength and delaying the failure of concrete of the wall.

4.2 Strains of Reinforcement

The locations of W.S.G were represented in Fig. 7, Fig 8. CW-RS showed strain hardening of reinforcement, while CW-ST, CW-PS showed decreasing of strain after the maximum strength was reached. This reverse of stress occurred by developing retrofitting effect. Fig 7 showed the vertical reinforcement strain near opening. They showed that the existence of openings influenced the strain. Generally, Solid showed smaller strain than opening specimens. Reinforcements of CW-RS, CW-ST, and CW-PS experienced more strains, because aspect ratio of these specimens was

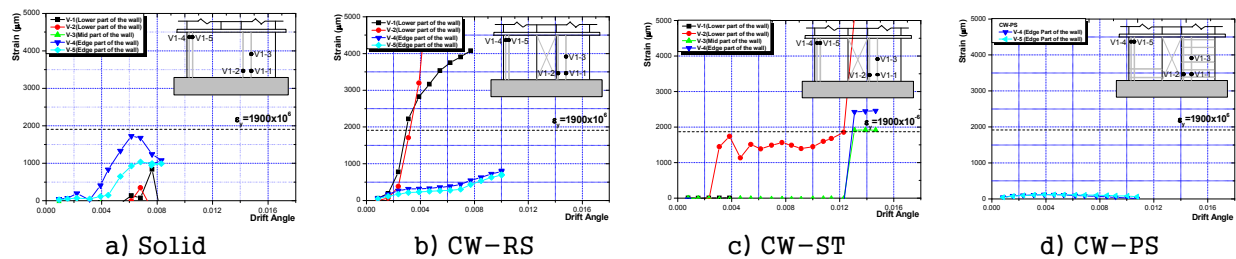


Figure 7 : Vertical steel strain of wall

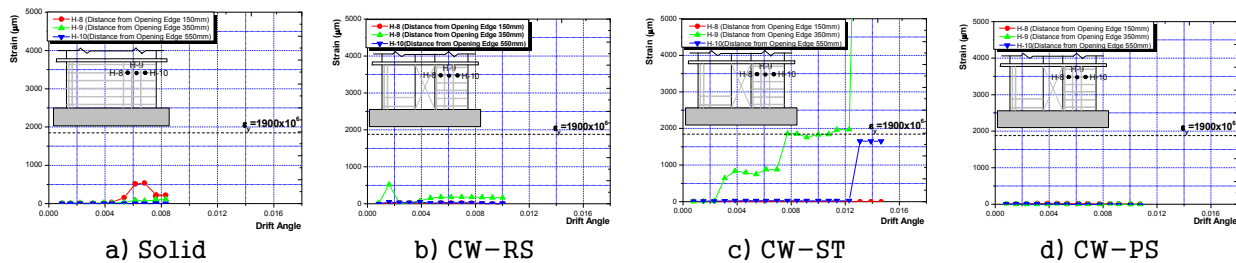


Figure 8 : horizontal steel strain of wall

closed to flexure governed shear wall. Solid specimen showed large strain at middle part or upper part of the wall. This was caused by the concentration of diagonal cracks at middle part of the wall. However, in the case of CW-RS, strains of lower part of the wall showed higher value than those of upper part of the wall. This was caused by flexure governed wall aspect ratio.

In the case of the retrofitted specimens, strains of reinforcement showed similar behaviour as CW-RS. However, lower part of wall strain was significantly higher because of the separation of wall-base connection. This may be caused by the stiffening of wall area with retrofitting.

Strains of horizontal reinforcement were represented in Fig. 8. In the case of Solid, while reinforcement did not yield, strains from edge to center part of the wall became larger. It was believed that Solid governed in shear failure made compressive strut wider.

In the case of opening specimens, shear resisting reinforcements generally did not yield, because these types of specimens were controlled by flexural behaviour. CW-RS showed these types of deformation well. However, CW-ST experienced yielding of horizontal reinforcement. It was caused by compressive strut which was occurred by the

confinement effect of steel plate. Horizontal reinforcement of CW-PS did not yield, also. It was believed that the anchorage of prestressing was not effective to confine the wall edge part.

4.3 Retrofitting effect

Fig 9 shows the strains of horizontal and vertical reinforcement of CW-ST. As the load increased, strains increased.

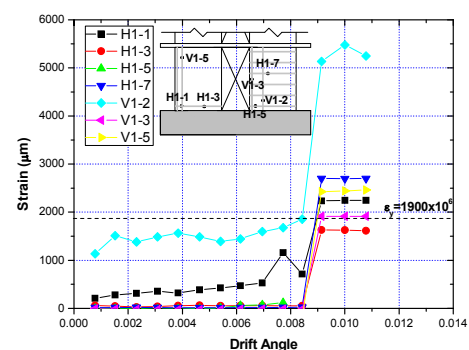


Figure 9 : Steel Strain of CW-ST

However, after 13th cycle, strains increased suddenly and most reinforcements experienced yielding. In this cycle wall panel was separated from base and crushing of concrete at the edge part occurred. So it is necessary to install the L-shape frames at the

lower wall edge part. After the maximum strength was reached, CW-ST specimen showed the ductile behaviour as shown Chapter 3. Therefore, steel plate was effective for larger drift of the wall.

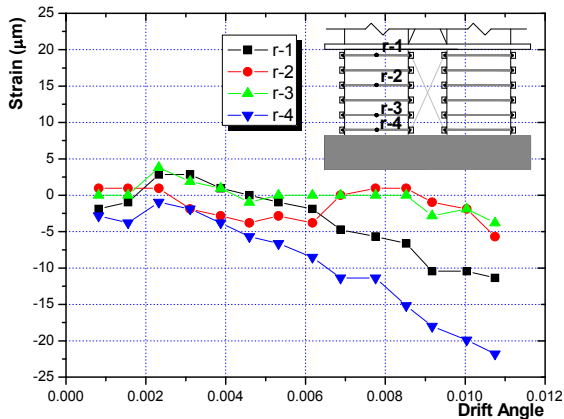


Figure 10 : Strains of PS-Tendons

Fig. 10 shows the strains of prestressing rod located at different height of the wall. They showed steady change of strain and largest strain at the location of the widest crack. This is because the prestressing retrofitting method contributed most when the cracks were widest. However, as the cracks were developed diagonal direction after 14th cycles, this retrofitting method was not effective for diagonal cracks.

CW-RS showed initial cracks at the drift of 6mm, but CW-PS showed it at 10mm drift. Furthermore, CW-PS showed 39% higher maximum load than CW-RS. Therefore, prestressing retrofitting effect occurred just after applying the retrofitting load.

5. CONCLUSION

Conclusion of this experimental study and two retrofitting effect were stated below

1. Solid, which had no opening, failed by shear with wider diagonal cracks. However, CW-RS, which had opening, failed in flexure since aspect ratio of wall panel changed because of opening.

2. Retrofitted specimens, CW-ST and CW-PS showed lower maximum strength

than Solid, but they showed 39%, 22% strength increase compared to CW-RS.

3. In the case of steel plate retrofitting, retrofitting effect occurred at later cycles as ductile behaviour. However, in order to prevent sudden failure of base of the wall, L-shaped frames were required.

4. In the case of prestressing retrofitting method, retrofitting effect was shown from the start. However, this method was less effective for diagonal cracks.

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