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Seismic behaviors of beam-column joint of reinforced concrete exterior frame under varying axial load

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ABSTRACT: Presented in this paper is the seismic test result of reinforced concrete beam-column joint of exterior frame. Seven 1/5 scale subassemblages were tested under alternate cyclic loads and axial loads. Column axial loads were constant compression, constant tension and varying from compression to tension. The effects of varying axial load and confinement by transverse beams were mainly discussed from the test results.

1 INTRODUCTION

A reinforced concrete multi-story frame building is generally subjected to bidirectional lateral force during severe earthquake. If earthquake load acts on in plane of exterior frame, the beam-column joints of inner part of exterior frame are subjected to constant axial load. However they are subjected to varying axial load if earthquake load acts on out of plane, especially axial loads for lower story vary from compression to tension.

The object of this study is to investigate the seismic behaviors of beam-column joint of exterior frame under varying axial load.

2 TEST SPECIMENS

Seven 1/5 scale cruciform models were made of subassemblages from lower story of a building. As shown in Fig. 1, three subassemblages consisted of two 12cm by 15cm beams and a 15cm by 15cm square column (isolated joint, J0-type). In addition to beams and columns, two subassemblages were provided a 12cm by 15cm short transverse beam on one side of the beam-column joint (exterior joint, J1-type), and two were also provided them on both sides (interior joint, J2-type). These specimens were classified into three cases according to the applied axial load. A specimen without transverse beam was applied constant compressive axial load, three specimens of each type were applied varying axial load from compression to tension, and remaining three were applied constant tensile axial load. Table 1 shows the variations of the specimens.

The main longitudinal reinforcement of beams consisted of 3-D10 reinforcing bars at the both top and bottom. The column was reinforced longitudinally by 4-D13 bars. Beams, transverse beams and columns were provided 4.1φ stirrups and hoops spaced 40mm, respectively. The beam-column joint was also placed three sets of 4.1φ hoop. Design details of test specimen and properties of concrete and reinforcing bars are shown in Fig. 2 and Table 2, respectively.

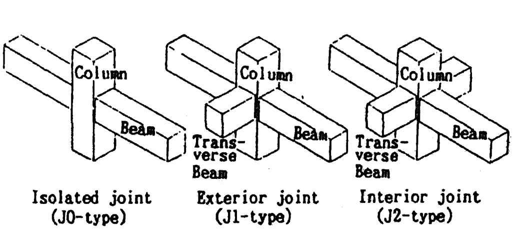


Fig. 1 Type of subassemblages

Table 1 Variations of specimens

name of specimen	transverse beam	type of axial loading	axial load (MPa)
J0C-1	none	constant compression	3.92
J0T-1	none	constant tension	-1.96
J0R-1	none	varying	3.92 (p) -1.96 (n)
J1T-1	one side	constant tension	-1.96
J1R-1	one side	varying	3.92 (p) -1.92 (n)
J2T-1	both sides	constant tension	-1.92 (p)
J2R-1	both sides	varying	3.92 (p) -1.92 (n)

(p):positive cycle (n):negative cycle

3 TEST PROCEDURE

The loading arrangement is schematically shown in Fig. 3.

Alternative cyclic loads were applied at the beam tips by two oil jacks according to the loading history as shown in Fig. 4(a). The transverse beams were not applied any loads. The axial load was applied at the top of column by an oil jack. The constant compressive and tensile axial loads were 91.8KN and -45.9KN, respectively. Varying axial load was applied in proportion to story drift angle. It was varied from compression (up to 91.8KN) at positive cycles to tension (up to -45.9KN) at negative cycles, and was kept constant if story drift angle exceeded 1/30 as shown in Fig. 4(b).

Story drift, beam and column displacement were measured with linear differential transformers (LVDT's) attached on beam and column tips. Joint shear deformation of J0-type specimen was measured with LVDT's. In cases of J1-type and J2-type specimens, they were measured with LVDT's attached at the transverse beam end.

Strains of longitudinal reinforcements, hoops and concrete were measured by wire strain gages.

4 TEST RESULTS AND DISCUSSIONS

The test results obtained from specimens J0C-1, J0R-1, J1R-1 and J2R-1 were described herein and the effects of varying axial load and transverse beam were mainly discussed.

4.1 Crack patterns and failing behaviors

Fig. 5 shows final crack patterns at beam-column joints of each specimen. The crack pattern of J1R-1 is that on the side without transverse beam.

Final crack patterns of specimens J0C-1 and J0R-1 were similar to each other. Namely, diagonal shear cracks occurred on the joint panel at the first loading cycle, and many shear cracks developed in whole region of joint and those widths extended during testing. The covered concrete of joint region crashed and spalled off at following large deflection loading cycles. J0C-1 with constant compression axial load was failed due to joint shear after beam yielding. J0R-1 with varying axial load was failed similar to J0C-1 at positive loading cycle, however it was failed due to joint shear without beam and column yielding at negative loading cycle.

The crack pattern of J1R-1 on the side without transverse beam was similar to those of J0-type specimens. While on the opposite side with transverse beam, shear cracks developed toward four sides of transverse beam end, however their lengths and widths were not so significant. The final failure

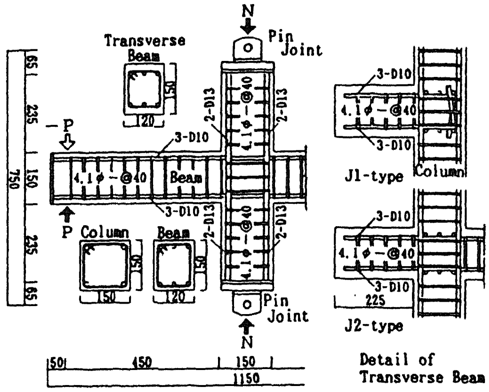


Fig. 2 Details of specimens

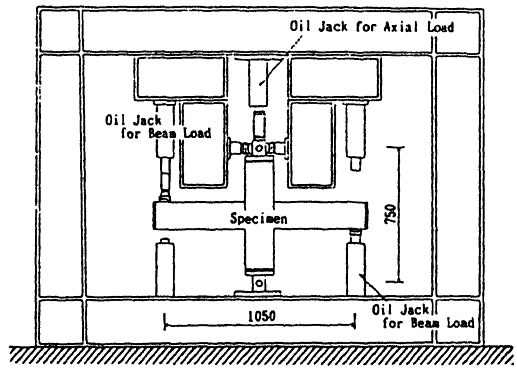
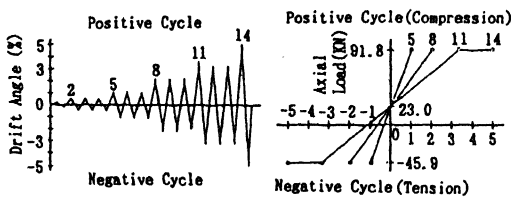


Fig. 3 Loading arrangement



(a) Beam loading (b) Axial loading

Fig. 4 Loading programs

Table 2 Material properties of specimens

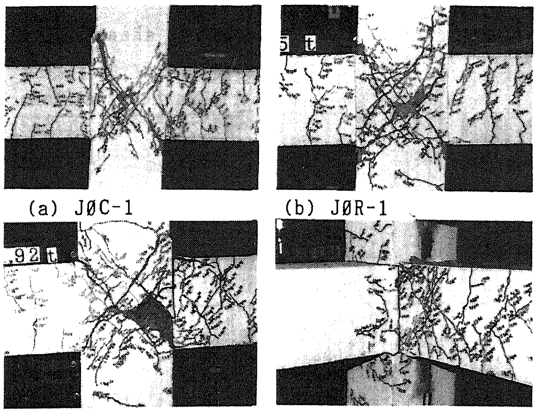
	compressive strength Fc (MPa)	tensile strength Ft (MPa)	Young's modulus E (MPa)
concrete	31.2	2.36	$2.13x10^5$
steel	yield strength σy (MPa)	tensile strength σt (MPa)	elongation (%)
D13	343	495	28.3
D10	340	507	27.8
4.1ϕ	447	508	12.0

of this specimen was joint shear failure after beam and/or column yielding.

The crack pattern of the transverse beams of J2R-1 was similar to J1R-1, and the final failure was flexure failure of beam ends.

4.2 Ultimate strength

Flexural strength of beams and columns and maximum joint shear stress obtained from all specimens are shown in Table 3, respectively. The failure modes of each specimen are



(a) J0C-1 (b) J0R-1 (c) J1R-1 (d) J2R-1

Fig. 5 Final crack patterns

also listed in this table.

The ratios of calculated design yield strength of column to that of beam were 1.8 at 91.8KN compressive axial load and 0.96 at -45.9KN tensile axial load, respectively.

Yield strength of beams and columns of each specimen agreed with those of calculated values, respectively.

Maximum joint shear stresses v_p were between 7.4 and 9.5MPa, and the ratios of v_p to the square root of compressive strength of concrete were between 1.33 and 1.70, respectively. There were not remarkable differences among each specimen because flexure failure occurred at beam and/or column ends before joint shear failure except J0R-1 that failed due to joint shear at negative cycles without flexure failure.

3.3 Hysteretic characteristics

Fig. 6 shows the relations between applied story shear V and story drift angle R.

They indicated the pinched shape and were similar to each other. For three specimens with varying axial load, pinching phenomena at positive cycles were more significant than those at negative cycles. Because axial loads at last cycle were still maintained tension at positive cycles until story drift angle exceeded scheduled story drift angle shown in Fig 4. (b).

Table 3 Test results

name of specimen	yield strength beam[1] test (KN)	beam test/cal.	column[2] test (KN)	column test/cal.	ultimate strength Vmax (KN)	ultimate shear stress of joint v_p[3] (MPa)	$v_p/\sqrt{F_c}$	failure[4] mode
J0C-1 (p)	24.7	0.93	----	----	28.8	8.89	1.59	FS->SP
(n)	24.7	0.93	----	----	26.6	8.22	1.47	FB->SP
J0T-1 (p)	26.9	1.01	27.6	1.07	29.0	8.94	1.60	FC->SP->FB
(n)	25.8	0.96	24.7	0.96	26.8	8.26	1.48	FC->SP->FB
J0R-1 (p)	29.3	1.10	----	----	30.7	9.49	1.70	FB->SP
(n)	----	----	----	----	24.0	7.41	1.33	SP
J1T-1 (p)	29.4	1.10	29.3	1.14	30.4	9.40	1.68	FB->FC
(n)	27.5	1.03	28.6	1.11	29.1	8.98	1.61	FB->FC
J1R-1 (p)	27.8	1.04	----	----	30.4	9.40	1.68	FB->SP
(n)	25.8	0.97	25.5	0.94	26.8	8.26	1.48	FC->FB->SP
J2T-1 (p)	27.2	1.02	26.8	1.04	29.0	8.94	1.60	FC->FB
(n)	27.5	1.03	27.8	1.08	28.4	8.76	1.57	FB->FC
J2R-1 (p)	29.0	1.09	----	----	29.9	9.23	1.65	FB
(n)	26.3	0.99	----	----	27.3	8.43	1.51	FB

1) $M_y=0.9a_t\sigma_y d$

2) $M_y=0.8a_t\sigma_y D+0.5ND(1-N/bDFc)$: compression $M_y=0.8a_t\sigma_y D+0.4ND$: tension

3) $v_p=(2M_b-V_c)/j_b j_c b_p$

where a_t, σ_y: area of longitudinal reinforcement, respectively

D, d: depth and effective depth of beam and column, respectively

j_b, j_c, b_p: lengths of moment arm of beam and column and width of joint, respectively

M_b, V_c: beam end moment and column shear, respectively

4) FB: beam flexure failure FC: column flexure failure SP: joint shear failure

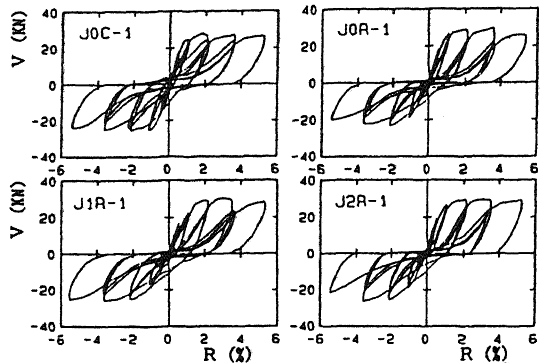


Fig. 6 Story shear V vs. story drift angle R relations

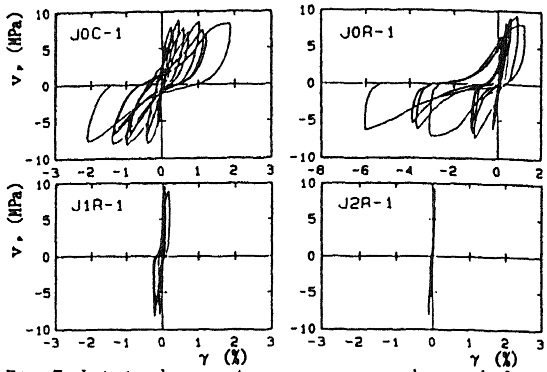


Fig. 7 Joint shear stress v_p vs. shear deformation γ relations

The relations between applied joint shear stress v_p and shear deformation γ are shown in Fig. 7.

Shear deformations from J0C-1 and J0R-1 increased according to loading cycle increased, and reached about 2% because these specimens failed due to joint shear. For specimen J0R-1 at negative cycles it was more than 6%. For J1- and J2-type specimens, shear deformations were less than those from J0-type specimens because they were measured at the transverse beam end. However judging from the final crack pattern as shown in Fig. 5, it seemed that J1R-1 failed due to joint shear.

Fig. 8 shows the beam, column and joint contributions to story drift angle R. Each contribution is expressed as a percentage of total drift angle. For specimen J0C-1, the joint contribution was about 20 to 40% and the largest contribution was by the beams. Joint contribution of J0R-1 at positive cycle was similar to that of J0C-1, while at negative cycle, this contribution increased extremely according to drift angle increased and reached more than 80% at final. Column contribution at negative cycle also increased and beam one decreased in comparison to those of J0C-1 because both joint shear and column flexure failures occurred at negative cycle. For specimens J1R-1 and J2R-1, beam-column joints indicated a few contributions because estimated contributions based on shear deformations measured at transverse beam ends.

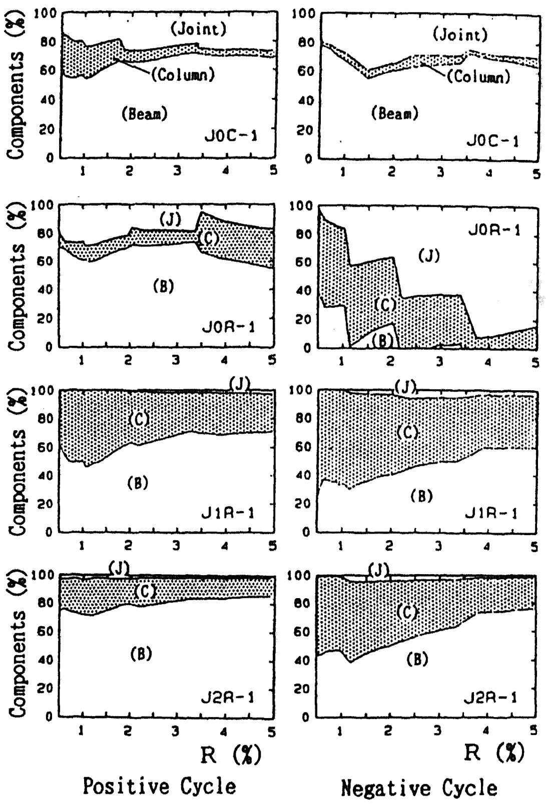


Fig. 8 Components of story drift angle R

5 CONCLUSIONS

The following conclusions may be drawn from the test results:

(1) The maximum joint shear stresses were between 1.33 and 1.70 times of the square root of concrete compressive strength.

(2) Seismic behaviors of specimens with varying axial load were inferior to those of specimens with constant axial load.

(3) The transverse beams provided on both sides improved seismic behaviors of beam-column joint, however the transverse beam provided on one side did not improve them.

REFERENCES

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