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DEVELOPMENT OF HOOPS WITH DOUBLE RIGHT ANGLE ANCHORAGE FOR RC COLUMNS

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SUMMARY

In this research a new type of hoop with double right angle anchorage (so-called here double anchorage type hoop) is proposed. To prove the feasibility of this type of hoops an experimental program divided into parts was carried out. First, pullout tests were carried out on bars with double right angle hook, and the results were compared with bars provided with 90° (single hook), 135° and 180° hooks. Results showed that for the double anchorage type, the bars reached the tensile strength indicating that enough anchorage strength was obtained. In the next stage experiments on column elements, reinforced with double anchorage and welded closed type hoops, were carried out. The behavior of the specimens with double anchorage hoops and specimens with welded closed type hoops showed comparable behavior in terms of ductility and ultimate strength.

INTRODUCTION

It is well known that the performance of the columns against earthquake actions improves considerably in terms of ductility, when the lateral reinforcements are placed not only with peripheral hoops but also with inner hoops, as shown in Fig. 1 (a).

Studies on the collapsed buildings after the Kobe Earthquake (Japan, 1995) and recent studies on public buildings to be strengthened, showed the fact that in many cases the required anchorage length (6d, d: bar diameter) for the 135° hooks was not satisfied, indicating problems related with quality control of this type of lateral reinforcement.

The development lengths, required by the Japanese standards [1] [2], are shown in Table 1. The length is changed according to the hook type, 4d for 180° hooks, 6d for 135°, and 10d for 90° hooks. As it can be understood from the table, the given development lengths for conventional bars (390 MPa or bellow) does not depend on the concrete strength in any case. Although the development length of the 135° hook was recommended to be extended to 8d, by the design guidelines based on ultimate strength concepts [3], 6d is the length still used in the normal practice.

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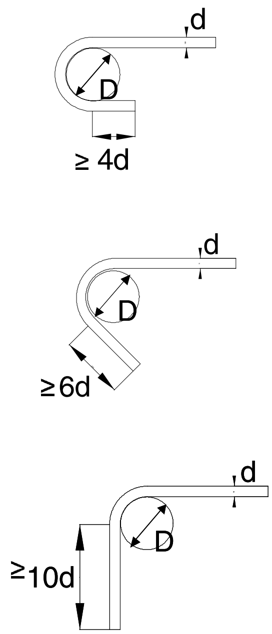
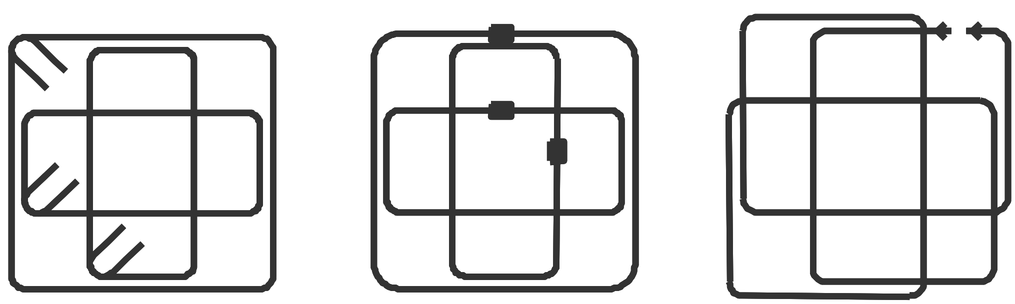
Table 1 Standards for hook bent for hoops

Bent angle	Type	Use	Bar grade	Bar diameter	Bent inner diameter
180° 135° 90°		Hoops Stirrups	SD295A SD295B SD345	≤ D16	≥ 3d
			SD390	≤ D16	≥ 5d



(a) 135º hook type (b) Welded closed type (c) Multi-spiral type

Fig. 1 Conventional lateral reinforcement

Furthermore, in accordance with the reinforcement arrangement regulations, the position of 135°hooks must be shifted for each layer of lateral reinforcement along the column. Therefore, the 135° hooks at the corners make difficult to place concrete and disturb the proper compaction with vibrators at the construction site.

For these reasons, closed welded lateral reinforcements without hooks illustrated in Fig. 1(b) are being used Japan not only for columns subjected to high axial stresses but also especially in Kansai Area (Western Japan) even for low rise buildings. Although the straight extension beyond the bent is not necessary, in this case, problems related to the quality control of welding remain as a weak point, turning to an increase of the construction costs.

The multi-spiral hoops like is shown in Fig. 1(c) are also being used. They have very good structural performance and easier quality control, but present some difficulties in the fabrication process due to the heavy weight of the bar cages and also the strong spring actions that causes torsional deformations.

In this research [4] a new type of hoop with double right angle anchorage (so-called here double anchorage type hoop) as shown in Fig. 2 is proposed. The feature of this lateral reinforcement is that it has a double 90° hooks placed not at the corner but also at the side of the column. By manufacturing the double anchorage type hoops, the problems presented by 135° hooks as well as the expensive welded hoops can be solved. Moreover, the double anchorage method can be adjusted to several configurations of column main bars. One example of a more complicated but possible configuration is shown in Fig. 3.

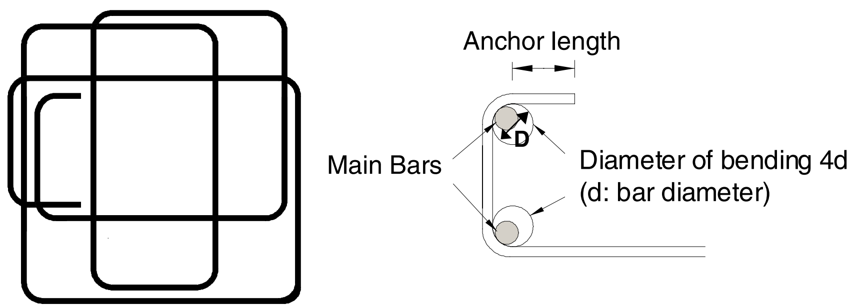


Fig. 2 Detail of double anchorage type hoops

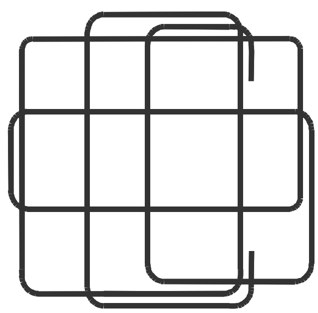


Fig. 3 Example of complicated configuration

EXPERIMENTAL PROGRAM

To verify the structural applicability of the double anchorage hoops two series of experiments were carried out. The first series was aimed to investigate the tensile capacity of the double right angle anchor hook, through pull out tests. Also this part of the investigation was focused on comparing the behavior of the double right angle anchor hook with the 180°, 135°, and 90°, used by the conventional hoops.

The second series was column member testing of 14 specimens, subjected to cyclic bending moments. This series was aimed to compare the behavior of the columns reinforced with the double right angle hoops with those reinforced with welded closed type hoops.

SERIES I - PULLOUT TEST

Specimens

The specimens are shown in Table 2 and Fig. 4. Eight hooked testing bars were anchored in each specimen at 200 mm interval representing the anchor part of the hoops. The testing bars were D13, D10 and D16, with specified yield strength of 390 MPa (Grade SD390), and the concrete strength was 24 MPa.

Closed welded lateral reinforcements with expanded polystyrene inside and plywood on both sides were provided in between testing bars, to minimize the influence of cracks that occurred in testing adjacent testing bars. The concrete was cast from the top in specimens 1 to 3. However, in specimens 11 to 20, each specimen was inverted in order to cast the concrete in the opposite direction.

Specimens No.1, 11, 14, had 8 testing bars with 135°hook, 180°hook and 90°hook. The other specimens had also 8 testing bars with double anchorage. The development lengths were varied as shown in Table 2 and Fig. 5.

Each testing bar was covered with rubber tube up to the beginning point of the first bent hook in order to isolate it from the concrete. M6 (6 mm screwed bar) bar was fixed on each testing bar at the beginning point of the first bent hook.

Table 2 Outline of Specimens (Series I)

Spec.	Bar Diameter	Covering Depth	Anchorage Position	Hook type	Development length (in bar diameters)
1	D13	30 mm	Bottom	135°	n=6, 8
				180°	n=4, 6
				90°	n=6, 8, 10, 12
2				2 x 90°	n=6, 8 m=4, 6, 8, 10
3					n=10, 12 m=4, 6, 8, 10
11	D13	30mm	Top	135	n=6, 8
				180	n=4, 6
				90	n=6, 8, 10, 12
12				2 x 90°	n=6, 8 m=4, 6, 8, 10
13					n=10, 12 m=4, 6, 8, 10
14		0mm		135°	n=6, 8
				180°	n=4, 6
				90°	n=6, 8, 10, 12
15				2 x 90°	n=6, 8 m=4, 6, 8, 10
16					n=10, 12 m=4, 6, 8, 10
17	D10	30mm			n=6, 8 m=4, 6, 8, 10
18					n=10, 12 m=4, 6, 8, 10
19	D16				n=6, 8 m=4, 6, 8, 10
20					n=10, 12 m=4, 6, 8, 10

In case of double anchor hooks:
n= middle development length and m: end development length

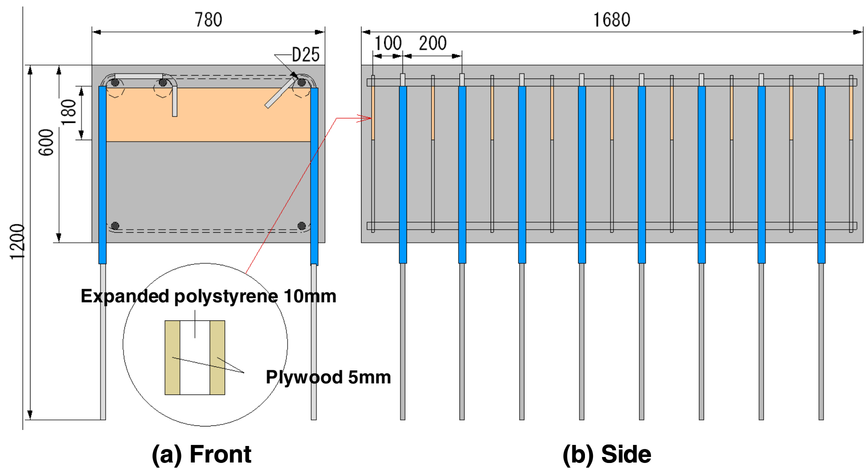


Fig. 4 Specimen

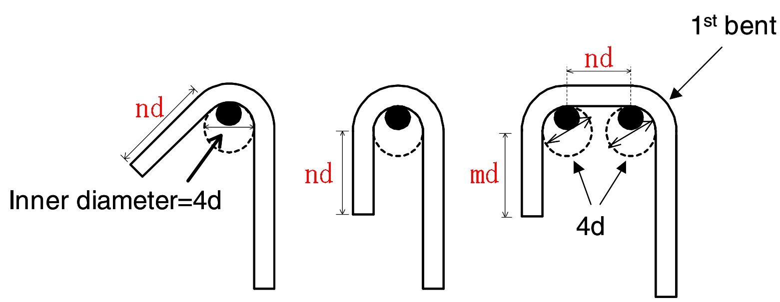


Fig. 5 Anchorage Development Details

Loading System and Instrumentation

The loading system and measuring devices are shown in Fig. 6. The specimens were laid down on one of its sides by turning 90° from the casting position. Each testing bar was subjected to a monotonic pull out load using a center hole jack. Load, displacement of anchorage reinforcement at the first bent hook, and strains around bent hooks were measured.

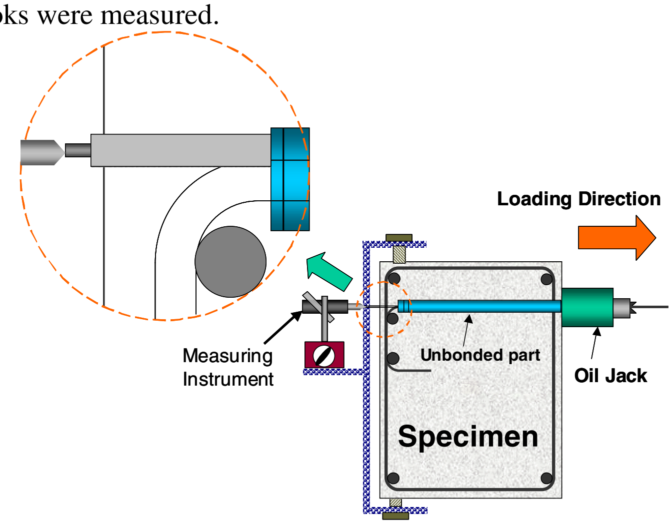


Fig. 6 Loading system

The displacement was measured at M6 bar from the backside of each specimen. Strains were recorded in 4 points (beginning point, inner and outer faces of middle point and end point of bent hook). The progress of failure was observed at the backside of each specimen

Material Characteristics

The material test results are shown in Table 3. The strength of reinforcements and concrete were higher than the specified values.

Table 3 Material Test Results

(a) Concrete

Spec.	Comp. Strength MPa	E GPa	Tensile Strength MPa
1-3	23.6	19.1	2.22
11-15	19.5	18.6	1.65
16-20	20.4	21.6	1.89

(b) Steel bars (SD390)

Diam.	Yield Strength MPa	Yield Strains μ	Tensile Strength MPa	E GPa	Elong. %
D13	491	4580	658	193	12
D10	444	4233	706	210	16.6
D16	434	4042	651	208	20.0

TEST RESULTS-SERIES I

Final Failure Patterns

In the case testing bars with 90° hooks, cone type crushing of cover concrete occurred. In the case of double anchorage type there were no cracks at the backside of the specimens. Even if the casting direction was changed, from the top or from the bottom, there was no difference in crack patterns.

Maximum Strength

The maximum strengths and types of failure are shown in Tables 4 and 5. The values indicated in the Tables are the differences between the material test results for tensile strength taken as 100 percent and the maximum strengths. The symbol ● represents the rupture in the straight unbonded part, while symbol ○ is for rupture in the bent hook. Symbol ∇ means failure when the hooked portion came out of concrete without rupture, and symbol x denotes cone type crushing of cover concrete.

Table 4 Conventional hooks types

anchor length \ type of hook	90°		135°		180°	
n=4	-	-	-	-	○	-2.7
n=6	x	-25.2	∇	-8.3	●	-0.01
n=8	x	-12.9	●	-1.0	-	-
n=10	x	1.7	-	-	-	-
n=12	●	1.0	-	-	-	-

Table 5 Double anchorage hooks

Pos.	Bottom anchorage								Top anchorage							
Anchor Length	m=4		m=6		m=8		m=10		m=4		m=6		m=8		m=10	
n=6	●	2.3	●	1.3	●	1.3	●	2.3	●	1.3	●	1.2	○	-2.0	●	0.5
n=8	●	1.9	●	2.3	●	0.1	○	1.4	●	2.2	○	-4.0	●	-0.4	○	-1.8
n=10	●	1.7	●	1.6	●	1.7	●	1.0	●	1.3	●	1.5	●	2.0	●	1.9
n=12	●	1.3	●	0.8	●	0.2	●	1.0	●	1.6	●	-0.7	○	0.0	●	2.0

The relations between maximum strengths and total anchorage lengths for D13 bars are shown in Fig. 7. Upper and lower broken lines were drawn to show the tensile stress and yield stress, respectively. The total anchorage length includes the bonded length and the bent hooks. The definition of the total anchor length is shown in Fig. 8.

In case of bottom anchorage with conventional hooks the tensile strength was only reached when the total anchorage length was more that 180 mm (14d). For the bottom anchorage, among the reinforcements with conventional hooks only those with 180 mm reached the yield strength. On the other hand for the double anchorage hooks the tensile strength was reached in almost all cases regardless of the position and anchorage length.

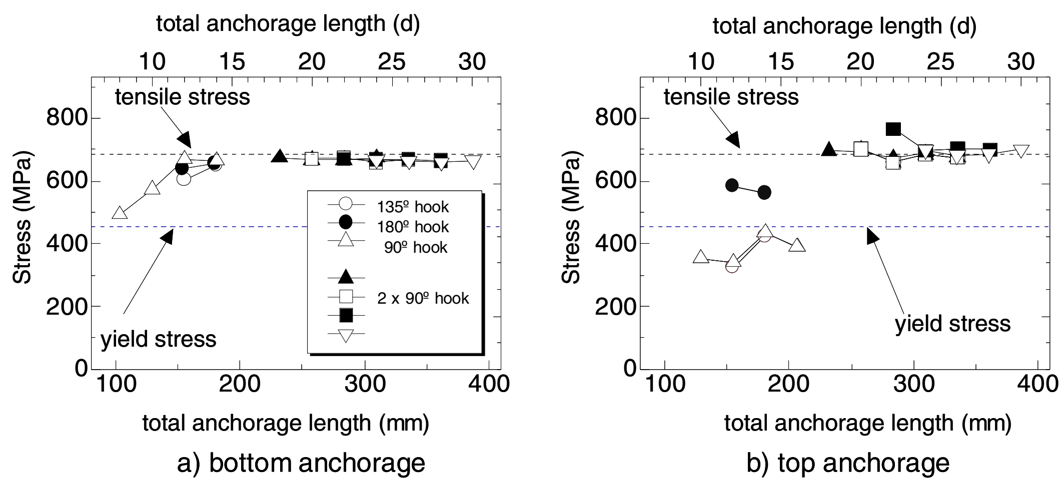


Fig. 7 Relation between maximum strength and total anchorage length

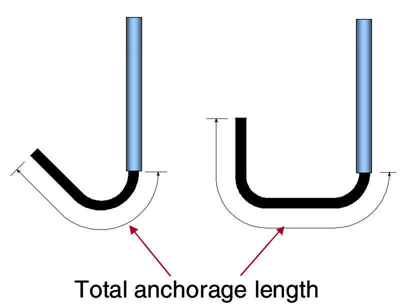
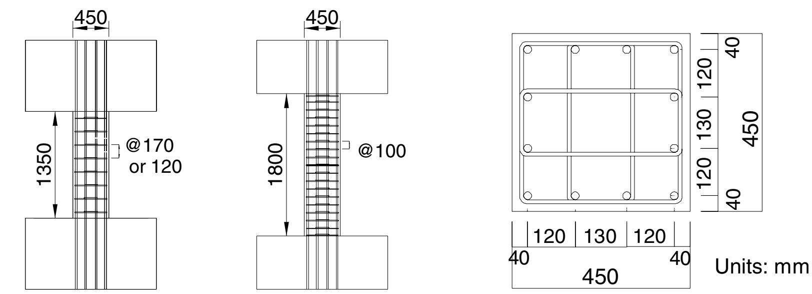


Fig. 8 Definition of the total anchor length

SERIES II – COLUMN TEST

Specimens

The specimens are listed in Table 6 and the typical specimens are shown in Fig. 9. For this experiment 24 MPa and 36 MPa were selected for the specified concrete strength (Fc). Among the tested specimens, 5 of them were designed to have bending failure type, and the remaining 9 specimens to have shear failure type. The column section was 450 x 450 mm, and the height was 1800 mm for the bending failure type and 1350 mm for the shear failure type. For the lateral reinforcement, bars of 10 mm diameter and yield strength of 390MPa were used. Welded closed type hoops, double anchorage type hoops, with the anchor length of the hook of 40 mm and 100 mm were selected for this experiment. The test results of the materials used for the experiment are listed in Table 7.



(a) Shear Failure (b) Bending Failure (c) Column Section

Fig. 9 Typical specimen

Table 6 Test Specimens

Spec.	Failure Mode	Main Bars	Lateral Reinforcement Spacing	Lateral Reinforcement Anchorage Type	Lat. Reinf Ratio p_w (%)	Axial Load Ratio η	Concrete Strength (MPa)
C1W	BFT	D19 SD345	100 mm	WCT	0.63	0.15	24
C1S				40 mm			
C1L				100 mm			
C2W	SFT	D19 SD685	170 mm	WCT	0.37		
C2S				40 mm			
C2L				100 mm			
C5W	BFT	D22 SD345	100 mm	WCT	0.63	0.25	36
C5S				40 mm			
C6W	SFT	D22 SD685	170 mm	WCT	0.37	0.1	
C6S				40 mm			
C7W			120 mm	WCT	0.53		
C7S				40 mm			
C8W			170 mm	WCT	0.37	0.25	
C8S				40 mm			

WCT: Welded Closed Type Hoop, Section: 450 x 450mm, Hoops: D10 (SD390)
S: double anchorage bar with anchor length of 40 mm
L: double anchorage bar with anchor length of 100 mm
BFT: Bending Failure Type SFT: Shear Failure Type

Table 7 Materials

(a) Concrete

Spec.	Fc MPa	σ_B MPa	σ_t MPa	E GPa
C1, C2	24	28.7	2.6	24.3
C5-C8	36	36.7	3.0	27.8

Fc: Specified strength, σ_B: Compressive Strength
σ_t: Splitting Strength, E: Young's Modulus

(b) Steel bars

Size	Grade	σ_y MPa	σ_t MPa	Comments
D19	SD345	401	562	C1 (main bar, BFT)
D22		400	527	C5 (main bar, BFT)
D19	SD685	732	946	C2 (main bar, SFT)
D22		722	930	C6-C8 (main bar, SFT)
D10	SD390	444	656	C1-C2 (lateral reinf.)
		431	549	C5-C8 (lateral reinf.)

σ_y: Yielding Strength, σ_t: Tensile Strength

Loading System

Each specimen was set under the loading apparatus shown in Fig. 10. The specimens were subjected to varying shear forces that were applied cyclically to produce anti-symmetric bending moment distribution while being acted upon by a constant axial load. The loading history was controlled in terms of lateral drift angle as shown in Fig. 11. The lateral drift angle R is defined as the relative displacement (δ) between the lower and upper stubs divided by height (h) of test portion ($R=\delta/h$). For specimens with shear failure type the applied loading history was once at R=1/800, then twice at 1/400, 1/200, 1/100, 1/50, 1/25. For the specimens with bending failure type the loading was furthermore extended once to R=1/16.

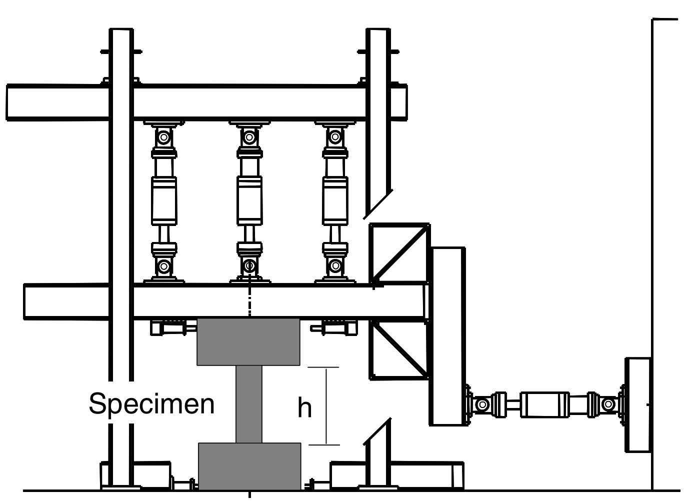


Fig. 10 Loading system

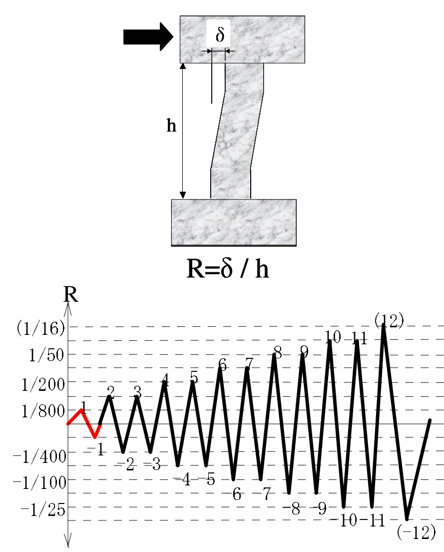


Fig.11 Loading history

TEST RESULTS

Crack Pattern

Figure 12 shows the typical crack patterns for bending failure type and shear failure type specimens at a drift angle of R=1/100 and 1/25, respectively. For all the specimens, the initial flexural cracks took place at the column ends when the drift angle was R=1/800. For bending failure type specimens, as the imposed deformation was increased, cracks developed wider, and crashing of concrete at the column compression side was observed at R=1/25, following remarkable concrete spalling off.

On the other hand, shear failure type specimens, small cracks developed at the central part of the column at R=1/200, then a big diagonal shear crack developed at R=1/100. Bond splitting cracks were observed along the 1st layer of main bars when the drift angle was R=1/50. Considering the comparison between the anchor methods of the lateral reinforcements, no differences were observed on the crack patterns among specimens with the same amount of reinforcement (p_w).

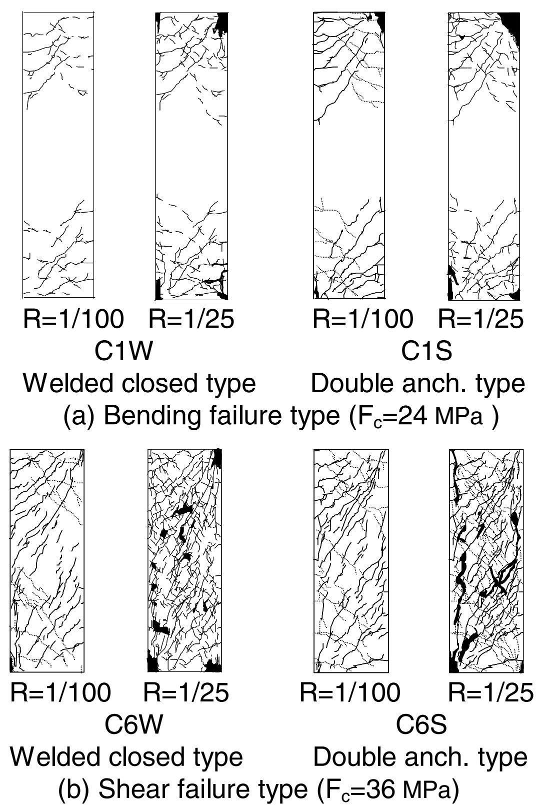
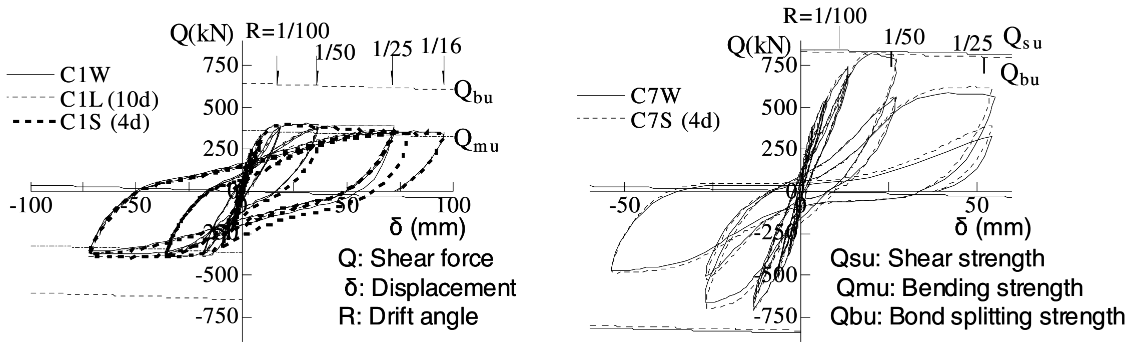


Fig. 12 Crack patterns

Load Displacement

The load-displacement relationships are shown in Fig. 13 (a) and (b), for specimens with bending failure type and shear failure type, respectively. The flexural strength (Q_{mu}), in terms of shear force, was calculated using the formulation given by the Building Center of Japan (BCJ) [5], the shear strength (Q_{su}) by so called Method A of the Architectural Institute of Japan (AIJ) [3], and the bond strength (Q_{bu}) by Kaku's Equation [6].

The P-δ effect due to the axial load is considered in the calculations of the ultimate strengths plotted in the figures. Considering the differences between the anchorage method and the anchor length, no differences were observed among the specimens with the same failure pattern.

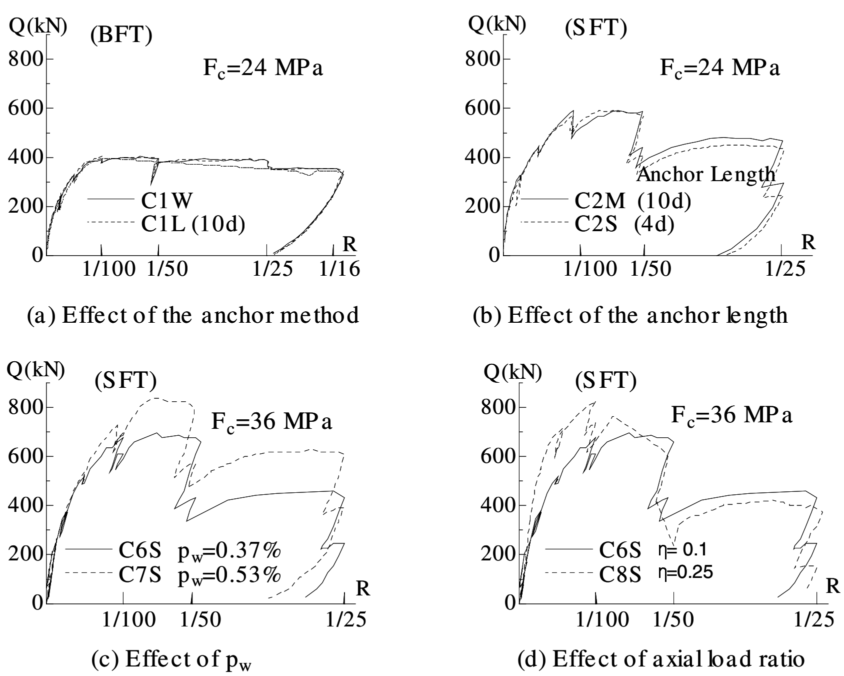


(a) Bending failure type (Fc=24 MPa) (b) Shear failure type (Fc=36 MPa)

Fig. 13 Load displacement curves

Envelope Curves

The envelope curves of the load displacement hysteresis loops are shown in Fig. 14. Comparison of the envelope curves of bending failure type showed no differences on the overall behavior between specimens with welded closed type hoops and those with the double anchorage type hoops.



(a) Effect of the anchor method (b) Effect of the anchor length

(c) Effect of p_w (d) Effect of axial load ratio

Fig. 14 Envelope curves

Among the shear failure type specimens with double anchorage type hoops, the influence of the anchor length, the lateral reinforcement ratio p_w and the axial load effect were compared. Test results showed no influence of the variation of the anchor length, and proved that 4d is enough to anchor the end of hoops.

The test results also showed that maximum strength increased as the lateral reinforcement (p_w) and the axial load ratio (η) were increased. However, for deformations beyond R=1/50 when a large axial forces are applied, remarkable strength decay was observed as shown in Fig. 14 (d).

Strain Distribution

Strain development of the lateral reinforcement

The position of the strain gauges for lateral reinforcement is shown in Fig. 15. For bending failure type, they were placed on four layers of hoops at both sides of the column. For the shear failure type they were placed on four layers of hoops in the middle height of the column.

The gauges (1~4) were positioned to measure strains in the loading direction. Because for each of the positions (1) and (4) there is one gauge belonging to the outer hoop (a) and another for inner hoop (b), the average strain was considered as the strain value for that position. Then the average value for the positions 1 to 4 was calculated as the strain value for each of the four layers where the strains were measured. Lastly, the average strain for each column was calculated considering the average strain of each layer.

The development of strains on the lateral reinforcement was plotted for each drift angle as shown in Fig. 16. For bending failure type specimens with concrete strength Fc=36 MPa, the lateral reinforcement yielded at R=1/25. The double anchorage hoops presented strain development comparable to those obtained for the welded closed hoops, presenting also adequate anchor strength.

Concerning to the shear failure type, the lateral reinforcement yielded at R=1/100. Specimens C6 (p_w=0.37%) and C7 (p_w=0.53%) presented almost the same strain distribution progress in spite of the differences on the lateral reinforcement ratio.

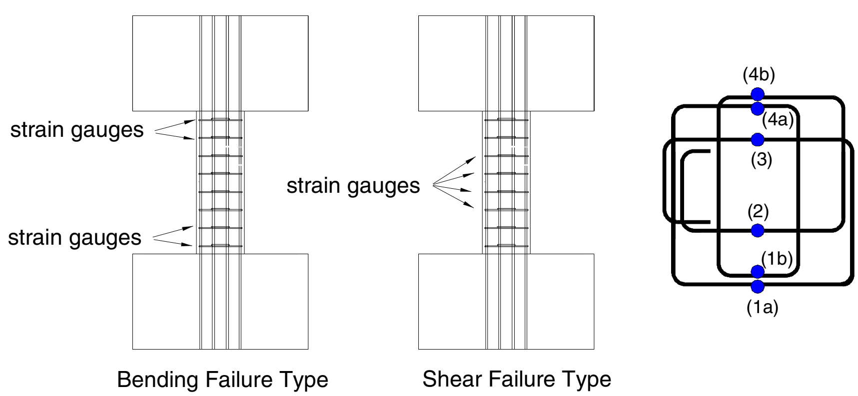


Fig. 15 Strain gauge for lateral reinforcement

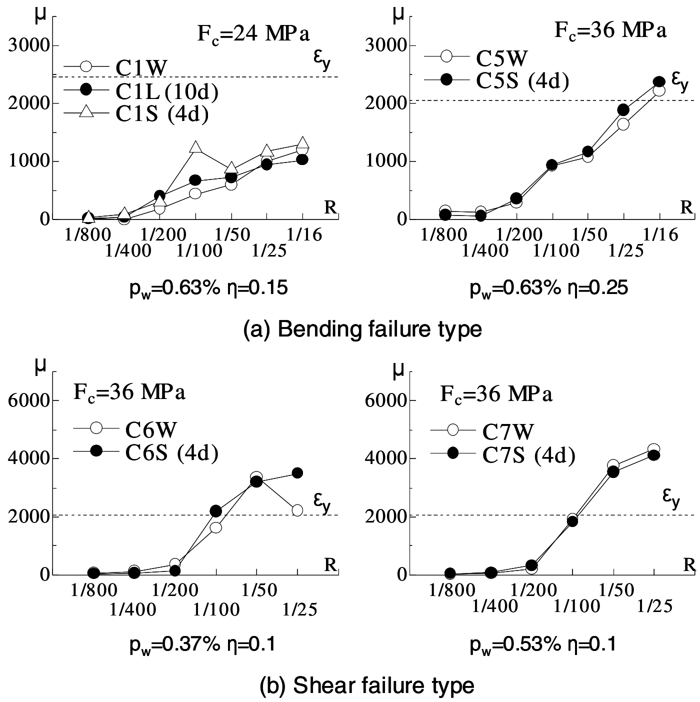


Fig. 16 Strain developments of lateral reinforcement

Strain distribution of the anchor end

The position of the strain gauges on the anchor part of the lateral reinforcement is shown in Fig. 17. The strain distribution of the anchor part for each lateral drift angle is shown in Fig. 18. The values plotted in the figure represent the average values of 4 layers of hoops with 2 strain gauges for each layer.

For bending failure type specimens C1 (Fc=24 MPa) the anchor part of lateral reinforcement did not yield, however for specimens C5 (Fc=24 MPa) the anchor part yielded at R=1/25.The shear failure type specimens either with welded closed type hoops or double anchorage types hoops presented very similar distribution, with bigger strain values at the center of the column (i) and at the start of bent (h), compared with those recorded for the anchor end (g).

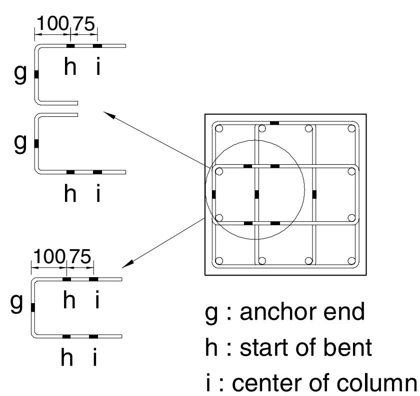
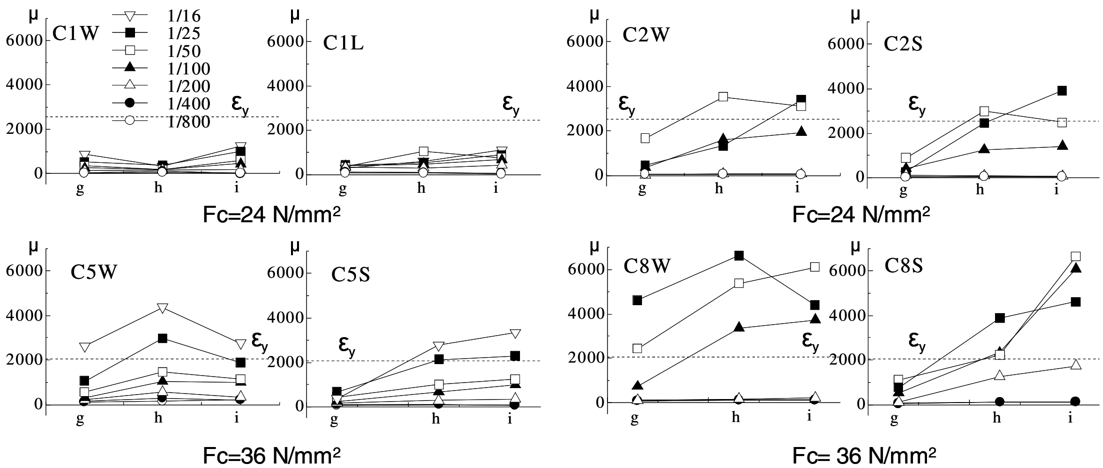


Fig. 17 Positions of the gauges on the anchor ends



(a) Bending failure type

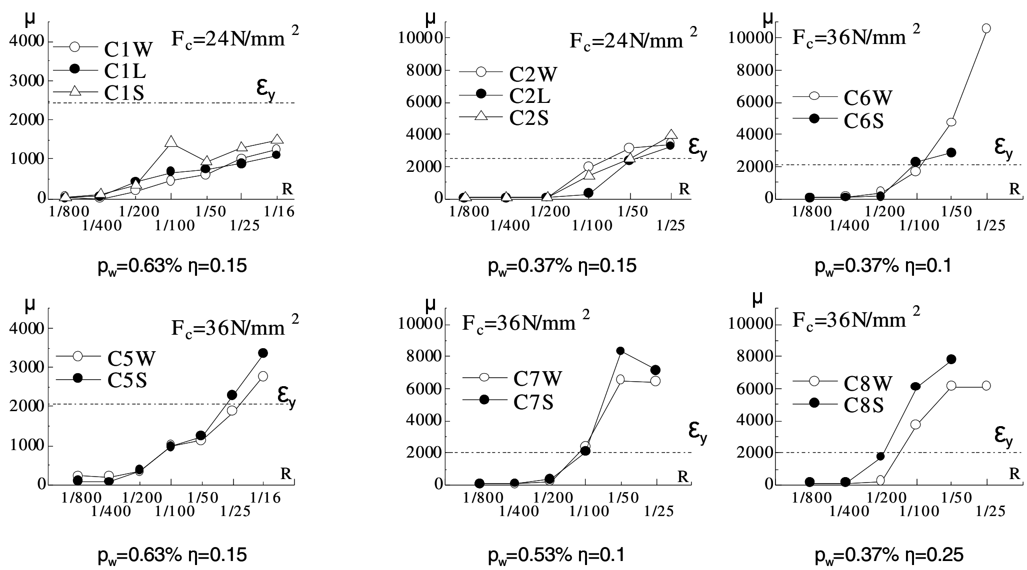
(b) Shear failure type

Fig. 18 Strain distribution of anchor end

Strain distribution at the anchor part

The strain development at the center of the column (**i**) is shown in Fig. 19. The values plotted in the figure are the average of the strains obtained by the strain gauges placed on four layers of hoops.

Until R=1/200 the strains were very small. After that due to the propagation of concrete cracks, the strains also increased remarkably. For shear failure type specimens the strains increased remarkably even after the specimens reached the ultimate shear strength at R=1/100. Specimens reinforced with the double anchorage type hoops showed adequate anchorage strength.



(a) Bending failure type

(b) Shear failure type

Fig. 19 Strain progress of lateral reinforcement

CONCLUSIONS

The following conclusions are deduced from the experimental results:

Series I - Pullout Test

- In case of the upper reinforcements with conventional hooks, the yielding strength was not reached, except for the 180° hooks. In the case of the double anchorage hooks the tensile strength was reached in all the cases regardless of the anchor length.
- The conventional hooks are affected by the casting direction, but the double anchorage hooks are not affected by the casting direction in almost all cases.

Series II - Column Test

- Bending failure type and shear failure type specimens either with welded closed type or double anchorage type of lateral reinforcement showed a comparable seismic performance.
- Double anchorage type of lateral reinforcement with an anchor length of 40 mm showed enough anchor strength for normal strength ($\sigma_y \leq 390$ MPa) and provided enough confinement even under high axial force.
- When the lateral reinforcement ratio p_w becomes bigger, under the same axial force, the shear force resisted by the truss mechanism becomes bigger. Under large axial loads the resisting component of the shear force carried by the arch mechanism becomes greater. In addition the ultimate shear capacity of the column increases with the increment of the lateral reinforcement ratio and the axial load ratio (N/ b D Fc).

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