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Loading tests of seismic retrofitting method by outer reinforced concrete frames with framed steel brace

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ABSTRACT

The authors have proposed a seismic retrofitting method installing a new reinforced concrete frame with framed steel brace outside the existing reinforced concrete frame. In the actual retrofitting design, the size of the new outer reinforced concrete frame is determined depending on not only the size of the existing frame but also the presence or absence of the bay window. In this paper, loading tests conducted to understand the effects of the size of the outer frame on the seismic performance of the retrofitted frame are reported. Two 1/2.5 scaled one bay one story specimen frames were laterally loaded in the test.

1. INTRODUCTION

In the seismic retrofit of existing reinforced concrete buildings in Japan, seismic retrofitting methods installing framed steel braces inside the existing reinforced concrete frames have been generally used. However, this method has a critical problem that the building cannot be used during the retrofitting construction. Therefore, external type seismic retrofitting methods which allow the building to remain in use during the construction are preferable. The authors have proposed a seismic retrofitting method installing a new outer reinforced concrete frame with the framed steel brace outside the existing reinforced concrete frame in Ken Harayama (2011), as shown in Fig. 1.

In the actual retrofitting design of this external type method, the size of the new outer reinforced concrete frame is determined depending on not only the size of the existing frame or the new brace but also the presence or absence of the bay window. However, the effects of the size of the outer frame on the seismic performance of the retrofitted frame have not been sufficiently investigated. In this paper, the test results of two 1/2.5 scaled one bay one story specimen frames retrofitted by the outer frame with a different size are described in detail.

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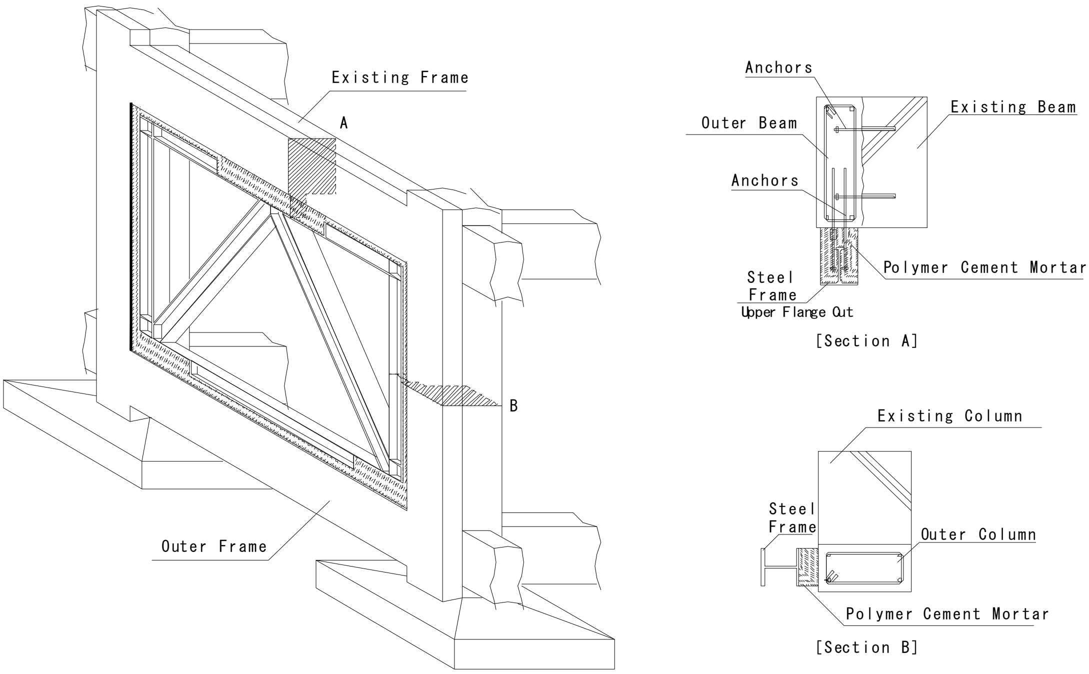


Fig. 1 Seismic retrofitting method by outer reinforced concrete frame with framed steel brace

2. SPECIMENS

The details of two specimens are shown in Table 1 and Fig. 2. The both specimens are 1/2.5 scaled one bay one story frames, and have transverse beams and a slab like the frame of actual buildings.

In SPA5, the section of the existing columns is 240 mm x 240 mm and has main re-bars of 8-D13, and the section of the existing beams is 200 mm x 320 mm and has main re-bars of 12-D13. The section of the outer columns is 130 mm x 240 mm and has main re-bars of 6-D13, and the section of the outer beams is 120 mm x 320 mm and has main re-bars of 8-D13. In SPA6, the section of the existing columns is 160 mm x 240 mm and has main re-bars of 6-9 ϕ . The section of the existing upper beams is 160 mm x 240 mm and has main re-bars of 10-13 ϕ , and the section of the existing lower beams is 160 mm x 320 mm and has main re-bars of 10-13 ϕ . The section of the outer columns is 244 mm x 240 mm and has main re-bars of 9-D13. The section of the outer upper beams is 244 mm x 240 mm and has main re-bars of 8-D13, and the section of the outer lower beams is 244 mm x 320 mm and has main re-bars of 8-D13. The width of the existing frame of SPA6 is smaller than that of the existing frame of SPA5, however, the width of the outer frame of SPA6 is larger than that of the outer frame of SPA5. The existing frame of SPA5 was designed to behave in the shear failure mode of the columns. On the other hand, the existing frame of SPA6 was designed to behave in the flexural yielding mode of the columns.

Pin-ended hollow tube braces with 70 mm diameter and 5 mm thickness are installed in the outer frame in the two specimens.

As shown in Fig. 3, SPA5 has joint anchors between the outer beam and the existing beam so that the two beams move together. SPA6 has joint anchors not only between the beams, but also between the columns for the transferring of the axial force of the columns.

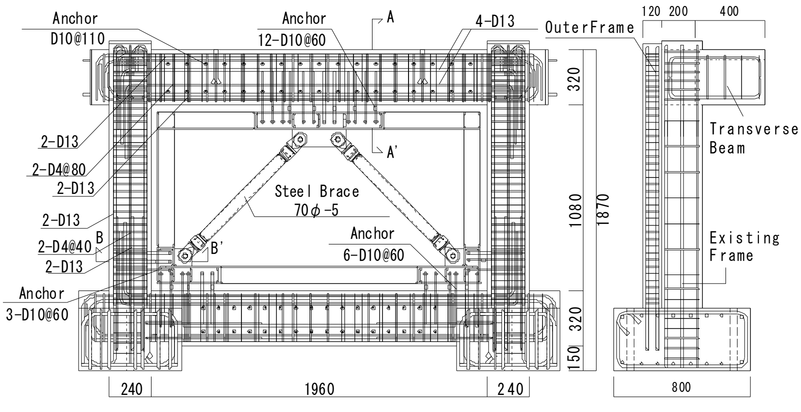
The compressive strengths of cement materials used for specimens are shown in Table 2, and the strengths of the steel materials are shown in Table 3.

Table 1 Details of specimens

Specimen		Column			Upper Beam			Lower Beam		
		Section	Main Re-Bars	Hoop	Section	Main Re-Bars	Stirrup	Section	Main Re-Bars	Stirrup
SPA5	Existing Frame	240×240	8-D13	2-D4@150	200×320	Upper: 6-D13 Lower: 6-D13	2-D4@100	200×320	Upper: 6-D13 Lower: 6-D13	2-D4@100
	Outer Frame	130×240	6-D13	2-D4@40	120×320	Upper: 4-D13 Lower: 4-D13	2-D4@80	120×320	Upper: 4-D13 Lower: 4-D13	2-D4@80
SPA6	Existing Frame	160×240	6-9ϕ	2-D4@150	160×240	Upper: 5-13ϕ Lower: 5-13ϕ	2-D4@70	160×320	Upper: 5-13ϕ Lower: 5-13ϕ	2-D4@100
	Outer Frame	244×240	9-D13	3-D4@40	244×240	Upper: 4-D13 Lower: 4-D13	3-D4@80	244×320	Upper: 4-D13 Lower: 4-D13	3-D4@80

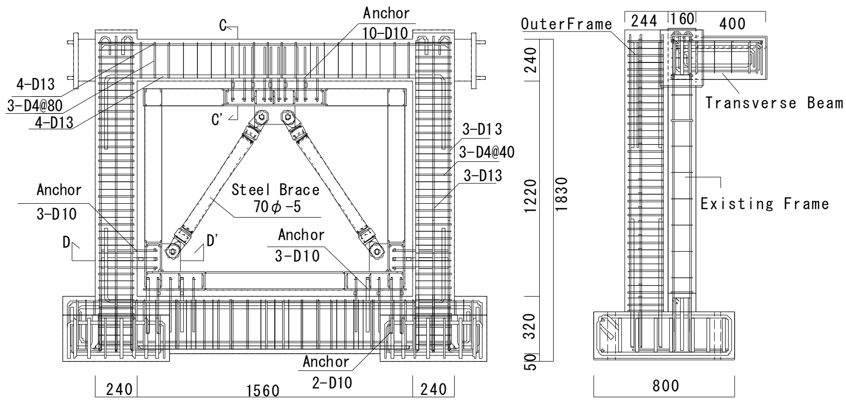
Table 1 Details of specimens (continued)

Specimen	Steel Brace	Steel Frame	Horizontal Joint Anchors of Outer Frame	Anchors between outer frame and existing frame
SPA5	Pin-ended Hollow Tube 70ϕ-5	H-100x100 ×3.2× 4.5	12-D10	Upper Beam:34-D10 Lower Beam:32-D10
SPA6			10-D10	Upper Beam:62-D10 Each Column: 51-D10 Lower Beam: 60-D10

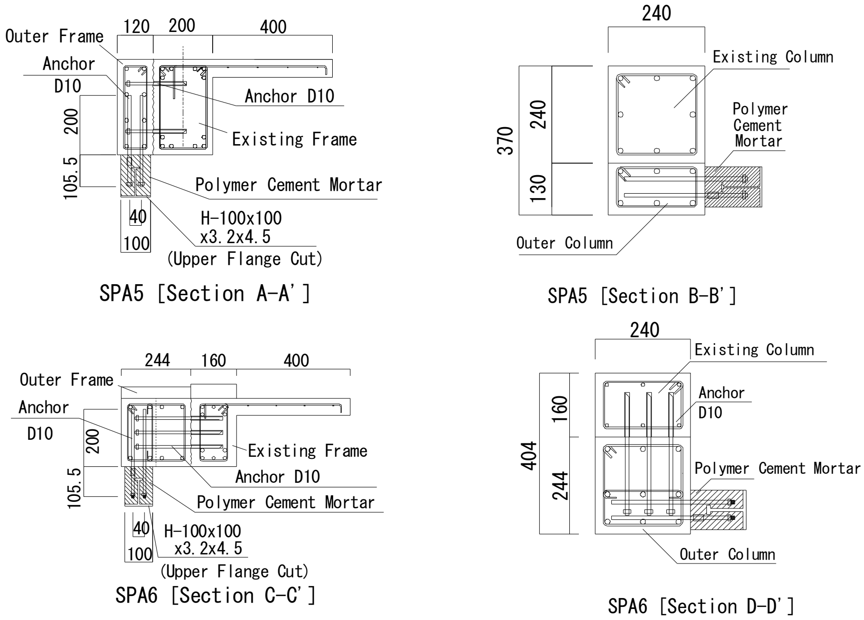


(a) SPA5

Fig. 2 Dimensions and details of specimens

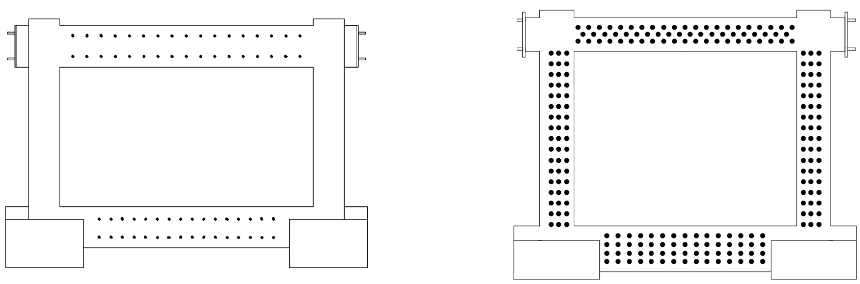


(b) SPA6



(c) Section

Fig. 2 Dimensions and details of specimens (continued)



[SPA5]
Upper Beam:34-D10
Lower Beam:32-D10

[SPA6]
Upper Beam:62-D10
Lower Beam:60-D10
Each Column:51-D10

Fig. 3 Anchors between existing frame and outer frame

Table 2 Compressive strengths of cement materials

Specimen		Compressive Strength of Concreat(N/㎟)		Infilled Mortar (N/㎟)
		Upper Beam and Column	Lower Beam	
SPA5	Existing Frame	11.1	29.7	57.2
	Outer Frame	24.0		
SPA6	Existing Frame	15.5	31.7	57.2
	Outer Frame	27.5		

Table 3 Strengths of steel materials

(a) SPA5

Steel Materials		Yield Strength(N/㎟)	Tensile Strength(N/㎟)
D13(SD345)		409	585
D13(SD295)		381	528
D10(SD295)		373	511
D4(SD295)		383	559
H-Shaped Steel Frame	Web t=3.2(SS400)	357	435
	Flange t=4.5(SS400)	289	418
Steel Brace	70ϕ-5(STKM13A)	409	506

(b) SPA6

Steel Materials		Yield Strength(N/㎟)	Tensile Strength(N/㎟)
D13(SD345)		368	531
9ϕ(SR235)		343	447
13ϕ(SR235)		344	454
D10(SD295)		380	520
D4(SD295)		368	510
H-Shaped Steel Frame	Web t=3.2(SS400)	360	468
	Flange t=4.5(SS400)	343	474
Steel Brace	70ϕ-5(STKM13A)	343	457

3. TEST PROCEDURE

A test setup is shown in Fig. 4. Loading schedule is shown in Fig. 5. The long term axial force was applied to the columns of the existing frame and maintained at 170 kN for SPA5 and at 115 kN for SPA6. The lateral force was applied to the upper beam ends of the existing frame. The loading was controlled by the story drift angle R, where R was δ/h; δ was the lateral displacement of the upper beam, h was the height of the existing frame.

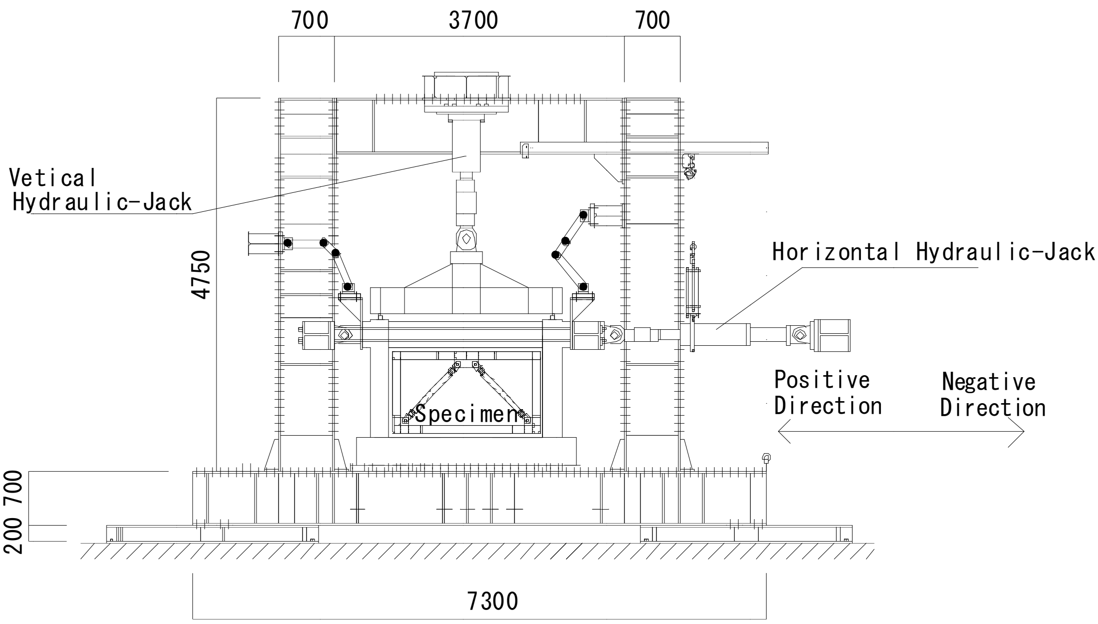


Fig. 4 Test setup

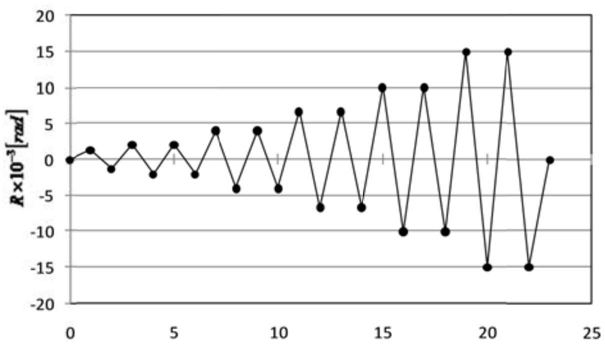


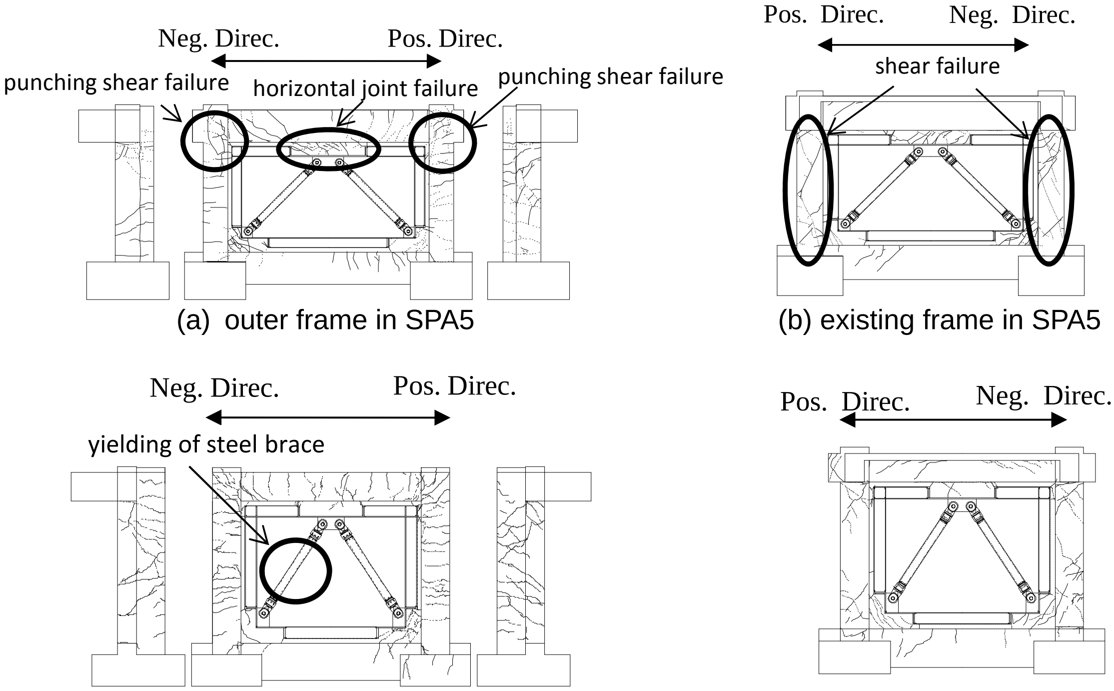
Fig. 5 Loading schedule

4. TEST RESULTS

Crack patterns of the specimens after the test are shown in Fig. 6. Shear force *Q* - story drift angle *R* relationships are shown in Fig. 7. Shear force is the value measured by the load cell attached to the horizontal hydraulic jack.

In failure process of SPA5, the flexural cracks occurred at the bottom of the tensile outer column in the loading cycle of *R*=0.002 rad. The flexural cracks occurred at the top of the tensile outer column in the loading cycle of *R*=0.004 rad., and in the same loading cycle, the shear cracks occurred at the existing columns. In the loading cycle of *R*=0.01 rad., the separation cracks occurred between the outer column and the existing column, and the maximum lateral strengths in the positive and negative were observed. Finally, the shear failure occurred at the existing columns, and the horizontal joint failure occurred in the outer frame accompanying the punching shear failure at the top of the tensile outer column. After that, the deterioration in the lateral strength was observed. The deformation capacity of SPA5, in which the stable cyclic Q – R relationship could be expected, was approximately R=0.01 rad.

In failure process of SPA6, the flexural cracks and the punching shear cracks occurred at the outer column in the loading cycle of R=0.002 rad. In the loading cycle of R=0.0067 rad., the cracks occurred at the joint mortar around the foot of the compressive steel brace, however, significant damage did not occurred. In the loading cycle of R=0.015 rad., yielding of the tensile steel brace occurred, but the punching shear failure did not occurred in the columns of the outer frame, and the deterioration in the lateral strength was not observed. The loading was quit after the loading cycle of R=0.015 rad. because of a large deformation occurring in the out-of-plane direction. Therefore, the deformation capacity is considered to be larger than R=0.015 rad.



(a) outer frame in SPA5

(b) existing frame in SPA5

(c) outer frame in SPA6

(d) existing frame in SPA6

Fig. 6 Crack patterns of specimens after the test

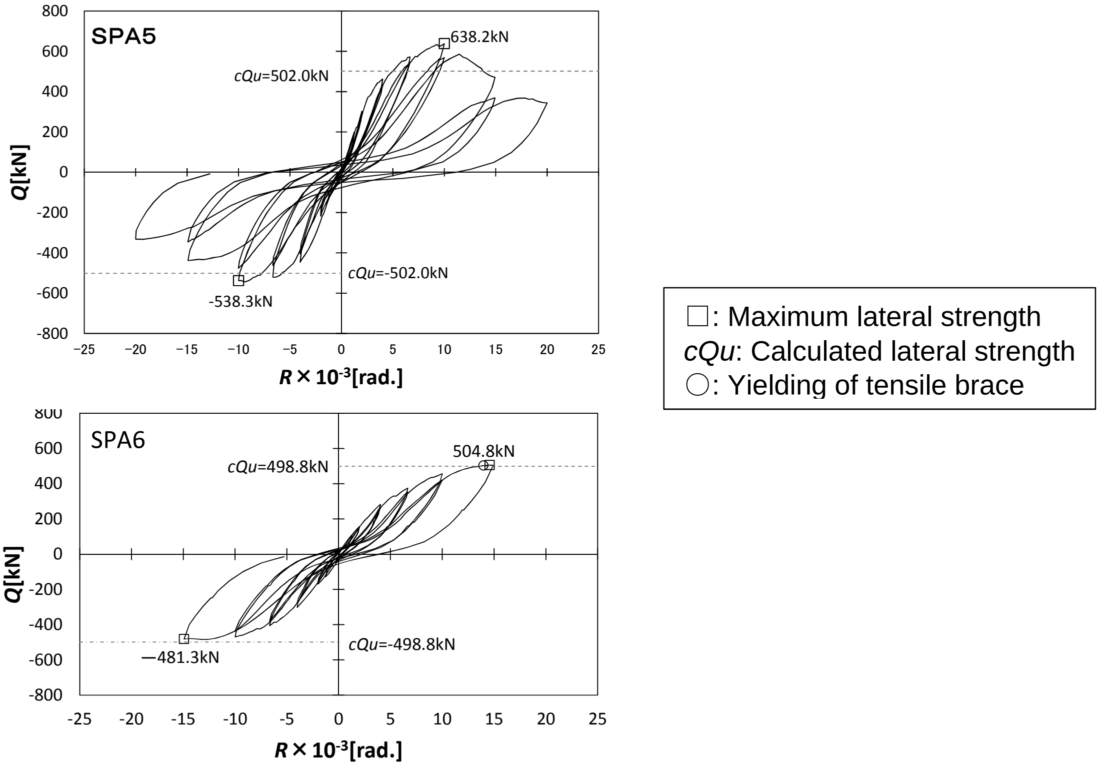


Fig. 7 Shear force Q - story drift angle R relationships

5. EVALUATION OF LATERAL STRENGTH

In the proposed retrofitting method, the lateral strength of the retrofitted frame can be evaluated by the superposition of that of the outer reinforced concrete frame with the framed steel brace and that of the existing reinforced concrete frame. In case that the outer frame with the framed steel brace behaves in the steel brace yielding mode, the lateral strength of the retrofitted frame is expressed by Eq. (1). In case that the outer frame with the framed steel brace behaves in the horizontal joint failure mode accompanying the punching shear failure of the tensile outer column, the lateral strength of the retrofitted frame is expressed by Eq. (2). The lateral resistance mechanism of the outer frame in Eq. (2) is shown in Fig. 8.

The experimental lateral strength ${}_eQ_u$ and the calculated lateral strength ${}_cQ_u$ of the specimens are shown in Table 4, where, ${}_eQ_u$ is the smaller one of the maximum lateral strengths in the positive and negative loading direction. The value of ${}_eQ_u/{}_cQ_u$ of SPA5 is 1.07, where ${}_cQ_u$ was given by Eq. (2). The value of ${}_eQ_u/{}_cQ_u$ of SPA6 is 0.96, where ${}_cQ_u$ was given by Eq. (1). The calculated lateral strength is well corresponding with the experimental lateral strength in the both of specimens.

$${}_cQ_u = \sum Q_c + {}_sQ_y + Q_{c1} + Q_{c2} \tag{1}$$

where ${}_cQ_u$=lateral strength of the retrofitted frame in the steel brace yielding mode; ΣQ_c=lateral strength of the existing frame; ${}_sQ_y$=lateral strength of the steel brace; Q_{c1}=

lateral strength of the tensile column in the outer frame; Q_{c2}=lateral strength of compressive column in the outer frame.

$$ {}_{c}Q_{u} = \sum Q_{c} + {}_{p}Q_{c} + {}_{a}Q_{j} + {}_{f}Q_{j} + Q_{c2} \tag{2} $$

where ${}_{c}Q_{u}$=lateral strength of the retrofitted frame in the horizontal joint failure mode; ΣQ_c=lateral strength of the existing frame; ${}_{p}Q_{c}$=punching shear strength of the tensile column in the outer frame in JBDPA (2001); ${}_{a}Q_{j}$=shear strength of anchors at the upper horizontal joint in JBDPA (2001); ${}_{f}Q_{j}$= shear resisting force by the friction in Takanori Kawamoto (2010) and Ken Harayama (2012); Q_{c2}=lateral strength of the compression column in the outer frame.

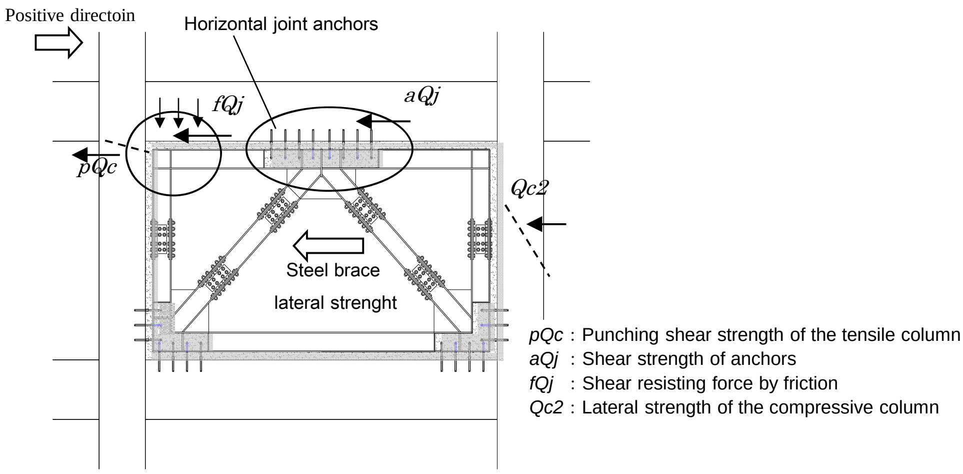


Fig. 8 Lateral resistance mechanism of the outer frame in Eq. (2)

Table 4 Comparison of experimental lateral strength ${}_{e}Q_{u}$ and calculated lateral strength ${}_{c}Q_{u}$

Specimens	Failure mode	*eQu*[kN]	*eQu*[kN]	*eQu / cQu*
SPA5	Horizontal joint failure mode	538.3	502.0	1.07
SPA6	Steel brace yielding mode	481.3	498.8	0.96

6. CONCLUSIONS

The following conclusions can be derived from this experimental study.

1) In SPA5 specimen with the outer frame of a relatively small section, the horizontal joint failure occurred in the outer frame accompanying the punching shear failure at the top of the tensile column of the outer frame. The yielding of the steel brace installed in the outer frame did not occur. The lateral strength of the specimen can be evaluated by Eq. (2). The deformation capacity of the specimen was approximately 0.01 (rad.) in the story drift angle.

2) On the other hand, in SPA6 specimen with the outer frame of a relatively large section, the horizontal joint failure or the punching shear failure did not occurred in the outer

frame. The yielding of the steel brace installed in the outer frame occurred. The lateral strength of the specimen can be evaluated by Eq. (1). The deformation capacity of the specimen was considered to be larger than 0.015 (rad.) in the story drift angle.

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