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EXPERIMENTAL STUDY ON HORIZONTAL REINFORCING EFFECTS AT RC EXTERIOR BEAM-COLUMN JOINTS WITH MECHANICAL ANCHORS

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Abstract

Mechanical anchors are generally used to terminate the beam longitudinal bars at an exterior beam-column joint of reinforced concrete high-rise buildings in Japan. In the case of applying mechanical anchors compared with standard 90-degree hooks, though development length could be shorter, cracks tend to concentrate around the anchor plates. When their cracks expand, the strength and ductility of frame decreases, thus the anchor failure should be avoided. In this study, for the purpose to develop a new reinforcing method to prevent not only the cracks concentrating around the anchor plates but also the diagonal cracks to spread at the center of beam-column joints panel, the tests of the half-scale exterior beam-column joints was conducted. Parameters of these tests were the placement of the horizontal shear reinforcement and their amount in the exterior joint. Concrete compressive strength was 45N/mm^2, yield strength of longitudinal bar was 490N/mm^2, and that of horizontal shear reinforcement was two kinds of 295 N/mm^2 and 785 N/mm^2. In addition, all of the test specimens were designed to be damaged at the area of beam-column joints, in reference to Dr. Shiohara studies [1~3]; column to beam bending strength margin was set to be less than about 1.5.

In the basic specimen #1, horizontal reinforcement at the joint was placed uniformly, and in the specimen #2, additional concentrated horizontal reinforcement was arranged at the column side of the beam longitudinal bars. In the specimen #3, additional concentrated horizontal bars were placed at the center of the joint panel. In the specimen #4, they were placed at the joint side of the beam longitudinal bars. In the specimen #5, additional horizontal reinforcement was placed as half amount as in #4.

From the test results of #1, after the maximum strength at about story drift of 1/50, the cracks at the beam-column joints expanded and the strength gradually decreased because of the joint bending failure. The reinforcing effect was largest in the #3, so the maximum strength was improved about 25% compared with #1, and it had maintained the strength until at the story drift angle of 1/15, also beam bending failure mode was remarkable. The maximum strength of #4 was equivalent to #3, but the strength decreased remarkably. The maximum strength of #5 was improved about 10%, but #2 was about 5% only.

Consequently, the horizontal reinforcement at the beam-column joints effects on the strength of the joint bending failure and anchor failure, and the additional horizontal reinforcement near longitudinal bars at the joint are also very effective for increasing the maximum strength and ductility.

Keywords: Exterior Beam-Column Joint, Horizontal Shear Reinforcement, Mechanical Anchor Development

1. Introduction

Mechanical anchors are generally used to terminate the beam longitudinal bars at an exterior beam-column joint of reinforced concrete high-rise buildings in Japan. In the case of applying mechanical anchors compared with standard 90-degree hooks, though development length could be shorter, cracks tend to concentrate around the anchor plates. When their cracks expand, the strength and ductility of frame decreases, thus the anchor failure should be avoided. In this study, for the purpose to develop a new reinforcing method to prevent not only the cracks concentrating around the anchor plate but also the diagonal cracks to spread at the center of beam-column joints panel, the tests of the half-scale exterior beam-column joints was conducted.

2. Experimental program

2.1 Test specimens outline

Five identical 1/2-scale models of RC exterior beam-column joints were prepared, and their parameters of this test were the placement of the horizontal shear reinforcement and their amount inside of the panel. Assuming high-rise buildings, concrete compressive strength was 45N/mm^2, yield strength of longitudinal bar was 490N/mm^2, and that of horizontal shear reinforcement was two kinds of 295 N/mm^2 and 785 N/mm^2. In addition, all of the test specimens were designed to be damaged at the area of the beam-column joints, in reference to Dr. Shiohara studies [1~3]; column to beam bending strength margin was set to be less than about 1.5.

In the basic specimen #1, horizontal reinforcement at the joint was placed uniformly, and in the specimen #2, additional high strength concentrated horizontal reinforcement (785N/mm^2) was arranged at the column side which was outside the beam longitudinal bars and placed as half amount as the tensile yield strength of beam bars. In the specimen #3, additional horizontal bars as same quantity as #2 were placed into the panel which was concentrated at the center of the joint panel. In the specimen #4, their arrangement was inside the beam longitudinal bars. In the specimen #5, additional horizontal reinforcement was placed as half amount as in #4.

Table 1 shows the list of test specimens and Figure 1 shows the reinforcing bar arrangements.

Table 1 – Lists of test specimens

Specimen No.					#1	#2	#3	#4	#5
Joint	Additional Horiz. bars	Bar arrangement				2-D10(SD785)×5sets			2-D10(SD785)×2sets
		placement				Outside	Center	Near beam bars	
Column	Cross section (mm)				500×500				
	Rebar				12-D22(SD345)				
	Hoop				2-D10(SD295) spacing at 100mm				
Beam	Cross section (mm)				Width 450 × Depth 500				
	Rebar				5-D25(SD490) upper & below				
	Stirrup				2-D10(SD295) spacinga at 100mm				
Calc. strength	Story shear force (kN)	Column bending	upper		367	367	386	386	386
			below	+	428	432	463	463	464
				-	309	305	307	307	308
		Beam bending			278	279	274	274	274
		Joint panel shear			312	317	388	388	394
	Column to Beam bending strength margin			+	1.32	1.32	1.41	1.41	1.41
				-	1.11	1.10	1.10	1.12	1.12

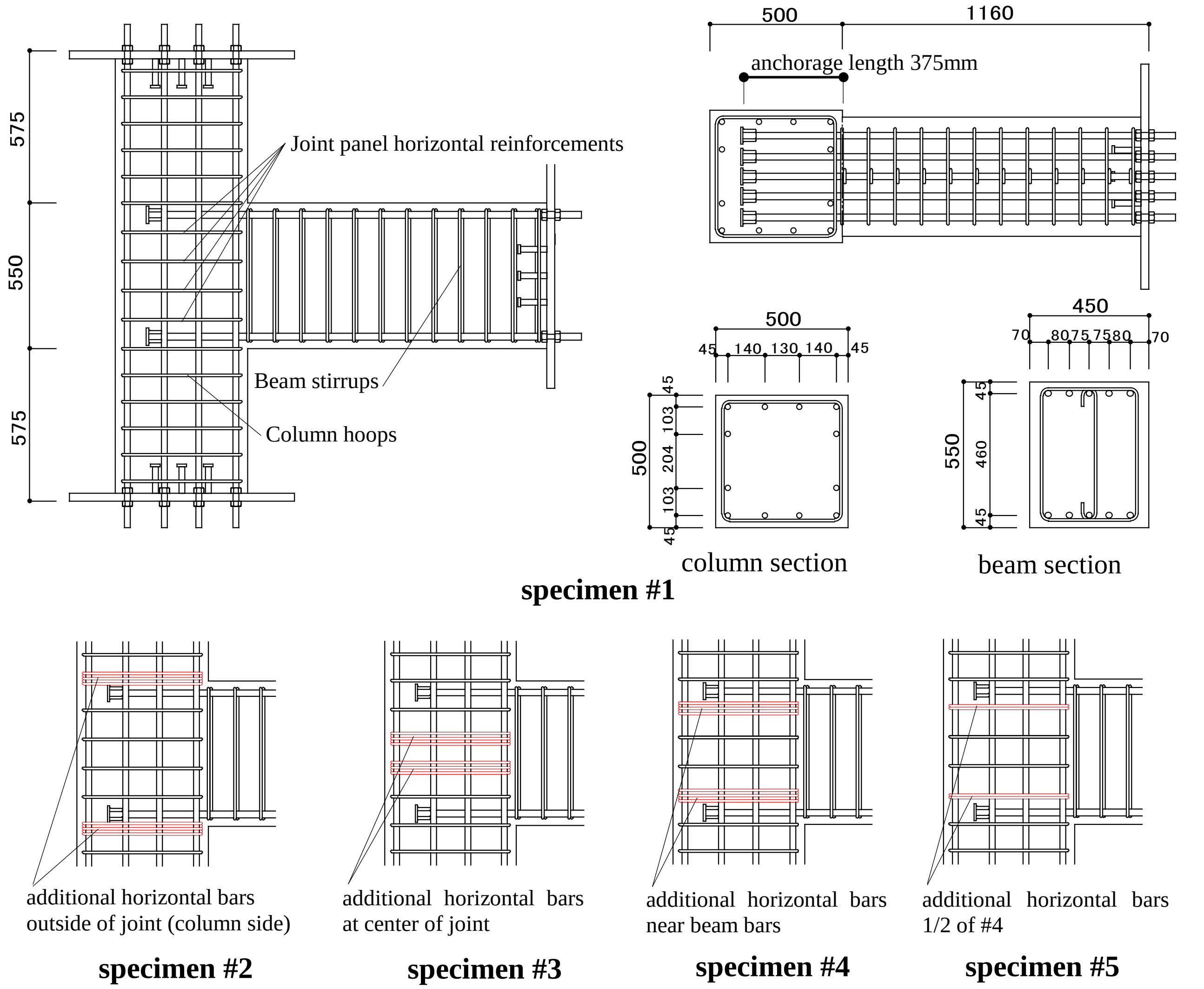


Figure 1 – Bar Arrangement of Test Specimens

2.2 Material properties

Material properties of concrete and steel were showed in table 2 and table 3 respectively. Material test for concrete compressive strength was conducted at the same time when the each beam-column test was conducted.

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)
#1	55.6	3.25	3.35
#2	56.9	3.25	3.70
#3	70.3	3.39	4.12
#4	70.1	3.48	3.90
#5	71.7	3.44	4.48

Table 3 – Properties of Steel bars

Type of bars				Yield strength (N/mm^2)	Yield strain ε_y(%)	Young's module ($\times 10^4 N/mm^2$)	Tensile strength (N/mm^2)
Hoop & stirrup	D10	SD295	#1,#2	352	0.213	18.8	472
			#3,#4,#5	350	0.223	17.5	472
Additional horizontal bars	D10	SD785	#2	847	0.416	20.8	1001
			#3,#4,#5	829	0.433	19.3	1027
Column rebar	D22	SD345	#1,#2	386	0.220	19.0	576
			#3,#4,#5	401	0.230	18.5	514
Beam rebar	D25	SD490	#1,#2	537	0.300	19.4	732
			#3,#4,#5	524	0.296	19.6	700

2.3 Loading setup and measuring method

Loading setup is shown in Figure 2. Inflection point of beam and columns were assumed at mid-span and mid-height of the target building respectively, and pin joints were attached at the ends of a beam and columns as locations of pins agree with the inflection points. Cyclic loadings were applied with Zero controlled axial force of upper column above the beam, and the loading setup beam balance was kept horizontally by two vertical oil jacks. Horizontal loading cycles were controlled by relative story drift angle of R=1/800(rad.), 1/400(rad.) of one cycle, and 1/200(rad.), 1/100(rad.), 1/50(rad.), 1/33(rad.) of two cycles, and 1/25(rad.) of one cycle, and finally loading up to R=1/15(rad.). Then loading direction which lower column got near to beam was defined plus loading direction, and loading direction which lower column went away from the beam defined as minus.

Story drift was measured as a horizontal relative displacement between top and bottom pins by displacement transducers fixed to aluminum-holder pin roller supported the column capital and its base. The shear deformation of the joint panel was measured using displacement transducers in diagonal directions in the panel zone. The lateral and axial loads on column and the vertical reaction load at the end of beam were recorded by using load cells respectively. The strain was measured at the respective load increments by strain gauges pasted to the main reinforcements of the column and beam, the hoops of the column, and the joint panel reinforcements.

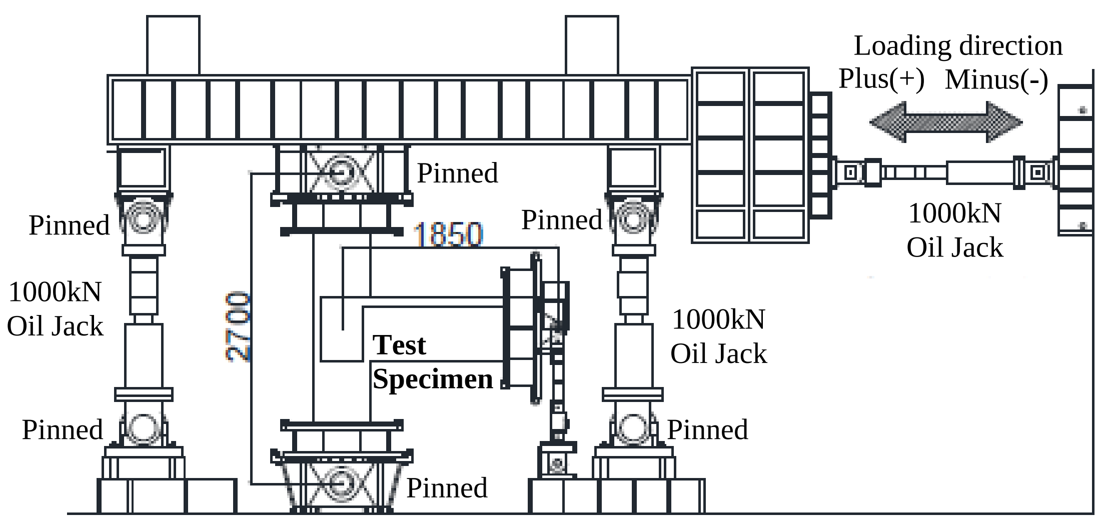


Figure 2 – Loading Setup

3. Test results

3.1 Story shear force and story drift angle relationships

Figure 3 shows the story shear force and story drift angle relationships. Also in the Figure 3, the calculation value ($_bQ_{mu}$) is shown. The beam yielding moment ($_bM_o$) has calculated using a stress-strain relationship by exponential function, assuming the plane holding at the cross section.

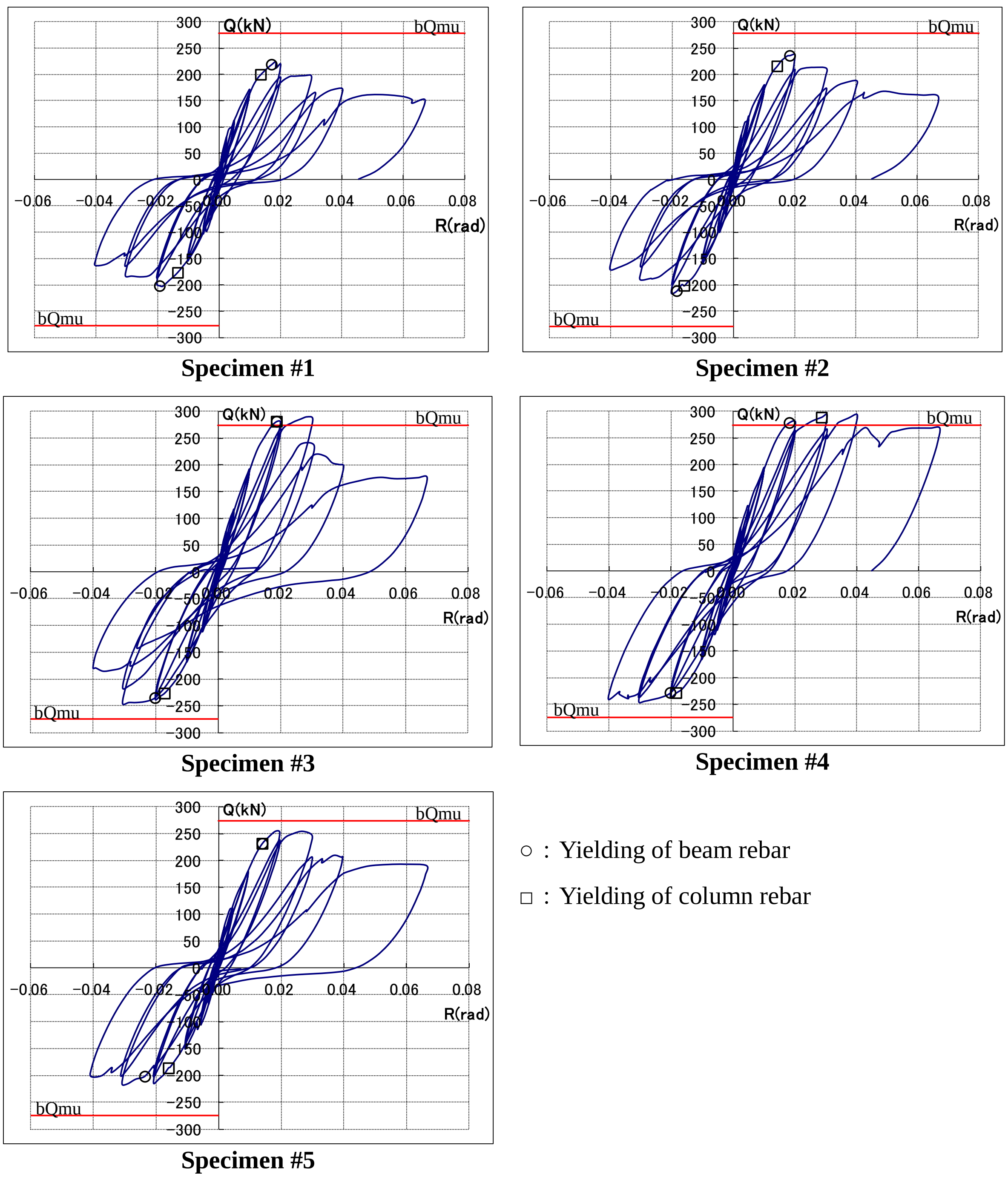


Figure 3 – Story shear force and story drift angle relationships

3.2 Failure process

The damage conditions at the point of maximum loading of each specimens shows in Figure 4. Drift angle of each specimens were, R=1/50 (rad.) for # 1 and # 2, R=1/33 (rad.) for # 3 and # 4, and R=1/42 (rad.) for # 5.

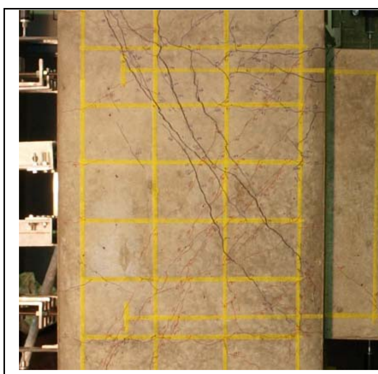
Diagonal cracks of #1 occurred at joint panel at R=1/200 (rad.), and at R=1/50, maximum strength was recorded and most of the longitudinal bars of column and beam yielded at the same time. After that, cracks penetrated behind the column from anchorage and shear force decreased. Then the maximum strength was smaller than the calculated beam yielding strength.

Damage process of #2 was almost same as #1. Even though additional reinforcement was arranged, it was not able to control the crack width spreading from the panel because it was arranged at the outside of panel (column side). Then the maximum strength was 5% larger than #1.

Diagonal cracks of #3 occurred in the beam-to-column joints at R=1/200 (rad.), and at R=1/50, most of the longitudinal bars of column and beam yielded at the same time, but the maximum strength was 20% larger than #1 and the crack width was smaller than #1. Even after column and beam bars yielded, strength increased and maximum strength was recorded at R=1/33. After that, though strength decreased quickly, cracks did not penetrate behind column compared with #1. Finally, the maximum strength was 25% larger than #1 and was over the calculated beam yielding strength.

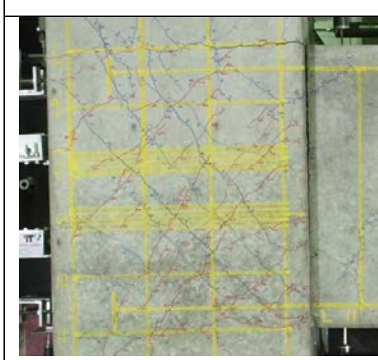
Damage process of #4 was almost same as #3 until the maximum strength at R=1/33. The strength did not decrease at R=1/15 and maintained as much as the maximum strength.

Failure process of #5 showed intermediate characteristics of #1 and #3. The maximum strength was 10% larger than #1.

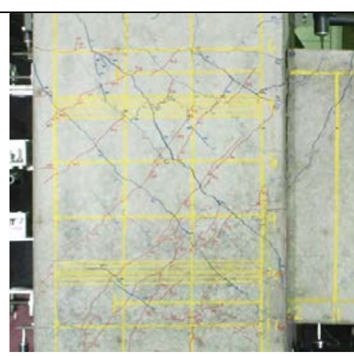


#1 (at R=+1/50rad)

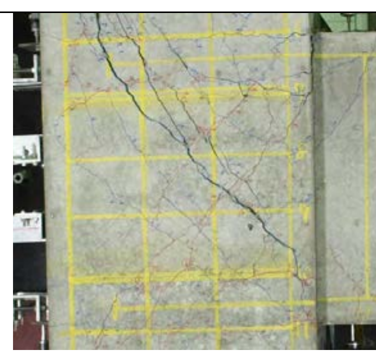
#2 (at R=+1/50rad)



#3 (at R=+1/33rad)



#4 (at R=+1/33rad)



#5 (at R=+1/42rad)

Figure 4 – damage conditions

3.3 Rate of deformation of each member

The change of percentage of beam, column, and beam-to-column joint deformation component is showed in Figure 5. At the small drift angle, beam deformation angle occupied a majority. And at the large drift angle, the deformation of beam-to-column joint would be dominant. However, the beam deformation of # 4 was always dominant even at R=1/25 because the maximum strength did not decrease at the end of loadings.

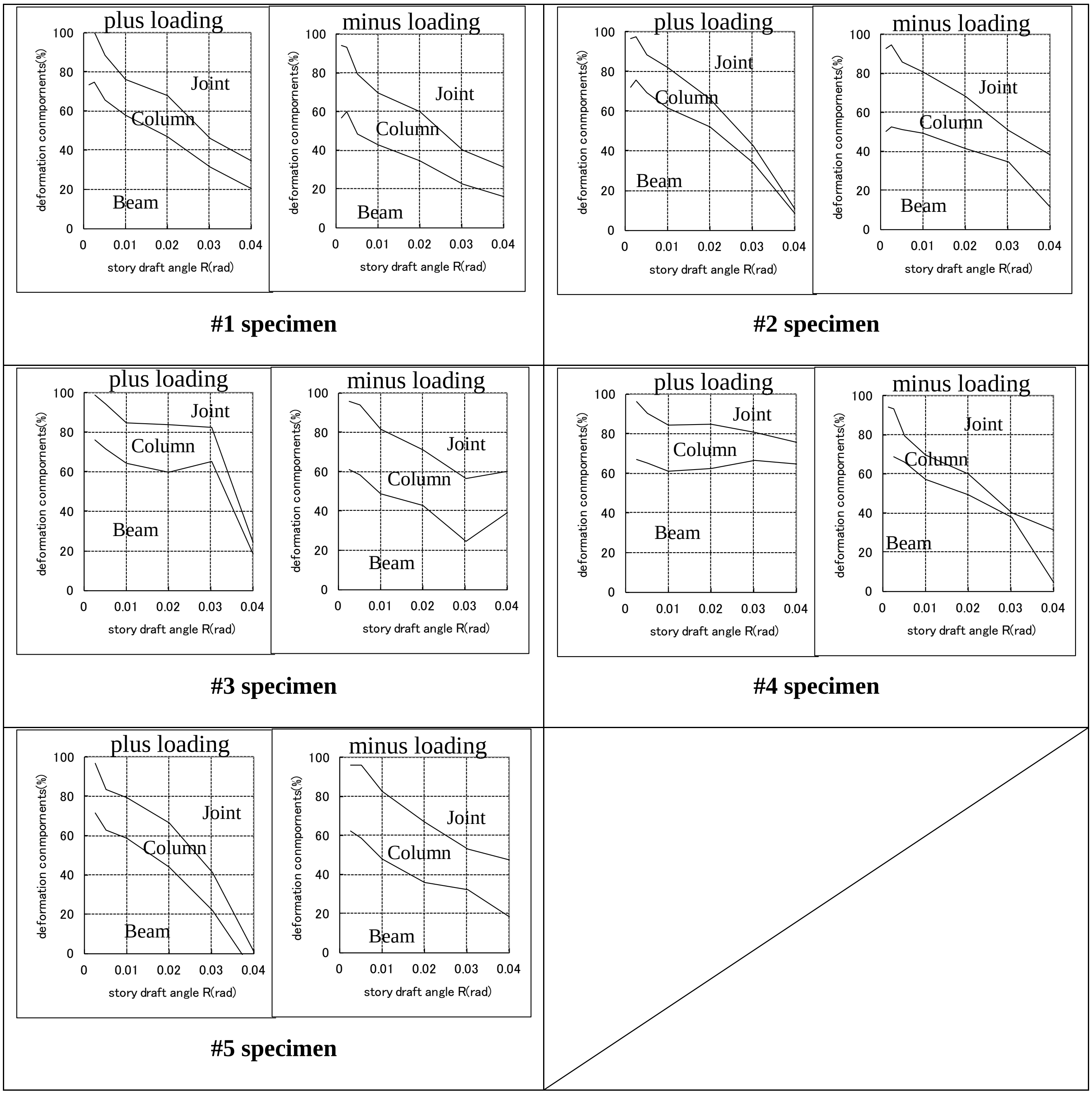


Figure 5 – change of percentage of beam, column, and joint deformation component

3.4 Strain of horizontal reinforcement in the beam-column joint

The strain of beam-column joint horizontal reinforcement is shown in Figure 6.

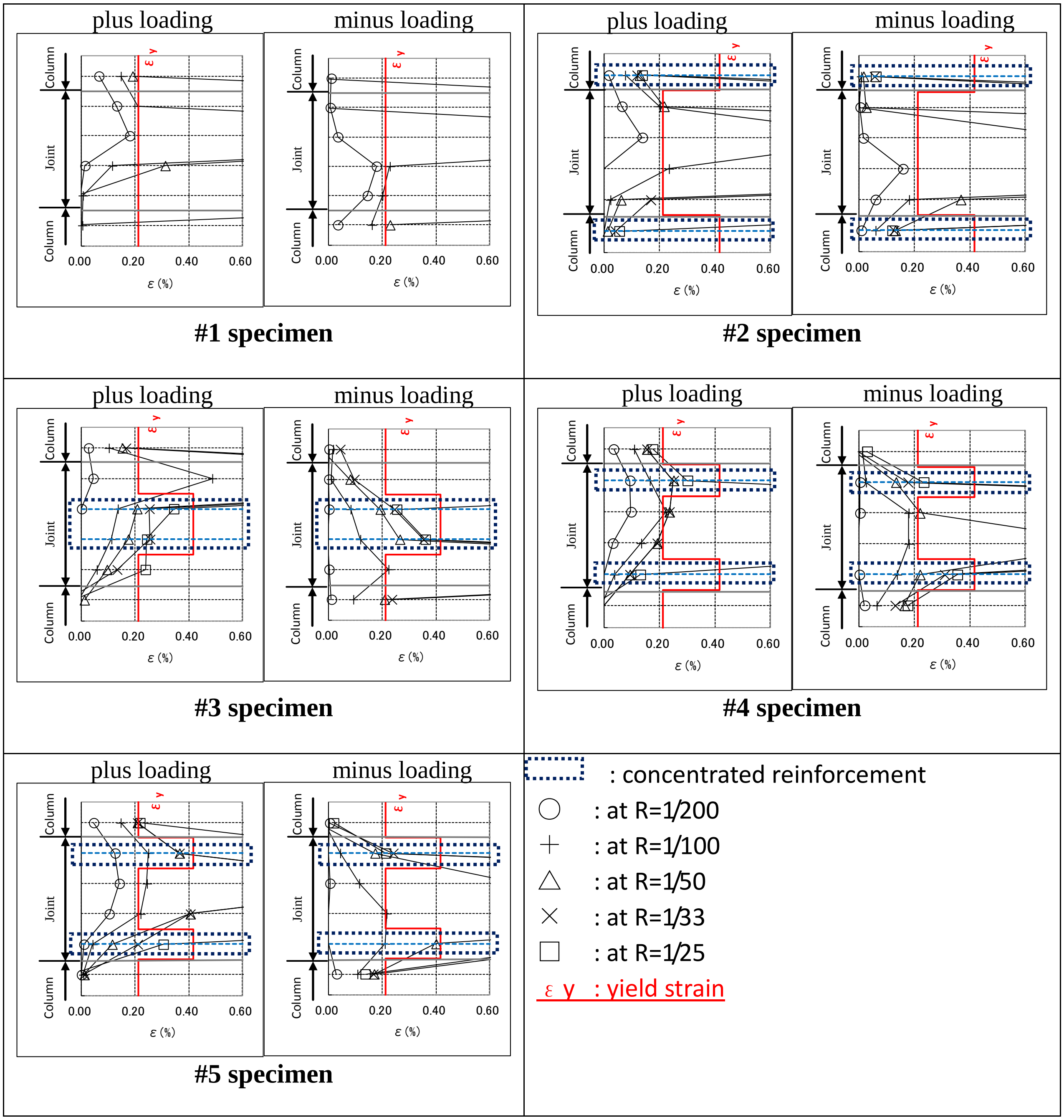


Figure 6 – strain of beam-column joint reinforcement

All the joint reinforcements of #1 yielded by the time when the maximum strength recorded at R=1/50 (rad.). At R=1/33 (rad.), hoops on the outside of the panel (column side) also yielded.

All the joint reinforcements of #2 yielded at R=1/50 as same as #1, but the strain of concentrated reinforcement outside of the joint panel (column side) did not yield until at R=1/25. In addition, because the story shear strength also did not increase more than that of #1, it would be showed that the concentrated reinforcement on the outside of beam main bars was not effective to increase the panel strength.

Concentrated reinforcement at the center of panel of #3 did not yield even at R=1/25. On the other hand, hoops near beam bars yielded at the small story drift angle of R=1/100. Hoops on the outside panel (column side) took the elastic range at R=1/33 and yielded at R=1/25 when the strength decreased.

Most of the joint reinforcements of #4 yielded at R=1/50, but the concentrated reinforcement on the inside of the joint panel and hoops did not yield even at R=1/25. That is, the concentrated joint reinforcement was good for the joint strength effectively.

Although the quantity of concentrated joint reinforcement of #5 was half amount compared with #4, the strain of reinforcement of #5 had the same tendency to #4, and at R=1/33, concentrated reinforcement almost yielded.

Consequently, the horizontal reinforcement at the beam-column joint was effective for increasing the strength of the joint bending failure and anchor failure, and the additional horizontal joint reinforcement near beam longitudinal bars were also very effective for increasing the maximum strength and ductility.

When the strain of horizontal reinforcement in joints was kept in the elastic range, beam main bars yielded certainly and the strength of joint would not be smaller than the expected strength by the design demand. To realize these, concentrated joint reinforcement near beam bars on the inside of panel would be very effective, but not on the outside of panel (column side).

4. Conclusion

Static loading tests of exterior beam-column joint were conducted as parameters of arrangement and quantity of horizontal reinforcement in joint panel. From the results of #1 specimen, after the maximum strength at about story drift of 1/50, the cracks at the beam-column joints expanded and the strength gradually decreased due to the joint bending failure. The horizontal reinforcing effect was largest in the #4, so the maximum strength is improved by about 25%, and it had maintained the strength at the story drift angle of 1/15, also beam bending failure mode was remarkable. The maximum strength of #3 which hoops placed intensively at the center of the joint was equivalent to #4, but the strength decreased remarkably after the maximum strength. The maximum strength of #5 which hoops arranged half volume of #4 was improved by about 10% compared with #1. Strength and ductility of specimen #2 which hoops placed outside of joint (column side) was almost the same as those of specimen #1.

As a result, in case of the damage control at joint and secure of the beam bending, the additional hoops placed into the joint were effective. It was very important for RC structures how arrange and how much the quantity of the joint horizontal reinforcement would be placed.

5. Acknowledgements

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