SEISMIC PERFORMANCE OF AN EXISTING RC FRAME RETROFITTED BY PRECAST PRESTRESSED CONCRETE SHEAR WALLS

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SUMMARY

This paper describes the seismic performance of a new retrofit method. This new retrofit method is using precast prestressed concrete shear walls on outer frames of a 5 storeys existing reinforced concrete building.

In order to develop this new retrofit method, two types of specimens were carried out. One type is a part of a pressure joint between the shear wall and the existing column or beam, and another is a frame part which is lower 2 storeys of this 5 storeys building.

INTRODUCTION

Since the 1995 Hyougoken Nanbu Earthquake, the retrofits for the old buildings are done but there are few researches about the retrofit method which the resident people can use it continuously during this retrofit.

Therefore, it is needed to develop the retrofit method using a precast reinforced concrete shear wall on the surface of existing reinforced concrete frame structure without taking out the mortar in finishing(Fig.1 and Fig.2). That is because the cast-in-place concrete is not used at the existing frame and the strength of the existing frame are increasing by the precast prestressed concrete shear walls

So, this paper describes the experiments about this retrofit method and these seismic performance. The experiments include the element part which means a part of the shear wall and the existing column or beam(Fig.3, Photo 1 and Table 1), and the frame part which means a 2 storeys shear wall retrofitting the existing frame(Fig. 5, Fig.6, Photo2, Table2 and Table3).

EXPERIMENT OF ELEMENT

The element specimens are parts of a shear wall connecting with a column or a beam by prestress bars. The parameter of these specimens is to include the finishing mortar or not between the shear wall and the column or the beam. These specimens make clear the friction property between the shear wall and the column or the beam.

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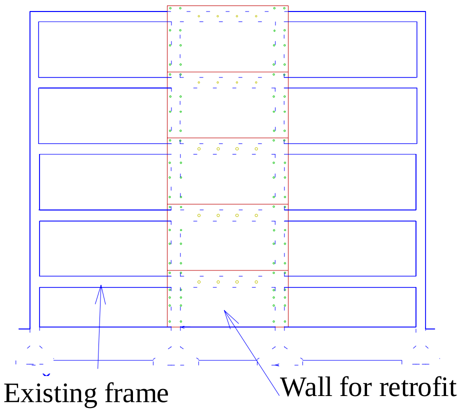


Fig, 1 Retrofit of outside wall

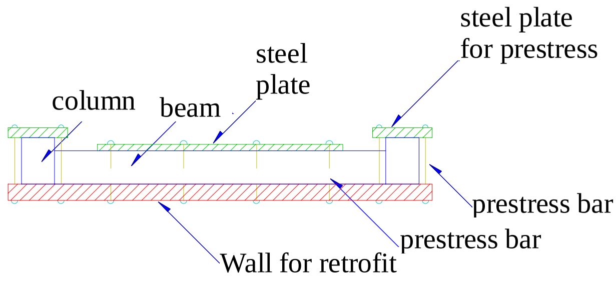


Fig2 Detail of wall and existing frame

In this retrofit method using the precast prestressed concrete shear wall on the existing frame, the columns are retrofitted by the mechanical anchorage for prestress and the 2 prestress bars alog the columns. The beams are retrofitted by the prestress bar in the anchorage openings.That is because the space between the horizontal steel bars in the columns are not much wide, and the main steel bars are arranged very much.

The element specimens are CW-M and BW-M which include the finishing mortar at the depth 30 mm shown in Fig.3-1 and Fig.3-2. Moreover, the specimens are CW and BW with the cement paste at the depth 3 mm.

The number of the element specimens is four. The scale is 1/2. The material properties are shown in Table 1. The type of the steel bars is SD295, the mechanical anchorage for prestress is SS400, and the prestress bars is SBPR80/95, No.1. The diameter of the prestress bars is 23 mm.

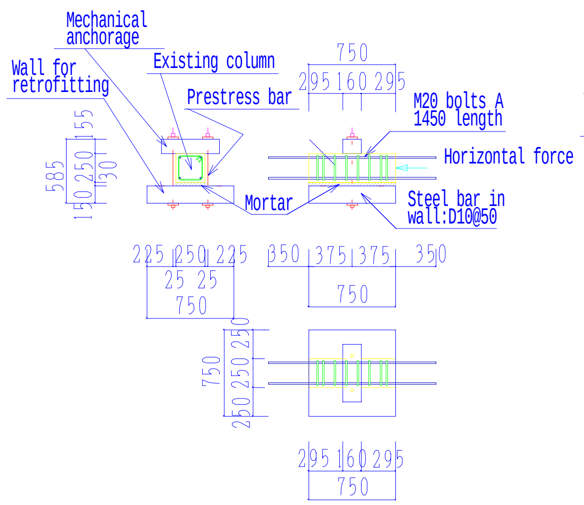


Fig.3-1 Specimen CW-M

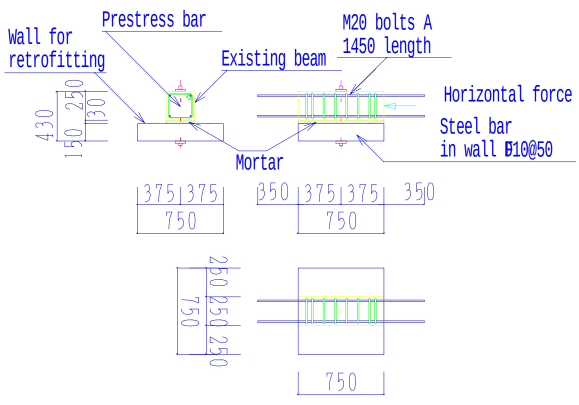


Fig.3-2 Specimen BW-M

At the loading of the element specimens, the shear wall is on the reaction floor horizontally, the prestress pressure 200N between a column or a beam and a shear wall is applied, and the friction force between a column or a beam and a shear wall is applied cyclically by the 2 oil-jacks on the both sides(Photo 1).

The relationships between horizontal load and displacement of element part specimens are shown in Fig.4. The failure mode of all specimens is slip at the connection between a column or a beam and a shear wall. The friction factor of the specimen CW-M and BW-M with mortar is 0.72 and 0.82 respectively, but the specimen CW and BW without mortar is 0.90 and 0.90 respectively. This means that the shear transfer performance at the connection between a column or a beam and a shear wall which includes the finishing mortar is sufficient and the retrofit method which does not remove the finishing mortar is available.

Table 1 Material properties of concrete, mortar and grout

Specimen	Part	ƒ Ð	, d
CW-M	column	27.4	2.70
	wall	45.3	2.84
	mortar in a pressure joint	16.7	2.83
BW-M	beam	28.4	2.73
	wall	40.7	2.77
	mortar in a pressure joint	24.5	2.69
	grout	5.8	1.74
CW	column	30.7	2.63
	wall	45.1	2.73
BW	beam	30.9	2.58
	wall	45.1	2.55
	grout	6.0	0.71
CW BW	paste in a pressure joint	51.4	1.76

notes)ƒ Ð Compressive strength(N/‡ ō^2)
, d Young's modulus ×10^4(N/‡ ō^2)

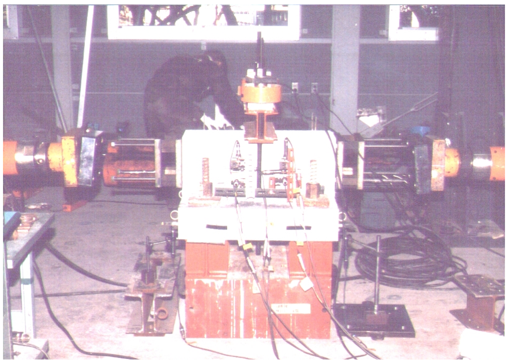
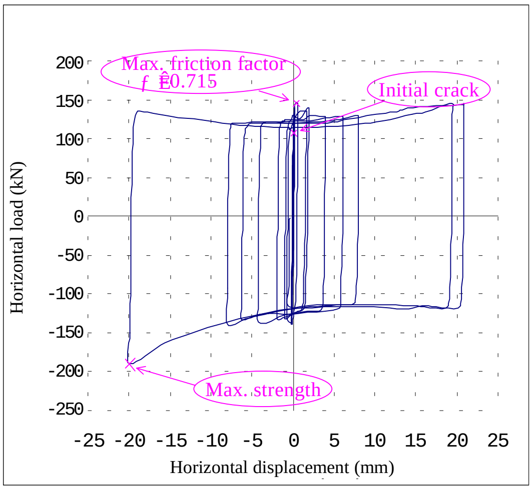
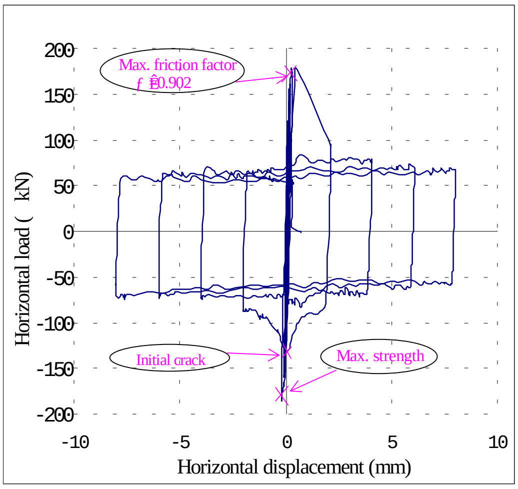


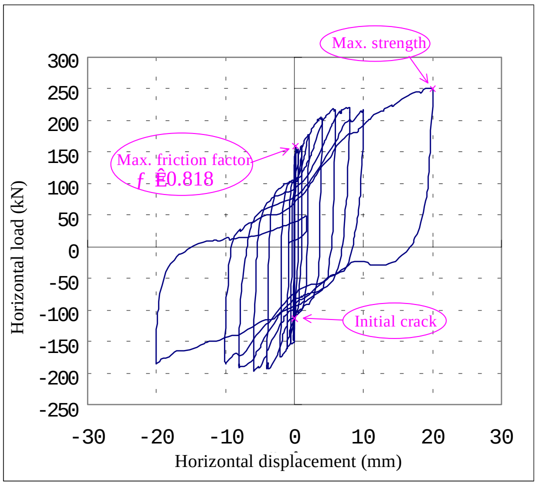
Photo 1 Test of element part specimen CW-M
(Depth of a pressure joint:30mm)



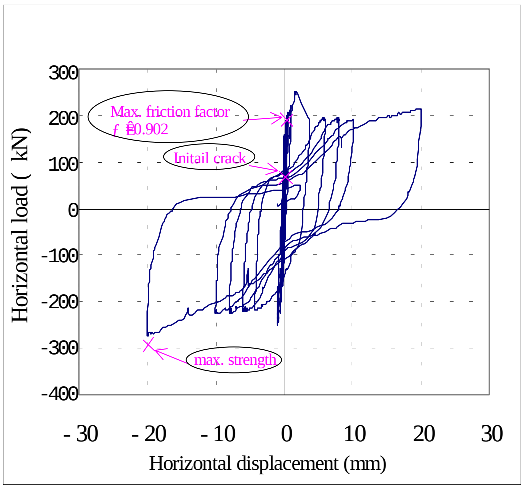
a) Specimen CW-M with mortar
(element part of column and wall)
(Pressure by 2 prestress bars:200kN)



b) Specimen CW without mortar
(element part of column and wall)
(Pressure by 2 prestress bars:200kN)



c) Speciment BW-M with mortar
(element part of column and wall)
(Pressure by a prestress bar:200kN)

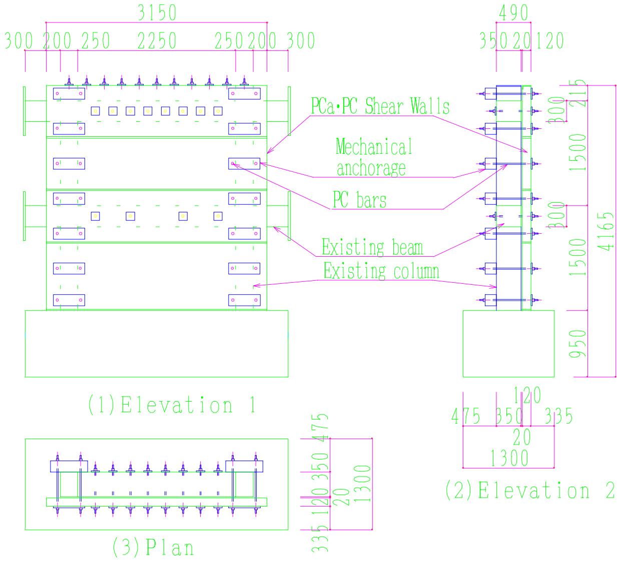


d) Specimen BW without mortar
(element part of column and wall)
(Pressure by a prestress bar:200kN)

Fig.4 Relationship between horizontal load and displacement of element part specimens

EXPERIMENT OF FRAME STRUCTURE

The frame specimen is a 2 storeys precast prestressed concrete shear wall connecting with 2 storeys reinforced concrete frame structure by prestress bars. This specimen is supposed to be a lower part of the 5 storeys old building which is constructed before the building code was modified. And this building's seismicity is appropriately a half of new buildings(Fig.5).



Notes)
(1)Pressure force in horizontal joints of shear walls: 2,040kN
(2)Pressure force between beams and shear walls: 3,170kN
(3)Pressure force between columns and shear walls: 8,000kN

Fig.5 Specimen of frame part

The frame specimen is designed in order that the strength is more than the required strength 735 kN for the original old building and that the failure mode should be shear failure of the prestress concrete shear wall enclosed by a frame. Therefore, the friction strength at the horizontal joints of the shear walls is increased sufficiently, and the friction strength between the frame and the shear wall is also increased. These friction strength is calculated by the friction factor 0.7 which was investigated at the element spciments.

Finally, the prestress pressure at the horizontal joints of the shear walls is 2,040 kN. The prestress pressure between the frame and the shear wall is calculated in order to get the shear transfer from the beams to the shear walls. The prestress pressure between the shear wall and the column on the 2nd floor which is 608(kN/a mechanical anchorage) is gotten by the 6 mechanical anchorages and 12 prestress bars. The prestress pressure on the 1st floor which is 725(kN/a mechanical anchorage) is gotten by the 6 mechanical anchorages. The prestress pressure between the shear wall and the beam on the 3rd floor which is 333(kN/a prestress bar) is gotten by the 8 prestress bars. The prestress pressure on the 2nd floor which is 127(kN/a prestress bar) is gotten by the 4 prestress bars.The shear walls are separated into two shear walls in a floor because of its weight. The columns and the beams are designed according to the original old building. The material properties is shown in Table 2 and Table 3.

Table 2 @Material properties of concrete, mortar and grout

Part	ƒ Ð	, d	ƒ Ã
Concrete of columns and beams	2.7	2.16	2,530
Concrete of PCa¥PC shear walls	3.4	2.54	2,300
Mortar in horizontal connections of shear walls	5.3	2.43	2,897
Mortar in prestressed connections between shear walls and a frame	5.7	2.40	3,523
grout	7.3	1.72	5,487

notes)ƒ Ð Compressive strength(N/‡ ô)
@ , d Young's modulus ±10^4(N/‡ ô)
@ ƒ Ã Stress at compressive strength ±10^-6(‡ Ø‡)

Table 3 @Material properties of steel bars and prestress bars

Type	ƒ Ð	, d	ƒ Ã	ƒ Ð
Steel bar D19(SD345)	38	1.81	2147	56
Steel bar D16(SD295)	36	1.79	2087	51
Steel bar D6(SD295)	38	1.93	1979	55
Prestress bar ƒ Ó 23(SBPR 1080/1230)	1154	2.03	5685	1247
Prestress bar ƒ Ó17 (SBPR 1080/1230)	1150	2.02	5693	1238

notes)ƒ Ð Yield strength(N/‡ ô)
@, d Young's modulus ±10^5(N/‡ ô)
@ƒ Ã Stress at yield strength ±10^-6(‡ Ø‡)
@ƒ Ð Tensile strength(N/‡ ô)

At the loading, the horizontal load is applied cyclically by the 4 actuators on the end of the beams and the axial force of the columns is applied constantly by the 2 oil jacks on the top of the column using 2 prestress bars through the column from top to bottom(Fig.6 and Photo 2).

The distribution of the horizontal load is calculated by the equation Ai in the Japanese building code which is 1:7.33 to 2nd floor : 3rd floor. The 4 actuators is controlled to keep this distribution constantly during the loading.The axial force is 240 kN which is the total of the dead load and the live load on the 2nd floor of the 5 storey building excluding the weight of a top of a actuator and a loading device. The axial force is applied one week later than the form panels removed and before the retrofit work by the shear walls. Against the outplane displacement, the steel columns are set around the frame specimen during the horizontal load.

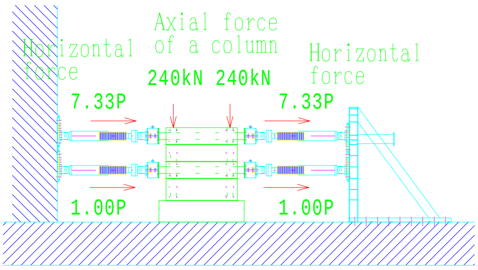


Fig.6 Loading test of
Specimen of frame part

Photo 2 Test of the frame part specimen

The relationship between the horizontal load on the 1st floor and the horizontal displacement on the 3rd floor is shown in Fig.7. In Fig.7, the horizontal load is the total of the 4 actuators. And the horizontal displacement is the average the measurement at the frame side and the shear wall side, and is calculated to correct the torsional displacement.

At the horizontal load 200 kN, the bending crack took place in the beams. At 400 kN, the bending crack took place in a column on the 1st floor. At the rotation angle 1/800 rad.(the horizontal displacement 3.9 mm), the shear crack took place at the horizontal joint between the lowest shear wall and the 2nd lowest one. At 1/540 rad.(5.8 mm), the many shear cracks took place in the lowest shear wall. The maximum strength 1,660 kN took place at the 1/200rad.(15.8 mm). The decreasing of the horizontal load took place at the 1/76 rad.(38.7 mm). The failure mode of the frame specimen was the combination of the 3 failure modes which were the shear failure in the lowest shear wall, the shear failure of the columns and the slip failure at the horizontal joint between the lowest shear wall and the 2nd lowest shear wall.The outplane displacement was less than 10 mm in the beam-column joint on the 3rd floor at the maximum strength. And, the outplane force was very small which was 50 kN – 70 kN.

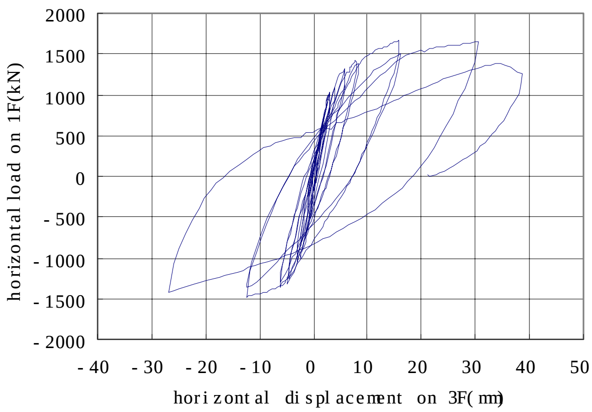


Fig.7 Relationship between load and displacement

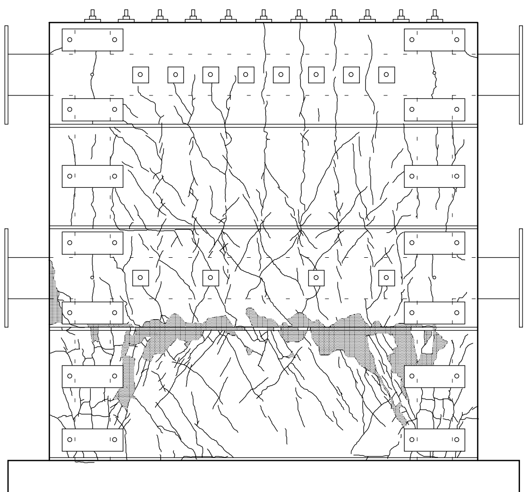


Fig.8 Cracks

COMPARISON OF THE STRENGTHS

The comparison of the strengths is shown in Table 4. The strength of the frame specimen is more than Qsu,min and less than Qsu,mean which are calculated the shear wall enclosed by a frame. And the strength of the frame specimen 1,660 kN is much higher than the shear strength Qsu,mean of two columns which is 301 kN. Moreover, the strength of the frame specimen is much higher than the total strength 1,036 kN of the required strength 735 kN and the shear strength of two columns 301 kN.

Table 4 Comparison of the strengths

Failure mode		Calculated strength of the frame speciment		
		Case 1: Qsu:min for column and wall	Case 2: Qsu:mean for column and wall	
Bending failure of a shear wall enclosed by a frame	Qmu	2,488	2,488	kN
Shear failure of a shear wall enclosed by a frame	Qsu	1,573	1,856	kN
Slip failure of a joint and shear failure of 2 columns	Qh 2*(Qsu of a column)	2,148	2,188	kN
Slip failure of a joint and punching shear failure and shear failure of 2 columns	Qh pQc 1.0*(Qsu of a column)	2,542	2,562	kN

Notes:

(1)Qmu is calculated by Mmu=a t *σy*lw+0.5Σ (aw*σwy)*lw+0.5*N*lw

(2)Qsu,min=[{0.053*$Pte^{0.23}$* (Fc+180)/{M/(Q*D)}+0.12}+2.7*(σwh*Pwh)^(1/2)+0.1*σo]*be*j

(3)Qsu,mean[{0.068*$Pte^{0.23}$* (Fc+180)/{M/(Q*D)}+0.12}+2.7*(σwh*Pwh)^(1/2)+0.1*σo]*be*j

(4)Qh=0.7*(σy*Σah+Nh)

(5)${}_pQ_c=k_{MIN}*\tau o*be*D$

CONCLUSIONS

It is possible to use the retrofit method which includes the finishing mortar because the element specimens have the sufficient property to transfer the shear strength between the shear wall and the column or the beam.

And it is made clear that the precast prestressed concrete shear wall is available for the retrofitting the old buildings because the frame specimen has the sufficient performance to increase the seismicity of the old buildings.

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