BLIND ANALYSIS OF RC BEAM-COLUMN JOINTS SUBJECTED TO MULTI-AXIAL COMBINED LOADINGS USING 3D NONLINEAR FEM

T. Kashiwazaki[1] and H. Noguchi[2]

[1] *Assistant Professor, Div. of Archit. and Urban Sci., Graduate School of Engrg., Chiba Univ., Chiba, Japan*
[2] *Professor, Div. of Archit. and Urban Sci., Graduate School of Engrg., Chiba Univ., Chiba, Japan*
Email: kashiwa@faculty.chiba-u.jp

ABSTRACT :

In Reinforced Concrete structures, beam-column joints are important structural member which translate stress between adjacent beams and columns. In this study, blind analysis of beam-column joints subjected to multi-axial combined loadings was carried out using three-dimensional (3D) nonlinear FEM. From analytical results of beam-column joints subjected to multi-axial loadings, hysteresis characteristics and failure modes are investigated.

KEYWORDS: reinforced concrete, beam-column joint, 3D nonlinear FEM, blind analysis

1. INTRODUCTION

In Reinforced Concrete structures, beam-column joints are important structural member which translate stress between adjacent beams and columns. Though structural design method of beam-column joints was mostly established by previous experimental results, it is hoped that the rational design method based on the theoretical stress transfer mechanisms is proposed.

3D FEM analysis may simulate really solid sharps and complex stress states of structural members, and then if it will get more accurate analytical results it will become useful tools for structural design. In order to verify analytically the previous stress transfer mechanisms of beam-column joints proposed by many researchers, Shiohara and Kusuhara et al. (2005) made a plan of international blind competition.

In this study, blind analysis of beam-column joints subjected to multi-axial combined loadings was carried out using 3D nonlinear FEM. From analytical results of beam-column joints subjected to multi-axial loadings, hysteresis characteristics and failure modes are investigated.

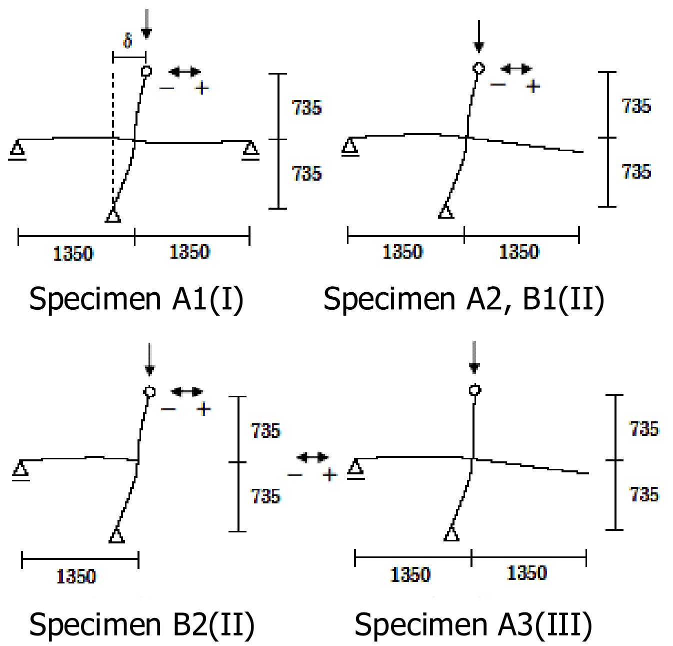
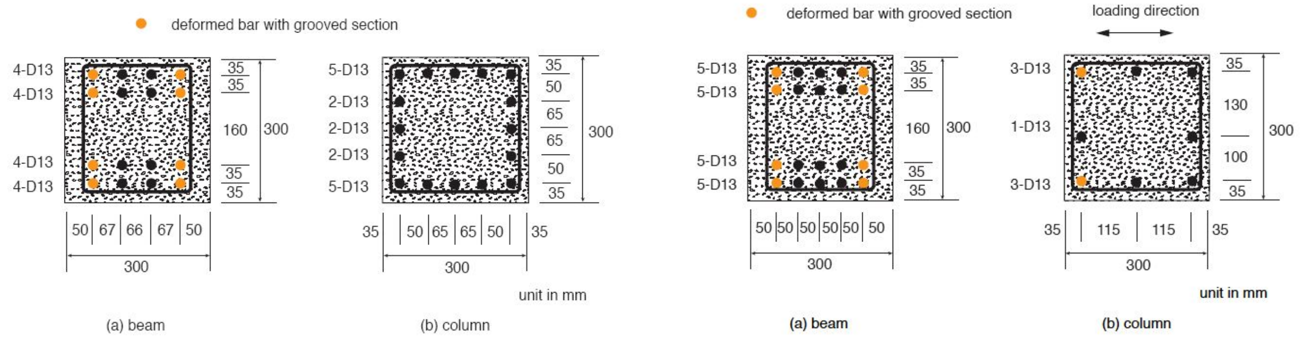


Fig. 1 Loading types and boundary conditions

Table 1 Properties of the specimens

Specimen		A1	A2	A3	B1	B2
Loading type		I	II	III	II	II
Column	Main bar	16-D13(SD345)			8-D13(SD345)	
	Hoop	D6@50(SD295) Pw=0.43%				
Beam	Main bar	16-D13(SD390)			20-D13(SD390)	
	Sttirup	D6@50(SD295) Pw=0.43%				
Joint	Hoop	3-D6@50(SD295) Pw=0.33%				



Specimens A1, A2 and A3 Specimens B1 and B2

Fig. 2 Bar arrangements of beams and a column

2. OUTLINES OF ANALYSES

2.1. Reference Specimens

Five half-scale RC beam-column joints, Specimens A1, A2, A3, B1 and B2 have been selected as reference specimens in this study. These specimens were tested by Shiohara and Kusuhara et al. (2005). All specimens have an interstory height of 1,470 mm and a beam span of 2,700 mm, as shown in Fig. 1. The dimensions of the beam and column are 500 mm x 500 mm. Specimens A1, A2 and A3 were arranged 16-D13 as beam main bars. On the other hand, Specimens B1 and B2 were arranged 20-D13 as beam main bars. Properties of the specimens and materials are shown in Tables 1 and 2, respectively. Bar arrangements of beams and a column are shown in Fig. 2.

Table 2 Material properties

Concrete	Young's Modulus	Comp. strength	Split strength
Fc24	25,900	28.3	2.67
Bar	Young's Modulus	Yield stress	Max. stress
SD345（D13）	176,000	357	493
SD390（D13）	176,000	456	582
SD295（D6）	151,000	326	488

Note: Unit in N/mm^2

As for Specimens A1, A2, B1 and B2, reversed cyclic loads were applied to the top of a column with constant axial force of 216 kN in the test. As for only Specimen A3, reversed cyclic loads were applied to the end of a beam.
In the test, the beam flexural yields before joint shear failure were observed in all specimens. And, as for Specimen A1, joint shear failure occurred obviously after the beam flexural yielding.

2.2.Analytical Models

The 3D non-linear FEM analytical program for RC structural members subjected to reversed cyclic loading was developed based on the two-dimensional FEM analysis program which was developed by Uchida and Noguchi (1998). The quasi-orthogonal multi-directional crack model was introduced into this program by Yu and Noguchi (2004).
In this analysis, according to the knowledge provided by the previous experiment about cyclic behaviour of concrete and the models proposed by Naganuma and Ohkubo (2000), the cyclic hysteresis loops including unloading and reloading curves in tension and compression regions, and the regions between tension and compression are defined as shown in Figs. 3-4 using multi-curves. They can simulate real cyclic hysteresis behaviour of concrete very well, and also contribute to removing the difficulty of the convergence in solving the equations.

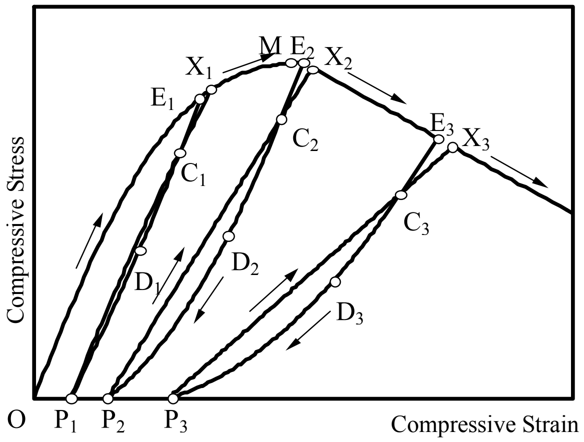


Fig. 3. Cyclic model of concrete in compression

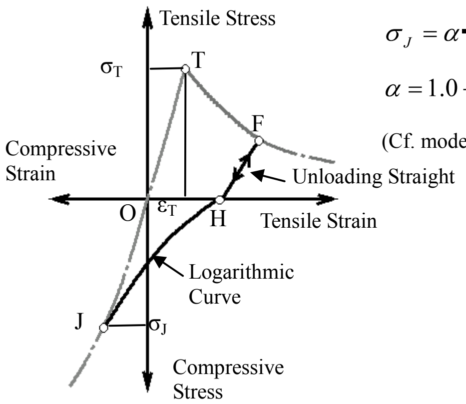


Fig. 4. Cyclic model of concrete in tension

Concrete was represented by 8-node solid elements. It was modeled as orthotropic material, based on the hypoelastic formulation, using the equivalent uniaxial strain concept proposed by Darwin-Pecknold (1977), modified by Elwi and Murray (1979) for the three-dimensional FEM analysis. The failure was judged by the five parameter criterion which was added two parameters to the three parameter criterion proposed by Willam and Warnke (1974). The five parameters were decided using the panel experiment by Kupfer et al. (1973). Saenz model (1964) was used for the ascending compressive stress-strain relationships of concrete. Confined effect by lateral reinforcement on the compressive descending stress-strain relationships were represented by Kent-Park model (1971). After cracking, tension-stiffening model proposed by Sato and Shirai (1978) was assumed. The reduction factor of compressive strength of cracked concrete proposed by Ihzuka and Noguchi (1992) was used.

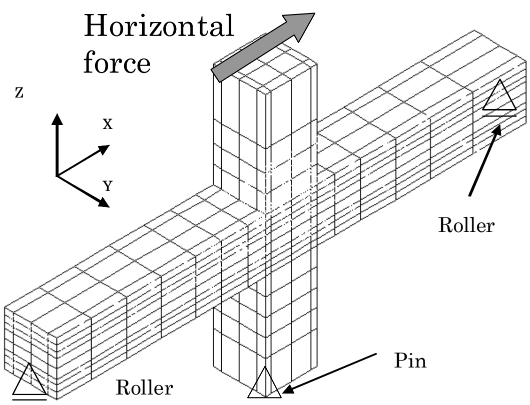


Fig. 5 FEM mesh and boundary conditions

Longitudinal and lateral reinforcement were modelled using truss elements. The cyclic hysteresis of reinforcement was defined using the Menegotto-Pinto model proposed by Ciampi and Paolo (1982). The bond between the longitudinal reinforcement and concrete was assumed as perfect. The slippage of beam longitudinal reinforcement through a joint was not considered. Figure 5 shows the FEM mesh and boundary conditons of Specimen A1.

3. ANALYTICAL RESULTS

3.1. Story Shear – Story Drift Angle Relations

The analytical story shear - story drift angle relationships of Specimens A1, A2 and A3 are shown as compared with the test results in Fig. 6. Moreover the analytical story shear - story drift angle relationships of Specimens B1 and B2 are shown in Fig. 7.

The analytical initial stiffness of all specimens was higher than the experimental one. It is considered that this was due to the local flexural crack on the critical section of the beam and the bond-slippage behavior between beam longitudinal bars and concrete in a joint, which were not taken into account in the model.

The analytical maximum story shear of Specimen A1 was higher than the test results. On the other hand, as for Specimen A2, the analytical maximum story shear was lower than the test results. And as for Specimen A3, the analytical maximum story shear of Specimen A3 gave a good agreement with test results. From the analytical results, the yielding of beam longitudinal reinforcement was observed at the maximum story shear in Specimens A1, A2 and A3. It was recognized that the beam flexural yielding occurred in Specimens A1, A2 and A3 similarly to the experiment. These failure processes were also reported by Shiohara and Kusuhara et al. (2005). In this analysis, it was recognized that the deterioration of maximum story shear was remarkable resulted in the differences of each specimens.

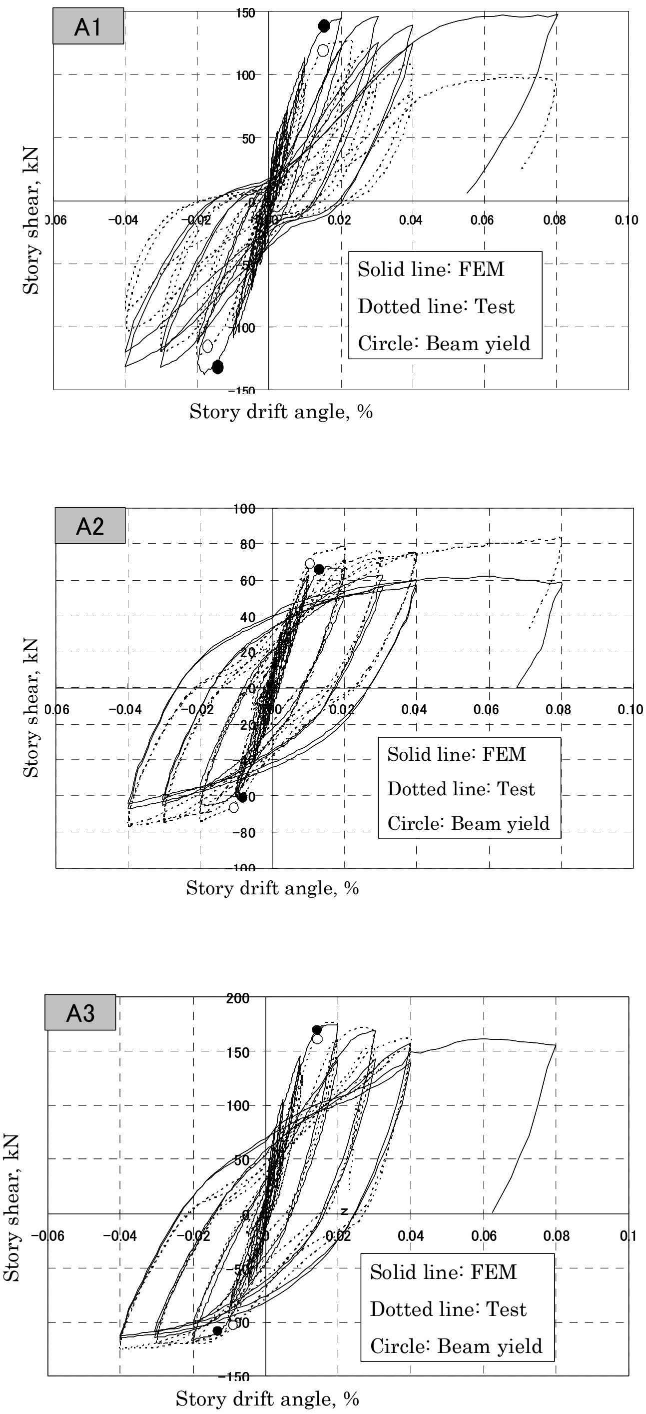


Fig. 6 Story shear – story drift angle relations, Series A

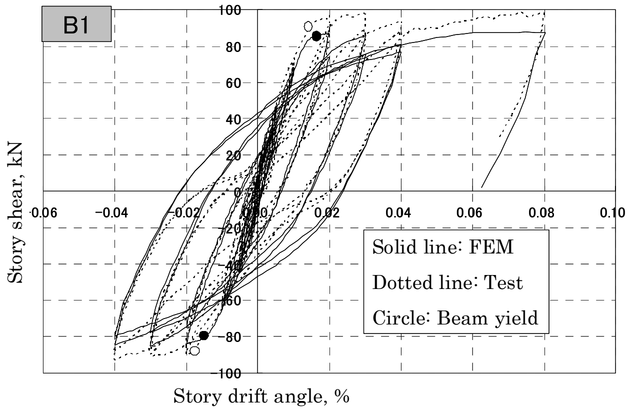
In Fig. 7, the analytical maximum story shear of Specimen B1 was slightly lower than the test results. And also, as for Specimen B2, the analytical maximum story shear was lower than the test results. From the analytical results of Specimen B1, the beam flexural yielding was observed at the maximum story shear similar to the test. On the other hands, as for Specimen B2, the yielding of beam longitudinal reinforcement was not observed.

From Figs. 6-7, analytical hysteresis loop of all specimens overestimated the experimental one. It is necessary to estimate appropriately the deteriorations of shear and bond after beam flexural yielding in a joint.

4. CONCLUSIONS

In this study, blind analysis of beam-column joints subjected to multi-axial combined loadings was carried out using 3D nonlinear FEM developed by authors.
From analytical results of beam-column joints subjected to multi-axial loadings, the following conclusions may be made.

(1)Though the analytical initial stiffness of all specimens was higher than the experimental one, analytical maximum story shear approximately gave a good agreement with test results.
(2)Analytical failure process including beam flexural failure corresponded to experimental results.
(3)Analytical hysteresis loop of all specimens overestimated the experimental one. It is necessary to estimate appropriately the deteriorations of shear and bond after beam flexural yielding in a joint.



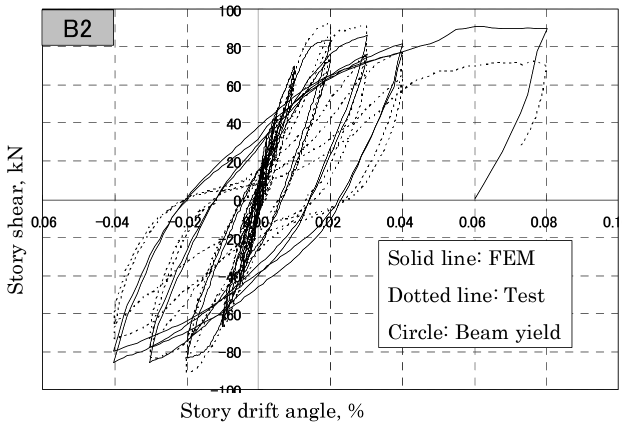


Fig. 7 Story shear – story drift angle relations, Series B

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