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Effect of Anchorage on Strength of Precast R/C Beam-Column Joints

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Abstract

Recently, there is a great demand for precast reinforced concrete (RC) construction methods on the purpose of simplicity in construction. Nishimatsu Construction Company has developed a construction method with precast reinforced concrete members in medium-rise building. In this construction method, how to joint precast members, especially the anchorage of the main bar of beam, is important problem.
In this study, the structural performance of exterior joints with precast members was investigated. The parameters of the test specimens are anchorage type of the main bar of beam (U-shape anchorage or anchorage plate) and the ratio of the column axial force to the column strength. Specimens J-3 and J-4 used U-shape anchorage and the ratio of the column axial force of specimen J-4 was higher. On the other hand, specimens J-5 and J-6 used anchorage plate, and the anchorage lengths are 15d and 18d, respectively.
Experimental results are summarized as follows; 1) For the joints with beam flexural failure mode, it was found that the maximum strength of specimen with anchorage plate is equal to or larger than that of specimen with conventional U-shaped anchorage if the anchorage length of more than 15d would be ensured. 2) Each specimen shows stable hysteretic curves and there were no notable effects on the hysteretic characteristics and the maximum strength caused by the anchorage method of beam main bar and the difference of column axial stress level.

Keywords: anchorage method, exterior joints, precast RC

1. INTRODUCTION

Recently, there is a great demand for precast RC construction methods on the purpose of simplicity in construction. Nishimatsu Construction Company has developed a construction method with precast reinforced concrete members in medium-rise building and the structural performance of precast beam or column was examined (Iizuka, S. et al., 1995; Iizuka, S. et al., 1997).

In the previous study, the strength of precast column is equal to or larger than that of column casted in the field (for example, Okamoto, M. et al, 1997). For a precast or half-precast beam, there were many experiments and they showed a good structural performance (for example, Hayashi, S. et al, 1996). However, There is little information about the effect of anchorage on strength and deformation of precast beam column joints.

In this construction method, how to joint precast members, especially the anchorage of the main bar of beam, is important problem. Usually, through joint method for the upper bar and bending method to the column for the bottom bar are used in the interior precast beam column joints (Matsumoto, T. et al, 1997). However, in the exterior joints, using anchorage plate is a general practice.

In this study, the structural performance of exterior joints with precast members was investigated. The parameters of the test specimens are anchorage methods of the main bar of beam (U-shape anchorage and anchorage plate), and the ratio of the column axial force to the column strength (0.1 and 0.4). The purpose of this study is to investigate the structural performance of exterior precast beam column joints with U-shape anchorage and anchorage plate.

2. OUTLINE OF EXPERIMENTS

2.1 Test Specimens

Table 1 shows the properties of the four specimens, which are designed to have flexural failure mode. The test parameters are anchorage methods and the ratio of the column axial force to the column strength.

Fig.1 shows the shape of the specimens J-3 and J-4. The span and story height are 3.5m and 2m which are about half scale of real building (the size of the specimen is 2257.5mm in length and 1530mm in height). The beam and column are precast RC members and only the concrete in the joint and the upper part of the beam was cast in the field. Specimens J-3 and J-4 used U-shape anchorage and the ratio of the column axial force of specimen J-4 was higher. On the other hand, specimens J-5 and J-6 used anchorage plate, and the anchorage lengths are 15d and 18d, respectively. For the splice of the column bars, the NMB splice sleeve whose inside space was filled with non-contraction grout mortar was used. The lap space of 10mm in depth between column bottom line and the slab surface line is also filled with non-contraction grout mortar. In Table 1, the comparisons of the calculated maximum strengths of each member are also shown to confirm the assumed failure mode.

The size of anchorage plate used for J-5 and J-6 is 50x50x12mm, which is designed not to obstruct reinforcements. The main bars of the beam were welded to the anchorage plate. The material properties are shown in Table 2. As shown in Fig.1, D19 (SD390) was used for main bar, and for stirrup 4-S10 @100 were used in column and 2-S10 @100 were used in beam.

2.2 Loading Method and Measurement

Table 1. Properties of Specimens

Specimen	J-3	J-4	J-5	J-6
Anchorage method	U-shaped		Anchorage plate	
Ratio of axial force	0.1	0.4	0.1	0.1
Column	Main bar: 16-D19, Stirrup: 4-S10 @100			
Beam	Main bar: 4-D19, Stirrup: 2-S10 @100			
Anchorage length	19.7d		15d	18d
Size	L = 2257.5mm, H=1530mm			
Failure mode	Beam flexural failure			
$_bQ_{su}/{_bQ_{mu}}$ [1)]	2.84	2.80	2.83	2.81
$_cM_{mu}/{_bQ_{mu}}$ [2)]	4.27	6.99	4.32	4.28
$_jQ_{mu}/V_{ju}$ [3)]	0.27	0.27	0.26	0.27

* Design concrete compressive strength: $F_c = 35$ N/mm^2

* Space of column in width to support the precast RC beam: 15mm

1) Ratio of beam shear strength the beam flexural strength

2) Ratio of column flexural strength to beam flexural strength

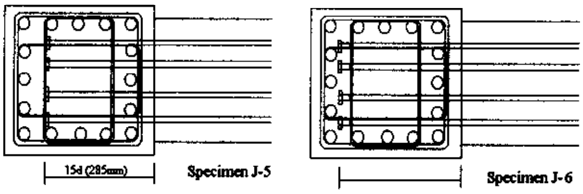
3) Ratio of joint shear strength to joint shear force at initial yielding

where, $_bM_{mu} = 0.9\, a_t \times \sigma_y \times d$, $_cM_{mu} = 0.8\, a_t \times \sigma_y \times D + 0.5ND\,(1 - N/(b \times D \times \sigma_B))$,

$_bQ_{su} = \{0.053\, p_t^{0.23}(180+\sigma_B)/(M/Qd + 0.12) + 2.7\sqrt{(p_w \times \sigma_{wy})}\}\, b \times j$,

$_jQ_{mu} = {_bM_{mu}}/j_b - Q_c$, $V_{ju} = 0.18\sigma_B \times b_j \times D_j$

And these equations are from the code of AIJ (Architectural Institute of Japan).



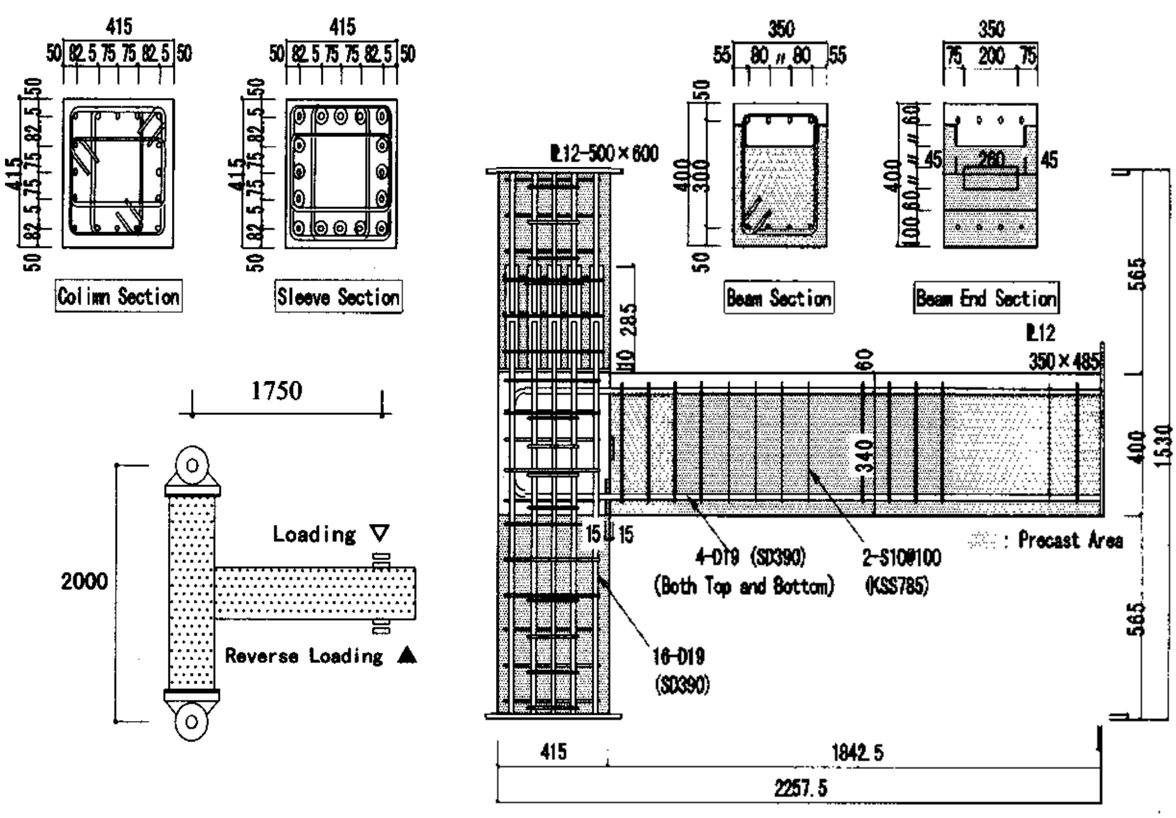


Figure 1. Specimens and Loading Method (Unit : mm)

Table 2. Material Properties (*Unit: N/mm^2)

Reinforcing bar	σ_y*	ε_y(μ)	σ_t*	E_s(x10^5)*
D19	412.5	4154	613.6	1.935
D10	986.4	6961	1072.4	1.988

Specimens	J-3	J-4	J-5	J-6
Precast concrete(MPa)	39.9	37.8	40.6	38.4
Concrete(MPa)	42.9	43.6	44.2	43.6
Grout mortar(MPa)	128.9	133.4	116.3	125.1

Table 3. Experimental Results (reverse loading)

Specimens	J-3	J-4	J-5	J-6
Cracking strength (calculation) (kN)	143.7	234.0	146.5	144.5
Cracking strength (experiments) (kN)	81.6	------	83.9	89.2
Exp. / Cal.	0.57	------	0.57	0.62
$_bQ_{mu}$ (kN)	93.2	93.2	93.2	93.2
Q_{cmax} (kN)	112.0	111.7	113.5	113.3
Q_{cmax} / $_bQ_{mu}$	1.20	1.20	1.22	1.22
$_J\tau_{max}/\sigma_B$	0.09	0.08	0.09	0.09

where, $_J\tau_{sc} = 1.6\sqrt{\sigma_B} \times \sqrt{(1+\sigma_0 / 1.6\sqrt{\sigma_B})}$: cracking of joint, Q_{cmax} = maximum strength
$_bQ_{mu}$ = story shear force at maximum flexural strength of beam
$_J\tau_{max}$ = average stress of joint at maximum strength when effective depth is distance between center of main bar line of the column, and effective width is $(b_B+b_c)/2$
And these equations are from the code of AIJ (Architectural Institute of Japan).

For the loading system, the top and bottom of the column were supported by the pin-rollers. The reversed cyclic lateral force was applied and controlled by the displacement at the end of the beam. The column axial load was kept constant as shown in Fig.1. Loading cycle is controlled by story drift angle (R). Three cycles for R=1/400, 1/200, 1/100, 2/100, 3/100 rad., two cycles for R=4/100 rad., and one cycle for R=5/100 rad. were applied for every specimen. The loading method is shown in Fig.1.

In the tests, the total displacement and shear deformation of the joint, and the flexural deformation of the beam were measured from the measuring frame that is also supported by the pin-rollers to the column ends. The flexural deformation of the beam and the column were measured from the anchor that was set to the concrete of the beam and column. Also, the strains of the main bars and stirrups at severe important location were measured.

3. Outline of the experimental results

3.1 Maximum Strength

The shear cracking strength of the joint and the maximum strength is shown in Table 3 and compared with the calculated results. Except for specimen J-4 under higher axial force, the shear cracking at the joint occurred at the 60% of calculated strength. But, the difference of anchorage method didn't give notable effect to the shear cracking strength.

The maximum strength of each specimen was about 1.2 times the calculated maximum strength. The failure mode of each specimen was beam flexural failure caused by the yielding of main bar and subsequent compressive failure at the end of the beam. Comparing the average stress of joint at maximum strength when divided by concrete compressive strength, the value of each specimen was about 0.09, so there was no notable effect of anchorage method or axial force level to the strength of partial frame with the range of this experiments.

3.2 Hysteretic Characteristics

The story shear force - story drift curve of each specimen is shown in Fig. 2. The dotted line shows the calculated maximum flexural strength of the beam.

After the flexural cracking of the beam occurred at the cycle of R = 1/400 rad., the yielding of beam main bar was occurred near the calculated maximum flexural strength of the beam. The shear cracking of the beam and the joint occurred near the cycle of R = 1/100 rad. The maximum strength appeared at the cycle of R = 4/100 rad., the compressive failure and spalling of concrete at the end of a beam were observed.

The comparison of equivalent viscous damping (H_{eq}) is shown in Fig.3. In each specimen, the value of H_{eq} at the time of R = 1/50 rad. was over 0.13 and ensured the limit condition of bond deterioration in the design guidelines for earthquake resistant reinforced concrete buildings based on ultimate strength concept. H_{eq} of specimen J-5 and specimen J-6 using anchorage plate are larger than that of

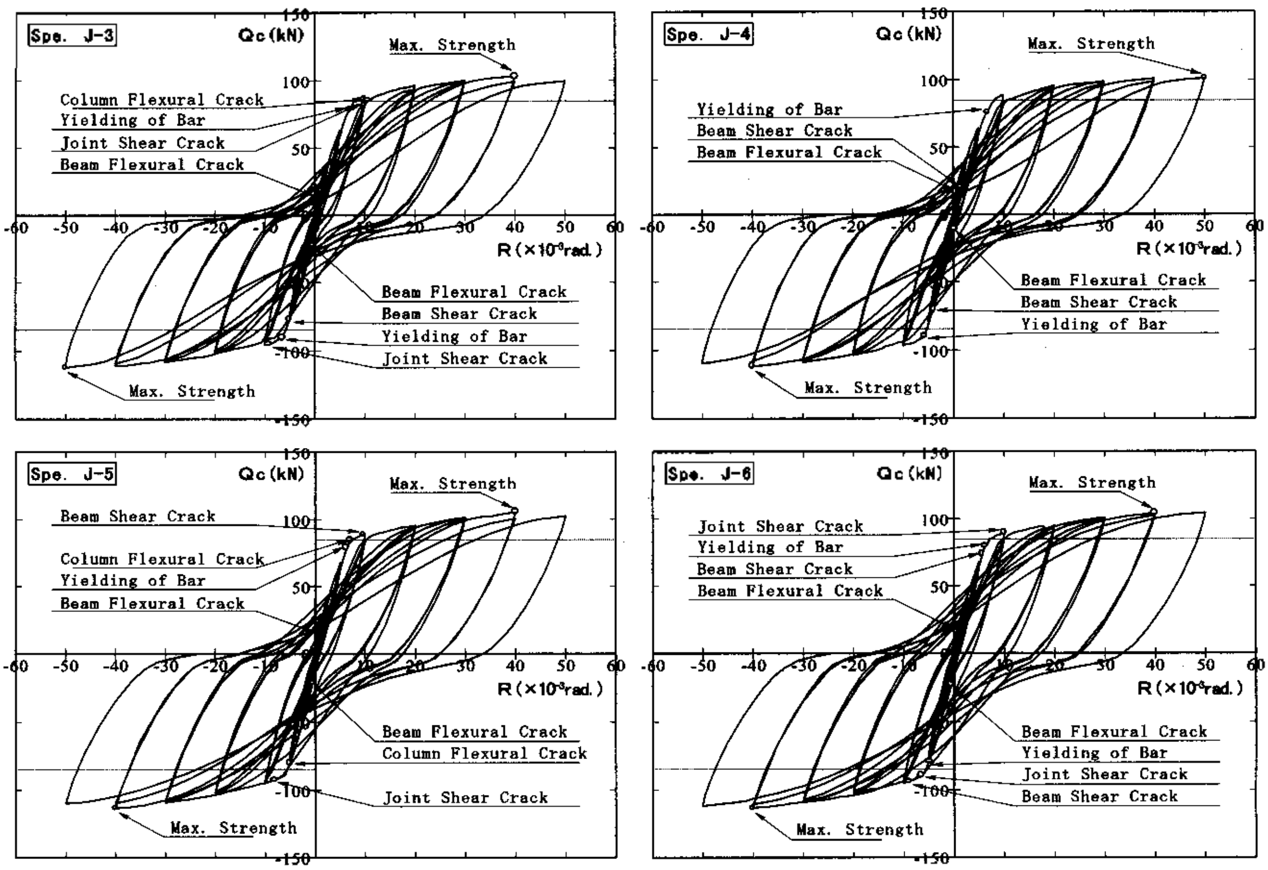


Figure 2. Story Shear Force - Story Drift Curves

specimen J-3 using U-shaped anchorage. This indicates that specimens with anchorage plate have better energy-dissipates capacity than the specimens with U-shaped anchorage. From the comparison of specimen J-3 and J-4, it is also noticed that there was no notable effect caused by the difference of axial stress level.

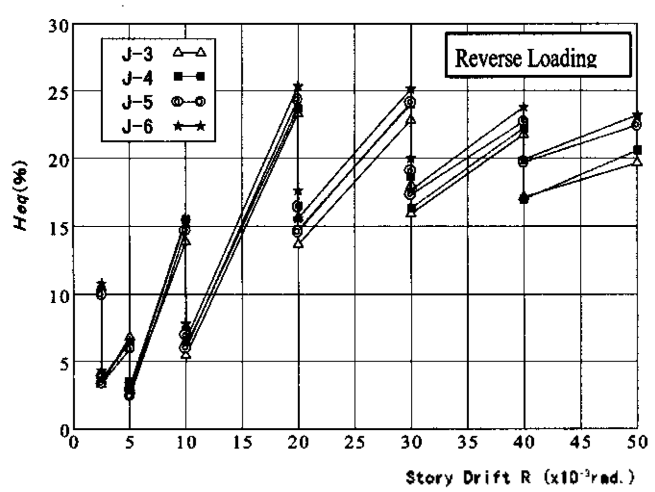


Figure 3. Comparison of Heq

4. EFFECTS ON DEFORMATION OF SUBASSEMBLAGE

Contributions of column, beam, and joint to the total displacement are compared in Fig.4.

In this study, each deformation contribution was calculated under the assumption that the contribution of joint and etc. can be calculated by deducting the flexural contribution of beam and column from the total displacement.

The contribution of beam was over 90% until the cycle of R = 3/100 rad., and the contribution of joint and etc. increased 10% to 20% as the total displacement increases. Especially, this tendency is notable in specimen J-4 with higher axial force and specimen J-5 with short anchorage length, in which the contribution of joint and etc. was large compared to the other specimens. In specimen J-4 with higher axial stress, the contribution of the column was large after the cycle of R = 3/100 rad. compared to the other specimens. This is because the slip of the beam main bar occurred for specimen J-5, and the rotation of the column member due to the concrete compressive failure occurred for specimen J-4. However, from the fact that the ratio of each deformation contribution was similar until the maximum strength except the specimen J-4 with higher axial force, there was no notable effect caused by the anchorage method of beam main bar.

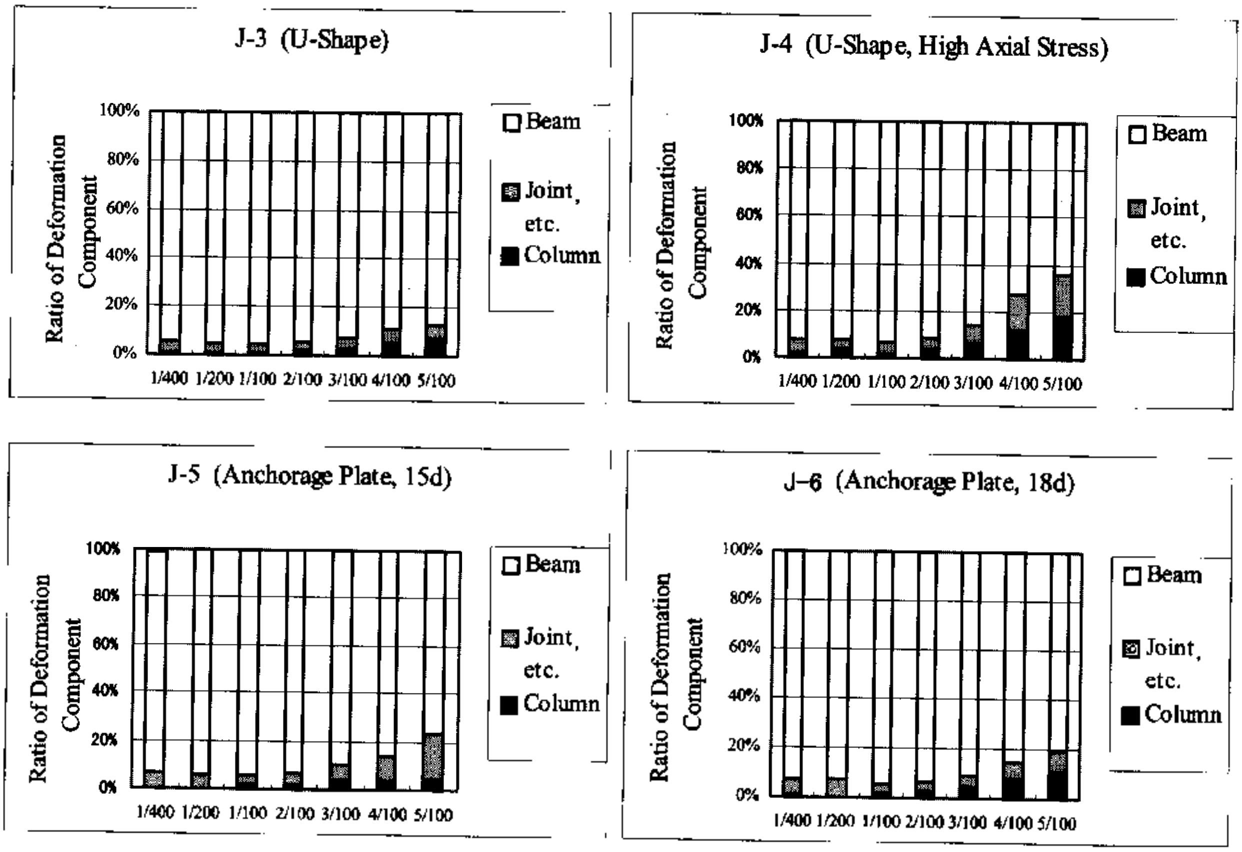


Figure 4. Contributions of Each Element to Total Displacement

5. STRAIN DISTRIBUTION OF MAIN BAR

The strain distribution of beam main bars across the joint cross section is shown in Fig.5.

In each specimen, the main bar yielded on the end of the beam and expected beam flexural caused. In the specimens with U-shaped anchorage, the strain near the U-shaped position is larger than that of the column center, the stress was concentrated near the U-shaped position. On the other hand, in the specimens with anchorage plate, the strain has peak near the end of the beam and decreased to the end of anchorage plate.

In this study, the slip of the beam main bar was not measured directly, but the opening at the end of the beam by the slip after the yielding of main bar was notable. Concerning for the stress concentration and the slip of main bar, the numerical investigations using finite element method would be necessary in the future. However, as mentioned above, there was no notable effect on the hysteretic characteristics or the maximum strength caused by the anchorage method of beam main bar.

6. CONCLUSIONS

In this study, the effect of anchorage method and column axial stress level on the strength and deformation of partial frame were investigated from the tests of exterior joints with precast beam and column.

The main conclusions from this experimental result are summarized as follows;

1) For the joints with beam flexural failure mode, it was found that the maximum strength of specimen with anchorage plate is equal to or larger than that of specimen with conventional U-shaped anchorage if the anchorage length of more than 15d would be ensured.

2) Each specimen shows stable hysteretic curves and there were no notable effects on the hysteretic characteristics and the maximum strength caused by the anchorage method of beam main bar and the difference of column axial stress level.

3) From the examination of the strain distribution of beam main bar in the joint, the stress concentration was appeared near the U-shaped location in the specimens with U-shaped anchorage.

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REFERENCES

Iizuka, S. et al. (1995) "Development of High-Rise Building Construction Method with Precast Reinforced Concrete Members (Part 2 Flexural Test of Beam Members)." *Annual Meeting of AIJ*, Structures C-2 (IV): 423-424. (In Japanese)

Iizuka, S. et al. (1997) "Development of Medium-Rise Building Construction Method with Precast Reinforced Concrete Members (Experiment on Column Members)." *Annual Meeting of AIJ*, Structures C-2 (IV): 145-146. (In Japanese)

Okamoto, M. et al. (1997) "Seismic Loading Test of the Precast RC column." *Proceedings of the Japan Concrete Institute*, Vol.19, No. 2: 1359-1364. (In Japanese)

Hayashi, S. et al. (1996) "Effect of the Joint on the Hysteresis Character of the Precast RC Composite Beam." *Proceedings of the Japan Concrete Institute*, Vol.18, No. 2: 1211-1216. (In Japanese)

Matsumoto, T. et al. (1997) "Effect of Various Beam-Bar Anchorages on Strength and Deformation of Precast R/C Beam-Column Joints." *Proceedings of the Japan Concrete Institute*, Vol.19, No. 2: 1269-1274. (In Japanese)

Architectural Institute of Japan (1990) Design Guidelines for Earthquake Resistant Reinforced Concrete Buildings Based on Ultimate Strength Concept. (In Japanese)

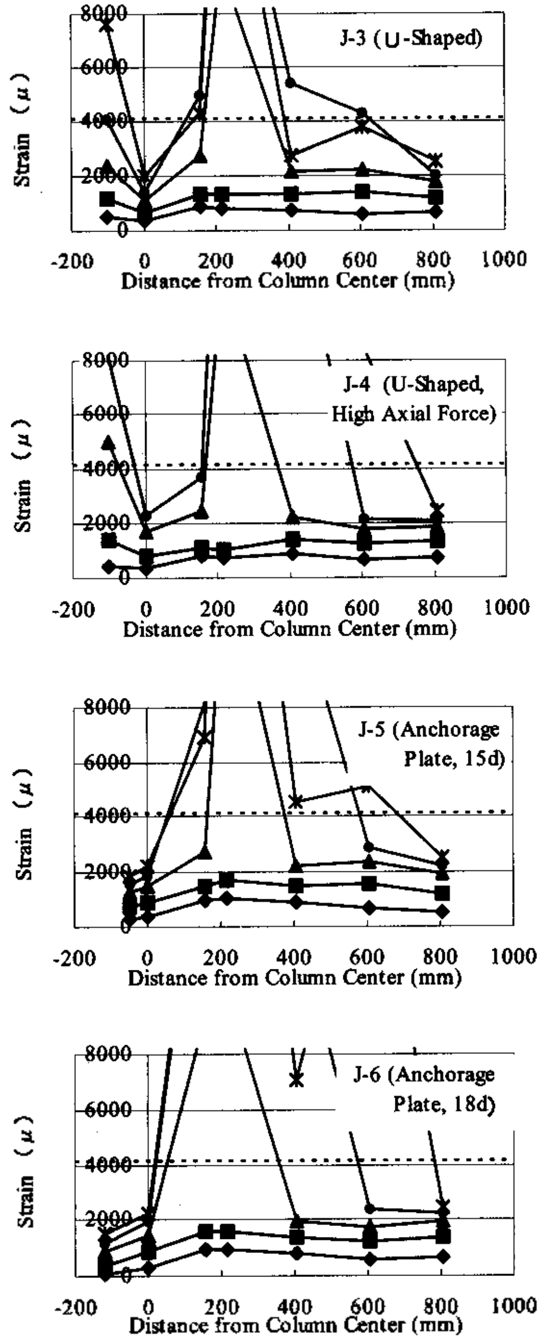

Figure 5. The Strain Distribution of Beam Main Bar and Measuring Location