An Experimental Study of a Seismic Retrofitting Method with Framed Steel Brace Systems Partially and Concentrically Jointed with Anchors

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SUMMARY:
The authors have been proposed the seismic retrofitting method by framed steel brace systems partially and concentrically jointed with anchors in order to decrease the number of anchors while keeping reinforced effects in this paper. The seismic tests of five specimens which are 1/2.5 scaled one-bay-one-story reinforced concrete frame models for the standard frame at the first floor of a 5-story school building reinforced by the proposed method were conducted to evaluate the structural performance of the proposed method. The following results were obtained from this experimental study.
(1) The reinforcing effect of the proposed method was one as the assumption.
(2) The proposed method has necessary enough deformability to show the reinforcing effect.
(3) The lateral strength of the proposed method can be evaluated appropriately by proposed evaluation method.

Keywords: Seismic retrofitting method, Framed steel brace, Anchors

1. INTRODUCTION

In contemporary Japan, in the seismic retrofitting of existing reinforced concrete buildings, the retrofitting method by framed steel braces installed in existing reinforced concrete frames proposed on Ref. [1] is generally used. In this method, framed steel braces and existing frames are jointed with a lot of anchors. However, in constructions of anchors, critical problems which are noises, vibrations and dusts occur. Therefore, the seismic retrofitting methods not to use anchors shown in Ref. [2] and [3] had been developed.

The authors have been proposed the seismic retrofitting method by framed steel brace systems partially and concentrically jointed with anchors [4], [5] in order to decrease the number of anchors while keeping reinforced effects. In this paper, seismic tests conducted to grasp the structural performance of the proposed retrofitting method and the evaluation of structural performance based on the results of seismic tests are reported.

2. CHARACTERISTIC OF THE PROPOSED METHOD

The details of the proposed method are shown in Figure 2.1. In this seismic retrofitting method, existing reinforced concrete frames and framed steel braces are jointed with the connection method by concentrated arrangement of joining anchors. As shown in Figure 2.1., the part of steel frame flange is cut, and the steel frame web is inserted in between anchors. Mortar is filled into this joint, and anchors are fixed in mortar blocks surrounded by stiffeners and webs. The lateral forces are translated by the shear key effects of this joining method. Incidentally, for constructions, the anchor in the side is a coupler formula by the long-nut.

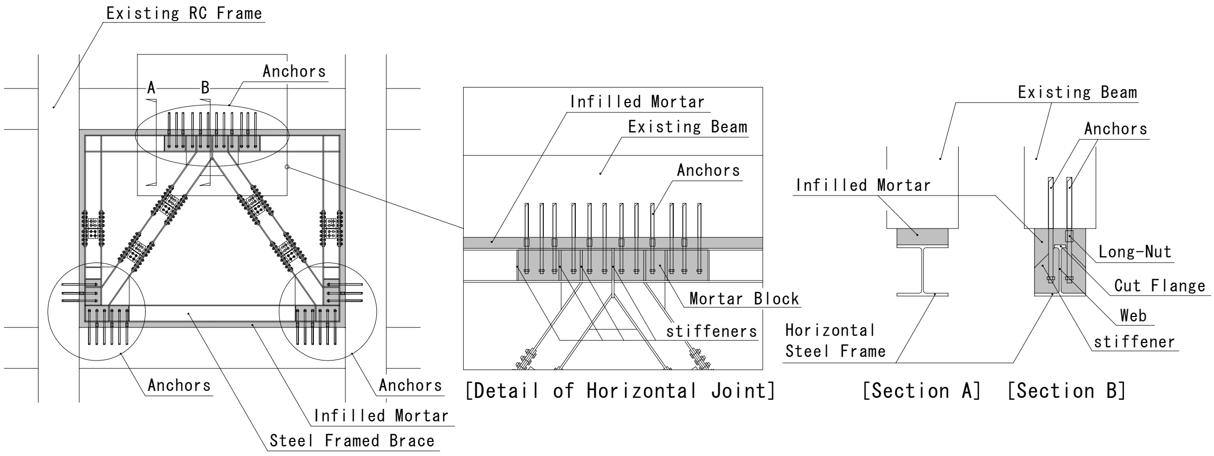
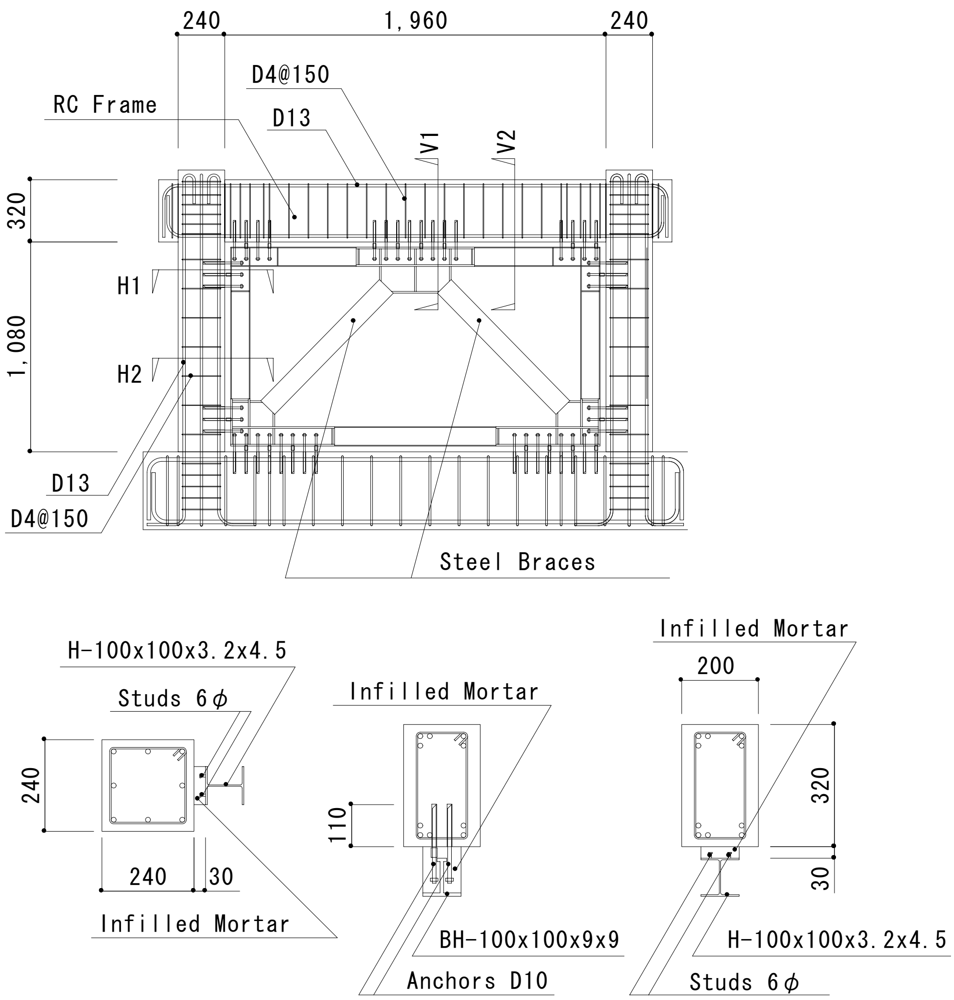


Figure 2.1. Details of the Proposed Method

3. SPECIMENS AND EXPERIMENTAL PROGRAM

The details of the specimens are shown in Figure 3.1., the list of specimens is shown in Table 3.1., and the mechanical properties of materials used for specimens are shown in Table 3.2..



(a) Section H1 (b) Section H2 (c) Section V1 (d) Section V2

Figure 3.1. Details of the Specimens (PA4)

Table 3.1. List of the Specimens

<table>
<tr><th rowspan="2">Specimen</th><th rowspan="2">Compressive Strength of Concrete (N/mm^2)</th><th colspan="2">Horizontal Joint</th><th rowspan="2">RC Frame</th><th rowspan="2">Steel Brace</th></tr>
<tr><th>Number of Anchors</th><th>Studs</th></tr>
<tr><td>PA1</td><td>12.6</td><td>—</td><td>—</td><td rowspan="5">【Column】
Section : 240mm×240mm
Main Reinforcing Bars : 8-D13
Hoop : D4@150
【Beam】
Section : 200mm×320mm
Main Reinforcing Bars : 12-D13
Stirrup : D4@100</td><td rowspan="5">H-100×100×3.2×4.5</td></tr>
<tr><td>PA2</td><td>13.6</td><td>8-D10</td><td>—</td></tr>
<tr><td>PA3</td><td>12.8</td><td>8-D10</td><td>2-6φ@120</td></tr>
<tr><td>PA4</td><td>14.1</td><td>16-D10</td><td>2-6φ@60</td></tr>
<tr><td>PA5</td><td>39.9</td><td>18-D10</td><td>—</td></tr>
</table>

Table 3.2. Mechanical Properties of Materials Used for Specimens

<table>
<tr><th colspan="2">Materials Used for Sprcimens</th><th>Yeiding Stress (N/mm^2)</th><th>Tension Strength (N/mm^2)</th></tr>
<tr><td colspan="2">D13(SD295A)</td><td>393</td><td>557</td></tr>
<tr><td colspan="2">D4(SD295A)</td><td>411</td><td>575</td></tr>
<tr><td colspan="2">D10(SD295A)</td><td>357</td><td>502</td></tr>
<tr><td rowspan="2">Steel Brace (SS400)</td><td>Flange t=4.5</td><td>339</td><td>428</td></tr>
<tr><td>Web t=3.2</td><td>373</td><td>446</td></tr>
</table>

The specimens are five reinforced concrete frames retrofitted by the proposed method, and are 1/2.5 scaled one-bay-one-story concrete frame models for the standard frame at the first floor of a 5-story school building. The shape, section, and arrangement bars of the specimens are same in all of the specimens. The test parameters of the specimens are the number of anchors, the existence or non-existence of studs installed in steel frame flanges, and the compressive strength of concrete. Specimen PA1 has no anchors. In specimen PA2 and PA3, 8 anchors were installed at the horizontal joint. 16 anchors were installed in specimen PA4., and specimen PA5 has 18 anchors. In specimen PA3 and PA4, the studs are installed in steel frame flanges.

In the all specimens, the calculated failure mechanism of reinforced concrete frames is shear failure of columns. The retrofitted frames of Specimen PA1, PA2, PA3 and PA4 were designed as the failure of the horizontal joint between upper horizontal steel frame and the upper beam with the punching shear failure of the tensile side column head. And specimen PA5 was designed as the steel brace yielding failure. Incidentally, the above mentioned joining method had been used to install a framed steel brace in a reinforced concrete frame in these specimens.

A loading apparatus is shown in Figure 3.2.. The specimens were subjected to horizontal cyclic loading with the 1,000kN hydraulic-jack attached the upper beam end under constant vertical loaded (340kN). The control method of the loading tests was displacement-controlled by the story drift angle (R).

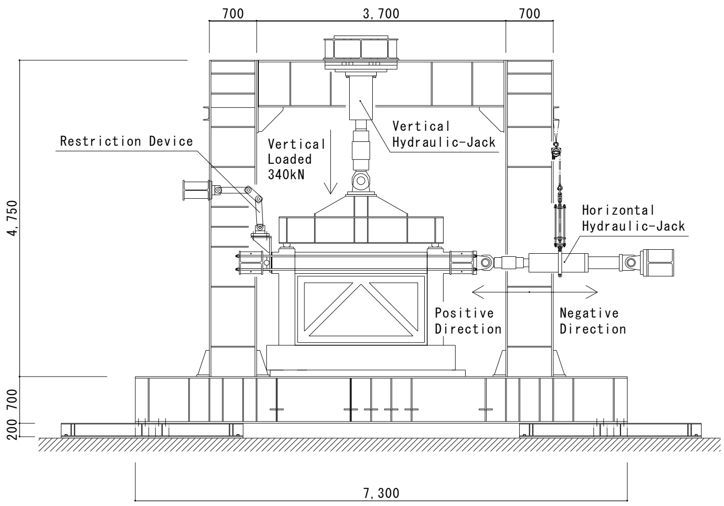


Figure 3.2. Loading apparatus

4. TEST RESULTS

4.1. Failure process

The crack patterns of each specimen at R=0.01rad. are shown in Figure 4.1.. As assumed, in specimen PA1, PA2, PA3 and PA4, the horizontal joint failure with the punching shear failure of the tensile side column head occurred, in specimen PA5, the compression buckling and tensile yielding of steel braces occurred.

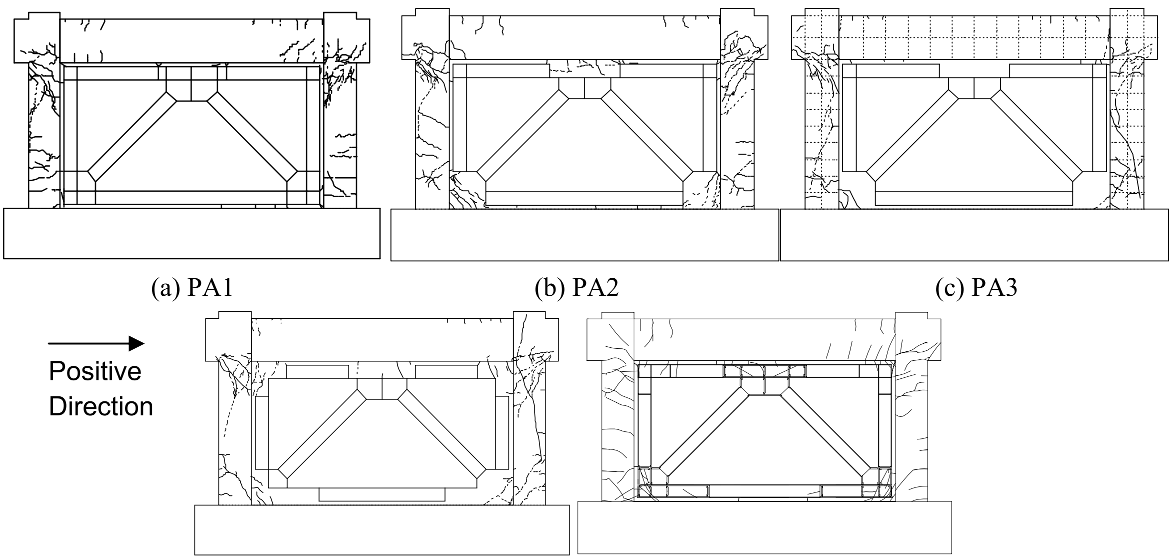


Figure 4.1. Crack Patterns at R=0.01rad.

In specimen PA1, PA2 and PA3, almost same failure process occurred. The maximum lateral strength was reached in the cycle of R=0.0067rad.. And then, the punching shear failure of the tensile side column head occurred in the cycle of R=0.01rad., and the lateral strength was deteriorated.

In specimen PA4, the maximum strength was reached with the steel brace compression buckling of the in-plane direction in the first cycle of R=0.01rad. And then, the punching shear failure of the tensile side column head occurred in the second cycle of R=0.01rad., and the lateral strength was deteriorated.

In specimen PA5, in the cycle of R=0.01rad., the maximum strength was reached, and the steel brace compression buckling of the in-plane direction occurred. In the cycle of R=0.015rad., the steel brace compression buckling of the off-plate direction occurred, and the lateral strength was deteriorated.

Incidentally, in all specimens except for PA1 which has no anchors, the failure of the joints where anchors were installed was not observed when the maximum strength was reached (PA2, PA3 and PA4: R=0.0067rad., PA5: R=0.01rad.).

4.2. Horizontal forth – Story drift angle relationship

The horizontal forth (Q) – Story drift angle (R) relationship of each specimen is shown Figure 4.2., and the envelope curves of Q-R relationships of all specimens are shown in Figure 4.3..

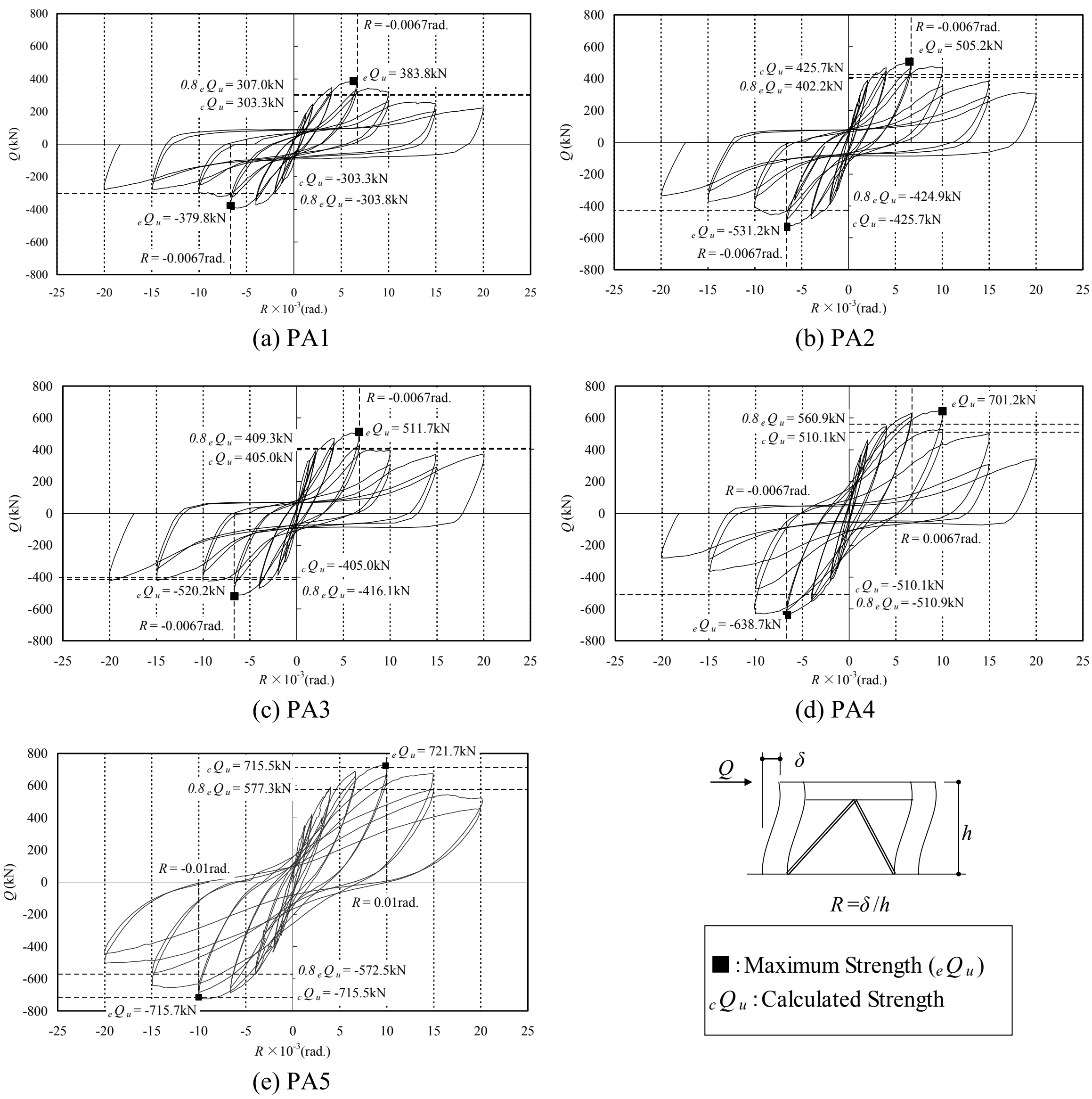


Figure 4.2. Q-R relationship

In specimen PA1, PA2 and PA3, the maximum strength occurred in the cycle of R=0.0067rad., and the lateral strength was deteriorated in the cycle of R=0.01rad.. In specimen PA4, the maximum strength occurred in the first cycle of R=0.01rad., and the lateral strength was deteriorated in the second cycle of R=0.01rad.. And in specimen PA5, the maximum strength occurred in the cycle of R=0.01rad., and the lateral strength was deteriorated in the cycle of R=0.015rad.. When judging that the story drift angle which can maintain 80% of the maximum strength is the limit story drift angle, the limit story drift angle of all specimens except for PA5 is evaluated to be R=0.0067rad., and one of the PA5 is evaluated to be R=0.01rad.. In all specimens, the ability to support the vertical load was not lost until the last cycle (R=0.02rad.).

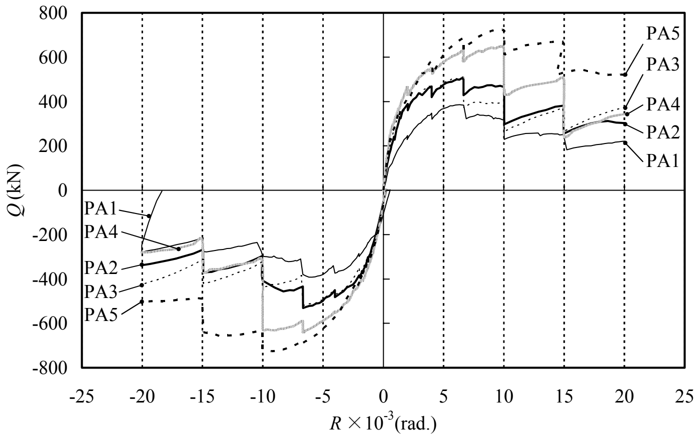


Figure 4.3. Envelope Curves of *Q-R* Relationships

Figure 4.3. shows that the lateral strength of specimens increases as the number of anchors increase. And the comparison between the envelope curve of PA2 and PA3 shows that the studs installed in steel frame flanges hardly influenced in the failure process and the lateral strength.

5. EVALUATION OF LATERAL STRENGTH

The horizontal force transfer mechanism of this proposed method is shown in Figure 5.1.. And the experimental lateral strength of each specimen (${}_eQ_u$) and the calculated lateral strength of each specimen (${}_cQ_u$) are shown in Table 5.1.. The calculated lateral strength is smaller value of the retrofitted frame strength in the steel brace yielding failure evaluated by Eqn. 5.1. and the retrofitted frame strength in the horizontal joint failure evaluated by Eqn. 5.2.. Eqn. 5.1. is obtained from summing up the lateral strength of the steel brace and the lateral strength of the tensile side column and the compression side column, and is proposed on Ref. [1]. Eqn.5.2. is obtained from summing up the punching share strength of the tensile side column head, the shear resisting force by the friction between the upper beam and the horizontal steel frame, the shear strength of anchors installed between the upper beam and horizontal steel frame and the lateral strength of the compression side column as shown in Figure 5.1..

$${}_cQ_{su1}={}_sQ_u+Q_{c1}+Q_{c2} \quad (5.1)$$

${}_cQ_{su1}$: Lateral Strength of the Retrofitted Frame in the Steel Brace Yielding Failure
${}_sQ_u$: Steel Brace Lateral Strength
Q_{c1} : Tensile Side Column Lateral Strength
Q_{c2} : Compression Side Column Lateral Strength

$${}_cQ_{su2}={}_pQ_c+{}_fQ_j+{}_aQ_j+Q_{c2} \quad (5.2)$$

${}_cQ_{su2}$: Lateral Strength of the Retrofitted Frame in the Horizontal Joint Failure
${}_pQ_c$: Punching Shear Strength of a Tensile Side Column
${}_fQ_j$: Resisting Force by the Friction
${}_aQ_j$: Lateral Strength of Anchors Installed in Horizontal Joints
Q_{c2} : Compression Side Column Lateral Strength

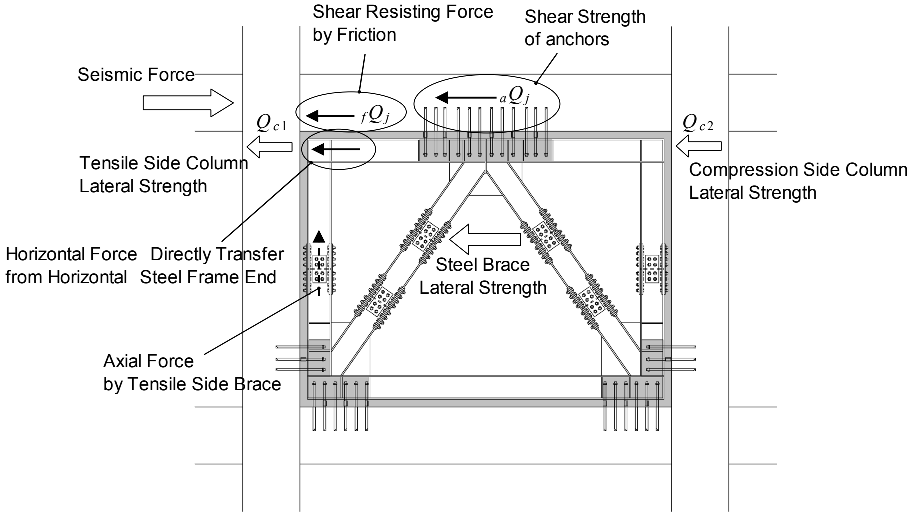


Figure 5.1. Horizontal Force Transfer Mechanism

Table 5.1. Comparison of Calculated Lateral Strength and Experimental Strength

Specimen	$_eQ_u$ (kN)	$_cQ_u$ (kN)								$_eQ_u/_cQ_u$
		Failure Mode	$_pQ_c$	$_fQj$	Q_{c1}	Q_{c2}	$_aQ_j$	$_sQ_u$	$_cQ_u$	
PA1	383.8	$_cQ_{su1}$	—	—	55.0	60.6	—	555.2	670.8	0.57
		$_c\boldsymbol{Q}_{su2}$	**190.9**	**48.8**	—	**60.6**	**0.0**	—	**300.3**	**1.28**
PA2	505.2	$_cQ_{su1}$	—	—	55.7	61.4	—	555.2	672.3	0.75
		$_c\boldsymbol{Q}_{su2}$	**206.0**	**43.5**	—	**61.4**	**114.8**	—	**425.7**	**1.19**
PA3	511.7	$_cQ_{su1}$	—	—	55.1	60.8	—	555.2	671.1	0.76
		$_c\boldsymbol{Q}_{su2}$	**193.9**	**40.1**	—	**60.8**	**110.2**	—	**405.0**	**1.26**
PA4	638.7	$_cQ_{su1}$	—	—	56.1	61.9	—	555.2	673.2	0.95
		$_c\boldsymbol{Q}_{su2}$	**213.6**	**67.7**	—	**61.9**	**234.6**	—	**577.8**	**1.11**
PA5	715.7	$_c\boldsymbol{Q}_{su1}$	—	—	**76.3**	**84.0**	—	**555.2**	**715.5**	**1.00**
		$_cQ_{su2}$	306.8	99.1	—	84.0	263.9	—	753.8	0.95

Table 5.1. shows that the calculated lateral strength of specimens ($_cQ_u$) are almost identical to the experimental lateral strength ($_eQ_u$). Therefore, Eqn. 5.1. can give the retrofitted frame lateral strength in the steel brace yielding failure, and Eqn. 5.2. can give the retrofitted frame lateral strength in the horizontal joint failure.

6. CONCLUSION

The following results were obtained from this experimental study.

1) The horizontal joint lateral strength increases as the number of anchors increase, and the failure mode are shifted from the horizontal joint failure to the steel brace yielding failure as the number of anchors increase.
2) The limit drift story angle of the horizontal joint failure is R=0.0067rad. and Eqn. 5.2. can give the retrofitted frame lateral strength in the horizontal joint failure.
3) The limit drift story angle of the steel brace yielding failure is R=0.01rad. and Eqn. 5.1. can give the retrofitted frame lateral strength in the steel brace yielding failure.
4) After the horizontal strength was deteriorated, the ability to support the vertical load was not lost until the cycle of R=0.02rad.

Incidentally, in Japan, this proposed seismic retrofitting method has been used for the retrofitting of existing reinforced concrete buildings more than 120 buildings as of 2012. Therefore, this proposed seismic retrofitting method is judged as the seismic retrofitting method which contributes for the promotion of earthquake proofing of existing buildings.

REFERENCES

[1] The Japan Building Disaster Prevention Association (Jan., 2002), Revise in 2001 Seismic Retrofitting Design Manual and Explanation of Existing Reinforced Concrete Buildings

[2] Takahiro Kei and Yasuyoshi Miyauchi, (Jan., 2001), Study on Retrofitting Adhered Steel Brace, J. Struct. Constr. Eng., AIJ, No. 539, 103-109

[3] Tetsuya Ohmura, Shizuo Hayashi, Kazuhiro Kanata, Toshiharu Nakamura, Yoshihiro Nishikawa, Yumi Suzuki and Tashiro Fujimura, (Jun., 2007), Sehar Transfer Mechanismof Seismic Strengthened Frames by Steel Braces without Dowel Anchors, J. Struct. Constr. Eng., AIJ, No. 616, 73-80

[4] Takanori Kawamoto, Eiichi Inai, Kenichi Watanabe and Ken Harayama, (Feb., 2010), Seismic Retrofitting Connection Method by Steel Brace with Anchors, AIJ J. Technol. Des., Vol. 16, No. 32, 161-166

[4] Ken Harayama, Eiichi Inai, Takanori Kawamoto, Yusuke Matsukane and Yoshihiro Inoue, (Feb., 2012), Applications of Seismic Retrofitting Method by Framed Steel Brace Sysytem Concentrically Jointed with Anchors, AIJ J. Technol. Des., Vol. 18, No. 38, 193-198