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A Study on Bar Arrangement Details of RC L-Shaped Beam Column Joints

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Abstract

It is necessary to transmit the stress to the column reliably from the beam top main bars at the exterior beam column joint on the top floor of the RC building. For this reason, it is common to bend the end portion of beam main bars at 90 degree and fix into the column with a sufficient length. On the other hand, for the purpose of pre-casting columns and beams members, there is also a demand to fix the beam main bars in a straight line in the beam column joint.

The purpose of this paper is to define the bar arrangement details necessary to fix the beam main bars in the exterior beam column joint, based on the results of many static loading tests of the roof-floor exterior beam column joint sub-frames that have been conducted so far.

As a result of the experiment, among the test specimens in which the beam main bars were fixed in a straight line in the beam column joint, those that had demonstrated remarkable decrease in the strength occurred the anchorage failure of the beam main bars. The specimens without anchorage failure did not show any decrease in the strength until large deformation with a story drift angle of 1/20 rad. Therefore, in order to fix the beam main bars in a straight line in the beam column joint, details of the bar arrangement are necessary so that the beam main bars do not cause anchorage failure.

The details of the bar arrangement to prevent the anchorage failure of the beam top main bar are as follows.

(1) Attach reliable anchorage devices to the ends of the beam and column main bars.

(2) The anchor end of the column main bar is provided above the top main bars of the beam, and enough amount of hoop-shaped reinforcing bars are arranged near the anchor end of the column main bar.

(3) The hoop-shaped reinforcing bars are not enough only by the outer peripheral bars, and the sub-hoops are also necessary arranged in the beam main bar direction and the orthogonal direction.

(4) If it is difficult to arrange the sub-hoop, it is effective in preventing anchorage failure of beam main bars that enclosed reinforcement or stick type reinforcing bars with 180 degree hook are arranged on the beam top main bars.

(5) These reinforcing bar amounts should be determined according to the beam main bar amount.

Beam rebar of the test specimens considered in this paper is about 0.8% of the cross-sectional area of the beam. If the tensile strength of the rebar of the beam is larger, it is necessary to examine the failure of the beam-column joint.

Keywords: RC Buildings, Exterior beam column joints, Anchorage failure

1. Introduction

It is necessary to transmit the beam stress to the column at the exterior beam-column joint on the top floor of the RC building. For this reason, it is common to bend the end portion of beam main bars at 90 degree and fix into the column with a sufficient length. On the other hand, for the purpose of pre-casting columns and beams members, there is also a demand to fix the beam main bars in a straight line in the beam column joint.

The purpose of this paper is to determine the details of the reinforcement required to fix the upper rebar of the top floor beam straight in the beam-column joint. The details of the arrangement will be based on the results of experiments conducted previously on the top floor beam-column joints.

2. Experimental program

2.1 Test specimens outline

In this paper, we show the experimental results of 8 characteristic specimens from the 4 series of experiments conducted previously. These specimens are simulating the external beam-column joint on the top floor of RC buildings.

Outline of specimens and reinforcement details are shown in Table 1 and Fig.1. In these specimens, column and beam rebars arrangement, and the strength of concrete and bars are common. Arrangement of reinforcing bars that confine column main bar anchorage and beam main bar anchorage is a variable factor.

Table 1 - Outline of Specimens

<table>
<tr><th rowspan="3">Specimen No.</th><th rowspan="3">Anchorage for top main rebar of beam</th><th colspan="2">Confinement for main rebar at the top of column (Reinforcement at column main bar anchorage)</th><th colspan="2">Confinement for top main rebar of beam (Reinforcement at beam main bar anchorage)</th></tr>
<tr><th colspan="2"></th><th rowspan="2">At the end of main rebar of beam</th><th rowspan="2">Vertical reinforcement along main rebar of beam</th></tr>
<tr><th>Force direction</th><th>Orthogonal direction</th></tr>
<tr><td>No.1</td><td>90° hook</td><td>None</td><td>None</td><td rowspan="5">None</td><td>U-shaped reinforcing bars 2-D10×3sets</td></tr>
<tr><td>No.5</td><td rowspan="7">Mechanical</td><td rowspan="2">6-D13(with sub hoop)</td><td>1-D13</td><td rowspan="4">None</td></tr>
<tr><td>AL1</td><td rowspan="6">None</td></tr>
<tr><td>AL2</td><td>6-D13</td></tr>
<tr><td>AL3</td><td>6-D13*1</td></tr>
<tr><td>BL1</td><td rowspan="3">6-D13</td><td rowspan="2">Enclosed reinforcement 4-D13(SD785)</td></tr>
<tr><td>BL2</td><td rowspan="2">U-shaped reinforcing bars 4-D13×3sets</td></tr>
<tr><td>BL5</td><td>Stick type reinforcement 8-D13(SD390)</td></tr>
</table>

*1: Reinforcement arranged under the top main rebar of beam

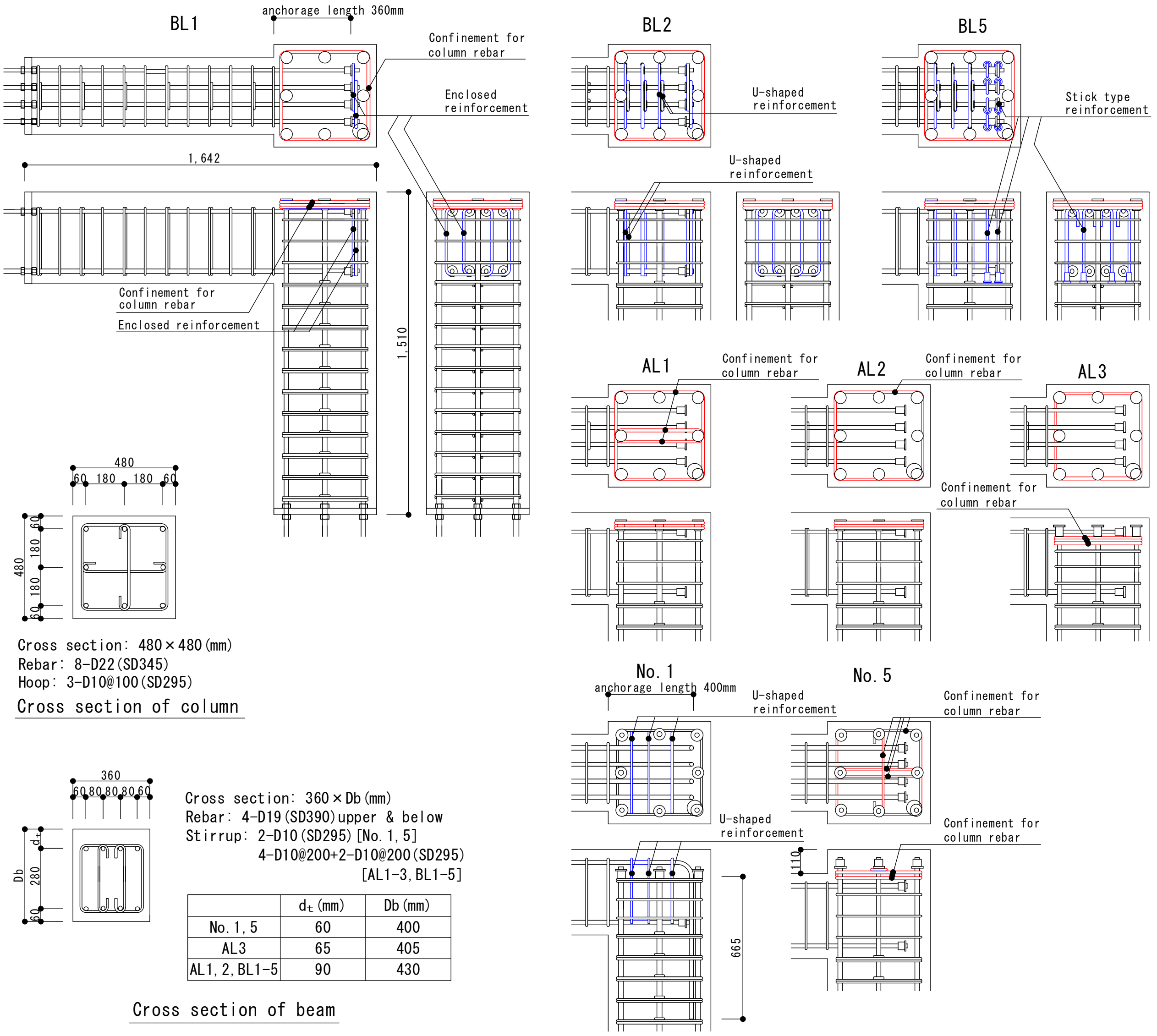


Fig.1 – Reinforcements of Specimen

In specimen No. 1, the upper rebars of the beam are bent at 90 ° and anchored in the column. In all other specimens, the upper rebars of the beam are anchored straight in the beam-column joint by using a mechanical anchorage, and the details of reinforcement at column rebars end and at beam rebars end are different from each other. In specimen No. 5, the end of the column rebars are located above the upper rebars of the beam, and a hoop-shaped confinement bars are arranged near the anchorage of the column main bar. The hoop-shaped confinement bars have the same tensile strength as upper rebars of the beam. And also a bar with 180° hook is arranged in the direction orthogonal to the load. AL1 has reinforcing bars similar to No. 5 in the loading direction, but the reinforcing bar in the direction orthogonal to the loading is omitted. AL2 has reinforcing bars equivalent to AL1, and the reinforcements are arranged only as outer hoop. In the specimen AL3, the same reinforcements as that of AL2 are located below the upper rebar of the beam. BL1 has enclosed shape reinforcement at the anchorage of the beam main bars in addition to AL2. BL2 has a U-shaped reinforcement placed above the upper rebars in the beam-column joint in addition to BL1. The similar U-shaped reinforcements are arranged in No. 1. In BL5, the reinforcements at the anchorage of the beam main bars are not enclosed shape but stick type. The stick type reinforcement has a 180° hook on one end, and mechanical anchorage on the other end. The stick type reinforcements in BL5 have the same tensile strength as enclosed shape reinforcements in BL1 and BL2.

In each specimen, the ratio of the calculated value of column bending strength to the calculated value of beam bending strength based on cross-sectional analysis is about 1.4, and the test piece assumes beam bending yield.

2.2 Material properties

Material properties of concrete and steel bars are shown in Table 2 and Table 3.

Table 2 - Properties of Concrete

Specimen No.	Compressive strength (N/mm^2)	Young's module ($\times 10^4 N/mm^2$)	Split tensile strength (N/mm^2)
No.1	27.7	2.32	2.45
No.5	34.2	2.86	2.59
AL1	30.6	2.73	2.47
AL2	30.8	2.79	2.45
AL3	30.8	3.17	2.68
BL1	33.2	2.42	2.58
BL2	33.5	2.58	3.09
BL5	33.9	2.69	2.76

Table 3 - Properties of Reinforcement

Type of bars				Yield strength (N/mm^2)	Yield strain (%)	Young's module ($\times 10^4 N/mm^2$)
Hoop & stirrup	D10	SD295	No.1,5	368	0.203	18.3
			AL1-3	363	0.181	20.3
			BL1-5	368	0.194	19.7
Column rebar	D22	SD345	No.1,5	395	0.212	19.6
			AL1-3	377	0.207	18.3
			BL1-5	392	0.211	19.3
Beam rebar	D19	SD390	No.1,5	445	0.237	19.7
			AL1-3	435	0.237	18.4
			BL1-5	458	0.246	19.9
Confinement for column rebar	D13	SD785	No.5	854	0.468	20.0
			AL1-3	846	0.426	19.9
			BL1-5	821	0.455	19.5
Confinement at the end of main rebar of beam	D13	SD785	BL1,2	806	0.473	19.3
		SD390	BL5	420	0.254	18.9
Confinement along main rebar of beam	D10	SD295	No.1	368	0.203	18.3
	D13	SD295	BL2,5	368	0.187	19.7

2.3 Loading

Loading setup is shown in Fig.2. The specimen was set so that the column was horizontal, and the position where the inflection point of the beam and the column was assumed was used as the pin support. The supporting point of the column was provided with a jack so that the load point did not move in the vertical direction, and positive and negative alternating loading was performed by the horizontal jack. Cyclic loading was controlled by increasing story drift R=±1/800rad, ±1/200rad, ±1/100rad, ±1/50rad, ±1/33rad, ±1/25rad, and finally up to +1/.15rad in one way. The loading was duplicated twice at every amplitude, except for final one way loading.The direction in which the columns and beams close is defined as positive force.

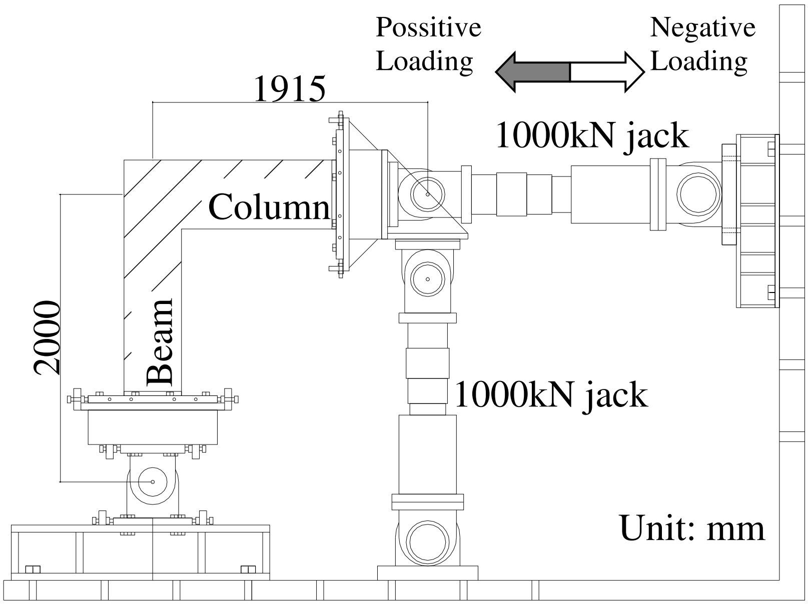


Fig.2 – Loading Setup

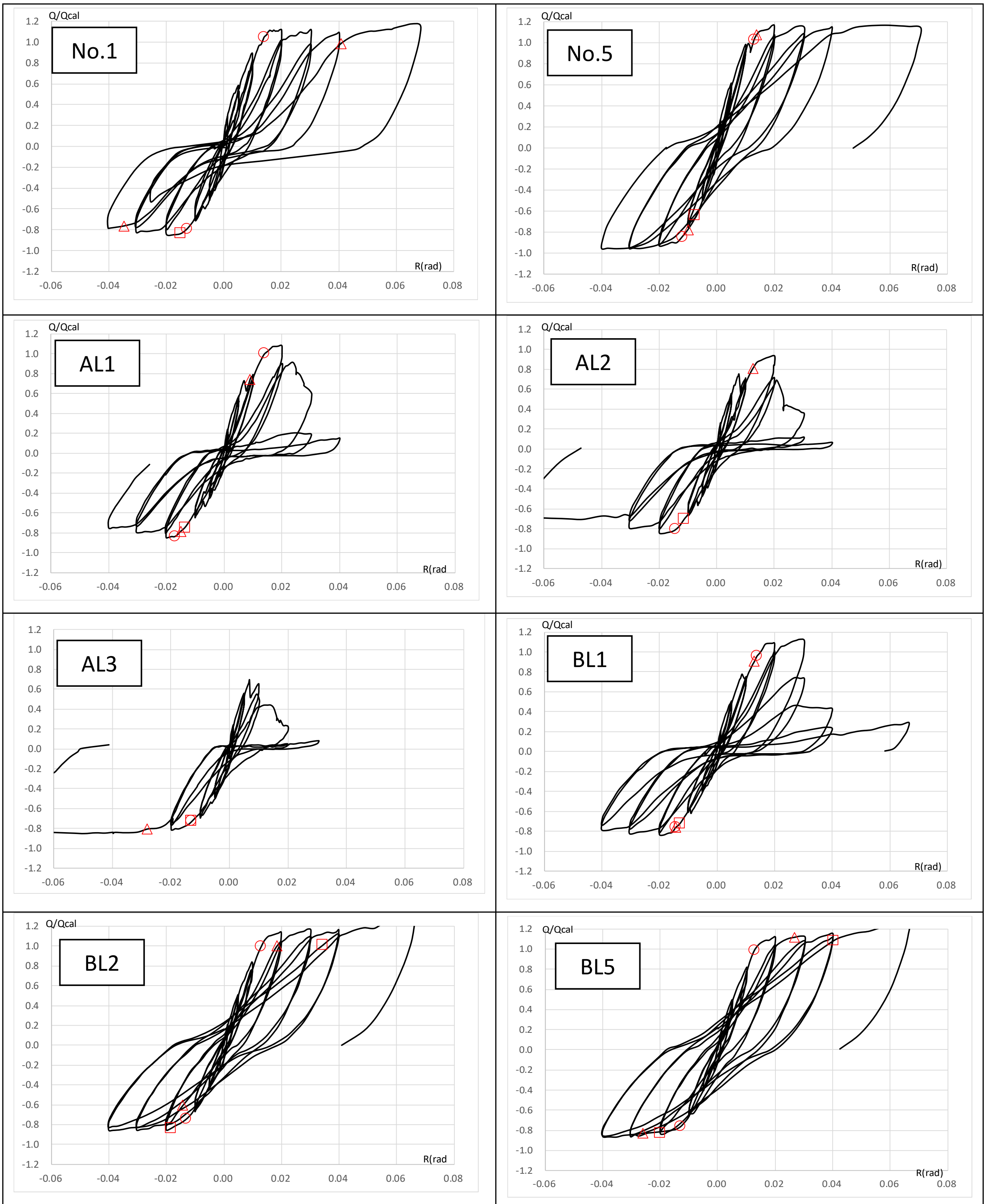
3. Test results

3.1 Failure Process

Fig. 3 shows the story shear force Q and the story drift angle R relationships of each specimen. Here, the story shear force is normalized by the calculated value of the story shear force at the time of beam bending yield. In Fig.3, marking "○", "□", "△" mean yielding of beam main bar, column main bar, joint hoop respectively.

The damage condition of the beam-column joint at the maximum strength in each specimen is shown in Fig. 4. The crack condition at the top of column after the strength reduction is shown in Fig.5.

In test specimen No.1, No.5, AL1, BL1, BL2, and BL5, the beam main bar yielded at positive loading. And the maximum loads of these specimens exceeded the calculated values of beam bending yield. The maximum load of the specimen No.2 was nearly to the calculated values. But the maximum load of the specimen No.3 was only 70% to the calculated values.



○:Yielding of beam main bar, □: Yielding of column main bar, △: Yielding of joint hoop

Fig.3 - Story Shear Force Q and the Story Drift Angle R Relationships

In No.1, the beam main bars yielded in the cycle toward R = +1/50, and the strength almost reached the maximum value. The strength was increasing up to R = +1/15, but the hysteresis curve showed slightly slip tendency.

In No.5, the beam main bars and the joint hoop yielded in the cycle toward R = +1/50, and Diagonal cracks (showing as "(A)" in Fig. 4) occurred at joint panel clearly. The strength did not decrease at R=1/15 and maintained such as maximum strength. Reinforcements at column main bars anchorage did not yield until the end of the load. The shape of the hysteresis curve is closer to the spindle shape compared to specimen No.1. This indicates that even if the upper rebars of the beam are anchored straight to the beam-column joint, stress is transmitted between the beam and the column with effectual reinforcement.

BL2 and BL5, specimens that the strength did not decrease until the end of the load, were in the same course as No.5. Reinforcements neither at column bars anchorage nor at beam bars anchorage yielded until the end of the load.

Both in AL1 and in AL2, diagonal cracks (showing as "(B)" in Fig. 4) passing through the end of column rebar occurred clearly by R = + 1/100. Joint hoop yielded in the cycle toward R = + 1/50. In AL1, the beam main bar yielded around R = +1/50, and the strength showed the calculated values of beam yielding. However, in AL2, its reinforcements at column rebar anchorage were arranged as only outer hoops, the beam main bars did not yield and the maximum strength was smaller than the calculated value of beam yielding. In both AL1 and AL2, the strength rapidly decreased after R = +1/50.

In AL3, its reinforcements at column rebar anchorage were arranged below the upper rebar of the beam, the strength dropped sharply at R = +1/100 without yielding at both the beam main bars and the joint hoop. Despite the reinforcement amount being equivalent to that of AL1, the maximum proof stress was reduced to about 70%. So it is important not only to secure the amount of reinforcement at the column rebar anchorage but also to arrange it effectively.

BL1 had the same course as BL2 up to R = +1/50, but from R = +1/50, cracks passing through the column rebars(B) became remarkable, and after R = +1/33, the strength rapidly dropped.

The crack condition at the top of column after the strength reduction is shown in Fig.5. Here, in addition to the specimen AL1, AL2, AL3, and BL1 that showed a decrease in strength, the cracking condition of BL2 and BL5 is also shown for comparison. It is probable that the arc-shaped crack (showing as "(C)" in Fig.5) passing through the anchorage of the beam main bars was remarkable. This means the cone failure (failure type in which the concrete in front of the anchorage of the beam main bars was scraped out) has occurred, and the anchorage strength was lost. Similar cracks are occurring in BL2 and BL5, but they are not noticeable.

It is considered that the strength reduction was caused by the cone failure in specimen AL1, AL2, AL3, and BL1. On the other hand, in No.5, BL2, and BL5, it is considered that since the reinforcement at the anchorage prevented cone failure, no reduction in strength occurred.

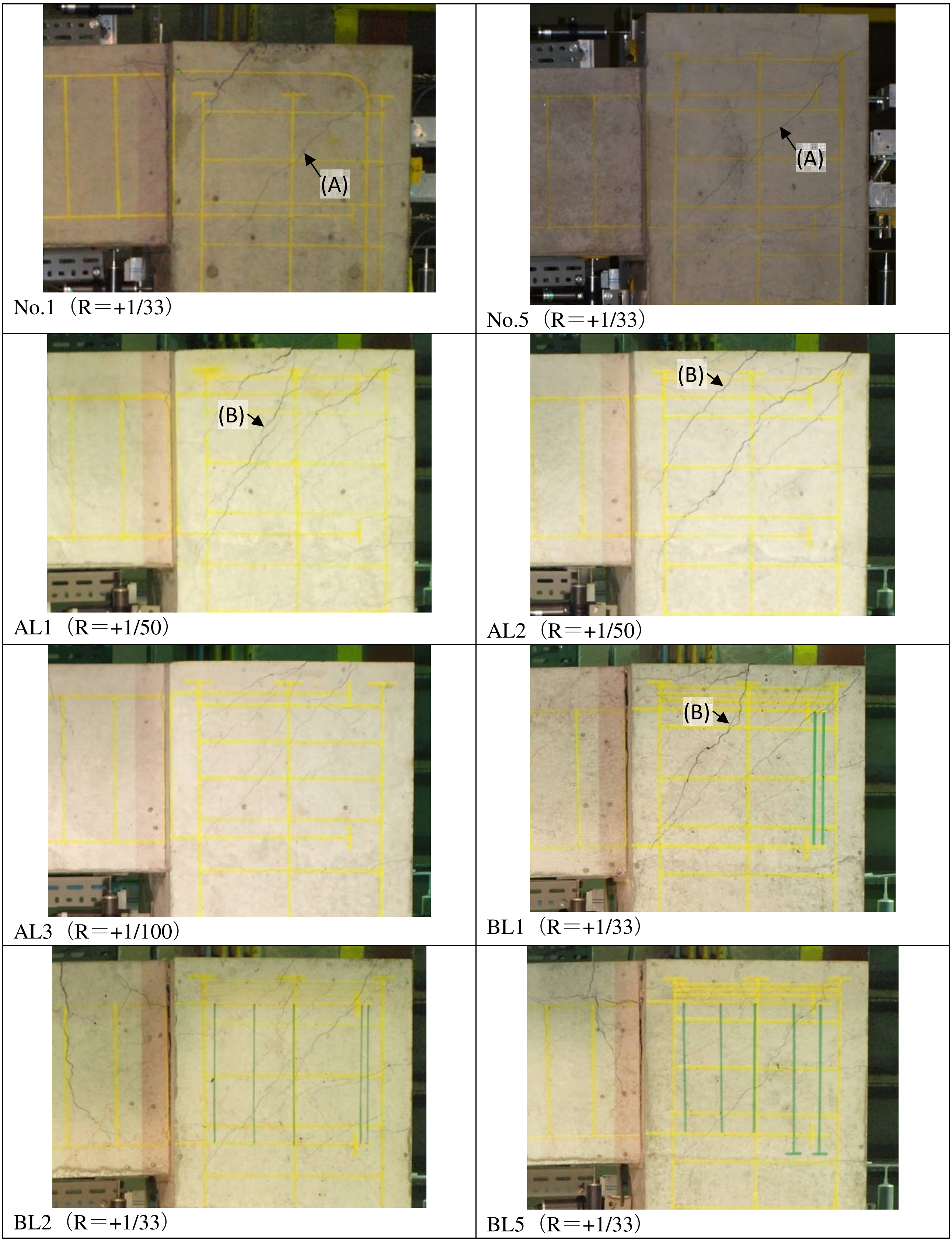


Fig.4 - Damage Condition of the Beam-column Joint at the Maximum Strength

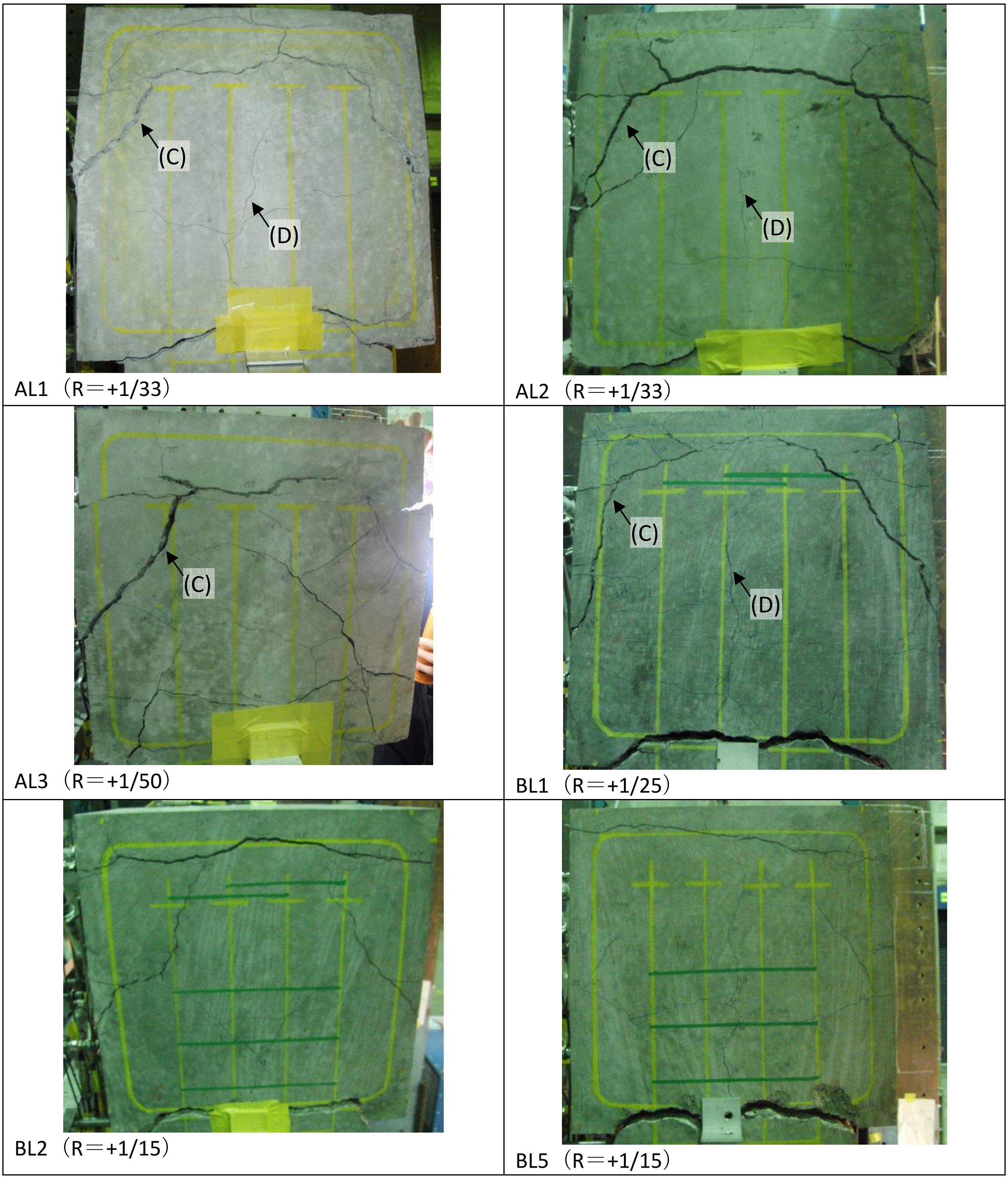


Fig.5 - Damage Condition of the Top of Column after the Strength Reduction

3.2 Effect of reinforcement at anchorage

(1) Effect of reinforcement at column main bar anchorage

When the beam main bars are bent by 90 ° and fixed in the column with enough length, the tensile stress of the beam main bars are transmitted as a lap joint between the extra length of bending part and the column main bars. On the other hand, in the case where the beam main bars are fixed straight in joint, the anchorage strength of the beam main bars is exerted by the bond strength and the bearing pressure on the front of the anchorage. In order to complete a stress transmission mechanism as a beam-column joint, hoop shaped reinforcement at column main bar anchorage have to transmit the bond strength and bearing pressure to the column main bars at backwards.

Specimens with reduced strength had cone failure. In AL3, because the reinforcements were not above the beam main bars, concrete above the bars is likely to split, cone failure occurred early, and the strength dropped.

From the comparison between AL1 and AL2, the reinforcement at the column main bar anchorage requires not only the outer hoop but also the sub hoop-shaped reinforcement. This is because it is necessary to arrange reinforcements near the beam main bars to transmit the stress of the beam main bars, and the outer hoop is far from the rebar inside the beam.

From the comparison between AL1 and No.5, sub hoop in the direction orthogonal to the force is also required. This is because compression strut is formed to connect column and beam main bar anchorage, and reinforcement is required to prevent the column rebars from being pushed outward. In AL1, AL2, and BL1, a linear crack (showing as "(D)" in Fig.5) is seen near the center of the column top, so it can be expected that the column rebar is pushed outward.

Fig. 6 shows the progress of strain of hoop shaped reinforcement at column main bar anchorage. Specimens that have caused anchorage failure show greater strain at the same deformation than those that have not. This indicates that reinforcements at column bar anchorage are effective in each specimen. On the other hand, if the reinforcements are not placed effectively, the deformation of the concrete cannot be suppressed, which indicates that anchorage failure of the beam rebars due to splitting of the concrete will occur. In No. 5 that anchorage failure did not occur, the strain of the inner reinforcement was larger than that of the outer hoop, but the opposite was true in AL1 that anchorage failure occurred. This is because AL1 has no reinforcement in the orthogonal to the force, and the outer hoop try to suppress the column rebar from being expanded outward, so that the strain of the outer hoop is increased.

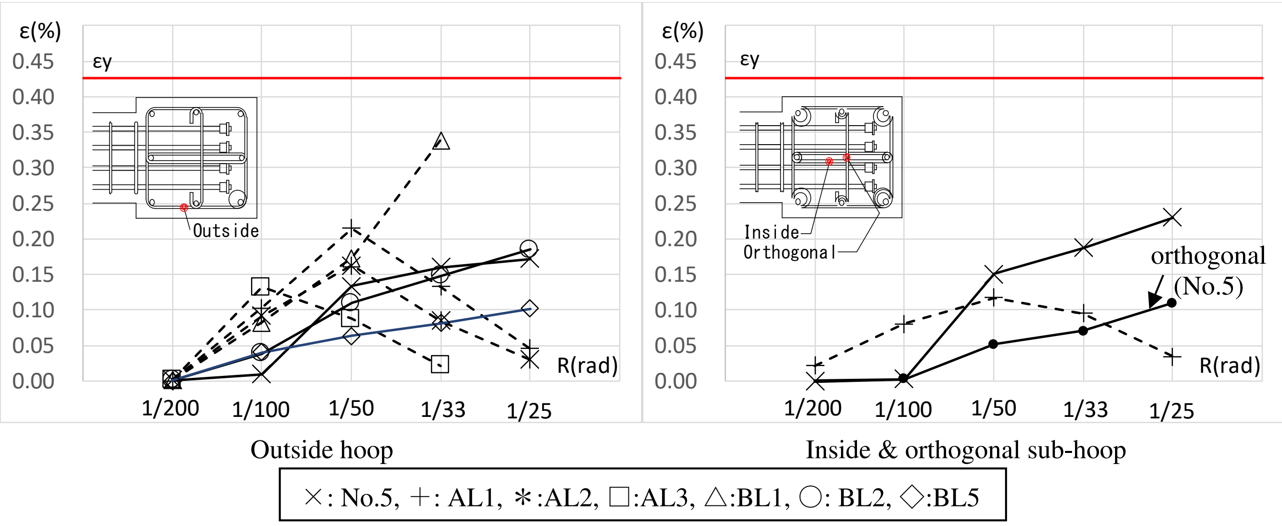


Fig.6 - Progress of Strain of Hoop Shaped Reinforcement at Column Main Bar Anchorage.

(2) Effect of reinforcement at beam main bar anchorage

According to the experimental results of AL2, BL1, BL2, and BL5, when it is not possible to arrange the sub-hoop shaped reinforcement at the column main bar anchorage, it is effective to arrange reinforcement at beam main bar anchorage. It is considered that this is because the reinforcement contributes to the stress transmission between the beam main bars and column main bars, as well as the extra length in the case of bending anchorage. From the comparison between BL2 and BL5, it is considered that the reinforcement at beam main bar anchorage does not necessarily have to have enclosed shape, but only needs to have sufficient anchoring performance.

From the comparison between BL1 and BL2, it is understood that the U-shaped reinforcement for the upper rebars of beam is important. This is considered to be the same as the sub-hoop-shaped reinforcement at column main bar anchorage in the direction orthogonal to the force, which prevents the column middle bar from being pushed outward.

Fig. 7 shows the progress in strain of the reinforcement at beam main bars anchorage. The strain increased in all of BL1, 2, and 5 until the large deformation, and it is considered that the reinforcement bars were effective for anchorage failure of the beam main bars.

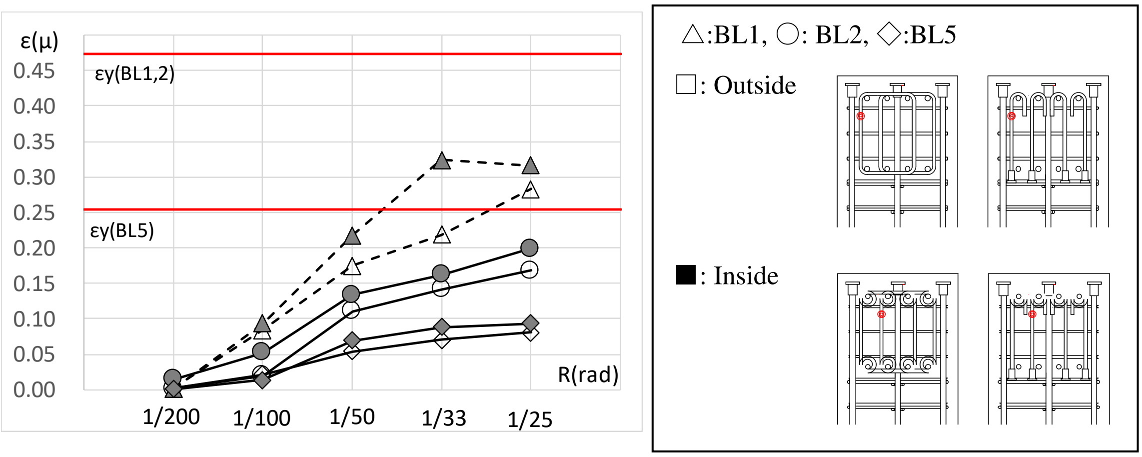


Fig.7 - Progress of Strain of Reinforcement at Beam Main Bar Anchorage

4. Conclusion

The details of the bar arrangement to prevent the anchorage failure of the beam top main bar are as follows.

(1) Attach reliable anchorage devices to the ends of the beam and column main bars.

(2) The anchor end of the column main bar is provided above the top main bars of the beam, and enough amount of hoop-shaped reinforcing bars are arranged near the anchor end of the column main bar.

(3) The hoop-shaped reinforcing bars are not enough only by the outer peripheral bars, and the sub-hoops are also necessary arranged in the beam main bar direction and the orthogonal direction.

(4) If it is difficult to arrange the sub-hoop, it is effective in preventing anchorage failure of beam main bars that enclosed reinforcement or stick type reinforcing bars with 180 degree hook are arranged on the beam top main bars.

(5) These reinforcing bar amounts should be determined according to the beam main bar amount.

Beam rebar of the test specimens considered in this paper is about 0.8% of the cross-sectional area of the beam. If the tensile strength of the rebar of the beam is larger, it is necessary to examine the failure of the beam-column joint.

5. Acknowledgements

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6. References

[1] Kawazoe,Y., Watanabe,H., Takahashi,A., Kiyohara,T., Kusunoki,K. and Tasai,A.(2009). An experimental study on RC L-shape beam column joint with mechanical anchored rebar. *Summaries of technical papers of annual meeting architectural institute of Japan 2009*:**C-2**, 369-370

[2] Kato,F., Kawazoe,Y., Tasai,A., Kusunoki,K., Kiyohara,T. and Koshiji,M.(2010). Experimental study on hysteretic characteristics of the RC L-shape beam column joint using mechanical anchorage, Part1 and Part2. *Summaries of technical papers of annual meeting architectural institute of Japan 2010*:**C-2**, 403-406

[3] Yoshimura,M., Kato,F., Tasai,A., Kusunoki,K., Kiyohara,T. and Adachi,T.(2011). Experimental study on the effect of confined reinforcement restriction bar of RC L-shape beam column joint with mechanical Anchored main rebar, Part1 and Part2. *Summaries of technical papers of annual meeting architectural institute of Japan 2011*:**C-2**, 481-484

[4] Kato,F., Yoshimura,M., Tasai,A., Kusunoki,K., Kiyohara,T. and Adachi,T.(2012). Experimental study on the effect of confined reinforcement restriction bar of RC L-shape beam and little outstanding column joint with mechanical Anchored main rebar, Part1, Part2 and Part3. *Summaries of technical papers of annual meeting architectural institute of Japan 2012*:**C-2**, 535-540

