11 WCEE

Paper No. 192. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

FLARE-BEVEL-GROOVE WELDING METHOD FOR REINFORCING BARS AND STEEL PLATES IN MIXED STRUCTURAL SYSTEM

Y. NAKAMURA Dept. of Structural Eng., Hiroshima Univ., Kagamiyama, Higashi-hiroshima, Japan 739
Y. MATSUZAKI Dept. of Architecture, Science Univ. of Tokyo, Kagurazaka, Shinjuku-ku, Tokyo, Japan 162
Y. SAKUTA, K.KOBAYASHI, Y. ICHIJOU
Technical Development Dept., Maeda Corporation, 2-10-26, Fujimi, Chiyoda-ku, Tokyo, Japan 102

ABSATRACT

In order to industrialize the construction work at site, MIMNA construction method was proposed. In this construction method, wooden formworks at site are eliminated as much as possible using steel tubular columns and precast concrete beams. In the beam-column joint of this construction method, flare-bevel-groove welding joints are proposed for reinforcing bars and steel plates of beam ends. Considering the ease of fabrication, and the strength requirements simultaneously, the best welding process was selected among many alternatives through many kinds of tests for welded specimens. Moreover, the loading experiments of the beam-column connection were carried out, and the occurence of plastic hinge at the expected location of the beam end was confirmed.

KEYWORDS

Mixed structural system, precast concrete, concrete filled tube column, flare-bevel-groove welding, tensile strength, fatigue strength, plastic hinge, yield strength, ultimate strength

INTRODUCTION

Industrialization of the mixed structural systems is dispensable nowadays in the construction industry due to the shortage of the site workers, the demand to shorten the construction period and for accomplishment of quality assurance of buildings.

This MIMNA (Maeda Industrialized Method for New Age) construction system is one of newly developed mixed structural systems. In this construction method, a concrete filled tube column is adopted, and in the site connection between a column and a precast concrete beam, steel plates and high tensile strength bolts are used. Therefore, in the construction site, formwork is eliminated with using prefabricated steel and precast conctrete members extensively.

MIMNA CONSTRUCTION METHOD

The beam-column joint of this construction method is illustrated in Fig.1. Concrete is precast inside of a column, and steel stiffener rings are used for connection with a precast concrete beam. They are connected with high tensile strength bolts at site. Moreover, a precast concrete floor slab system is adopted for floor construction. After formwork erection of columns is carried out, concrete is cast in place to columns and floors simultaneously. At this time, no formwork is used beneath beams. Consequently, it is noted that, precast concrete beams and concrete filled tube columns support all temporary construction loads.

Members of columns and beams are considered to be reinforced concrete in principle, and reinforcing bars of beam ends are connected with steel plates by welding.

In structural design, the location of a yield hinge is assumed to be the connection of plates and reinforcing bars, which is apart from the face of the column. Steel plates and high tensile strength bolts shall be designed to be elastic even after a plastic hinge of a beam-end occurs. And it is intended that a plastic hinge of a beam surely occurs at the end connection of reinforcing bars to steel plates under severe earthquake loadings.

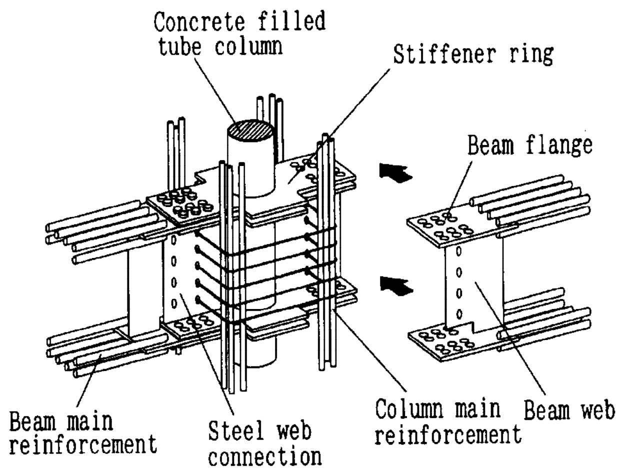

Fig.1 Details of beam-column joints

TESTS AND RESULTS OF WELDING OF REINFORCING BARS AND STEEL PLATES

Welding details of reinforcing bars and steel plates

Welding connections of reinforcing bars and steel plates were studied on several flare-bevel-groove welding details, illustrated in Fig.2. The welding detail D was selected as the best one among them shown in Table 1. Welding was carried out with CO_2 semi-automatic welding method.

Next, the placement of bars to plates was also studied for changing the direction of ribs and the several different spaces of bars through bending tests. Three kinds of reinforcing bars, that is, SD345-D19, D25, D32, were used. And parametric studies were carried out for the variation of used electric currents, voltages and torch angles. In bending tests of welded portions, all test pieces got excellent results with no crack in weld metals. An etched test piece is shown in photo.1, which exhibits excellent penetration of welds. And the clearance between reinforcing bars is recommended to exceed 1.5d (d is a diameter of a reinforcing bar) for the ease of welding.

Through these studies, the best recommended detail of welding was determined.

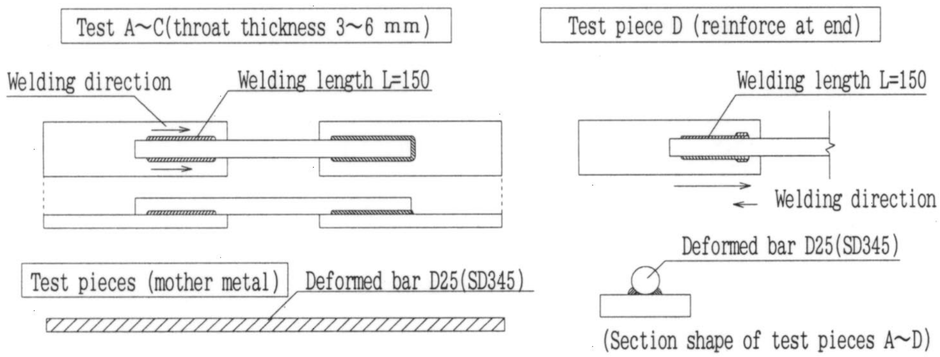

Fig.2 Tensile test pieces for selection of welding detail

Table 1 Tensile test results

Test piece	Weld Length (mm)		Throat thickness (mm)		Maximum load (ton)	Breaking point
A-1	155.9	152.6	8.8	8.1	29.2	Reinforcing bar
A-2	156.1	161.7	9.9	8.6	29.3	Reinforcing bar
A-3	156.8	155.9	7.8	8.9	26.4	Reinforcing bar (Starting point of welding)
Ave.	156.5		8.7		28.3	-
B-1	161.4	162.9	10.1	9.7	29.3	Reinforcing bar
B-2	148.9	152.7	10.9	12.1	29.0	Reinforcing bar (Starting point of welding)
B-3	152.4	154.7	13.1	9.1	29.0	Reinforcing bar (Starting point of welding)
Ave.	155.5		10.8		29.1	-
C-1	150.4	148.9	8.1	7.6	27.2	Reinforcing bar (Starting point of welding)
C-2	150.5	153.7	7.2	7.7	29.2	Reinforcing bar
C-3	160.0	148.1	8.8	9.1	24.4	Reinforcing bar (Starting point of welding)
Ave.	151.9		8.1		26.9	-
D-1	155.4	163.6	7.4	9.6	29.2	Reinforcing bar
D-2	158.4	157.4	8.5	10.4	29.2	Reinforcing bar
D-3	157.2	158.0	7.8	8.3	29.2	Reinforcing bar
Ave.	158.3		8.7		29.2	-
E-1	-	-	-	-	28.9	-
E-2	-	-	-	-	28.9	-
E-3	-	-	-	-	28.9	-
Ave.	-	-	-	-	28.9	-

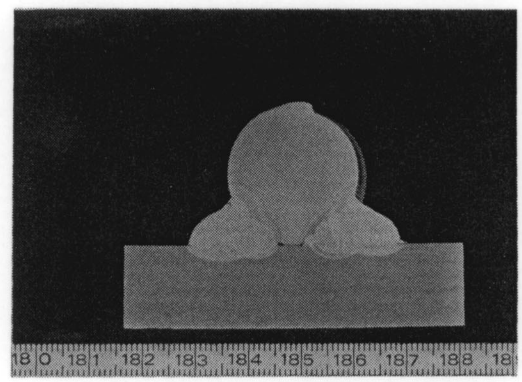

Photo. 1 Macro test result (D25)

Tests and results of flare-bevel-groove welding

Hardness tests and macro test results The results of the hardness tests on weld metals and heat-affected zones for section I, II and III of a test piece, illustrated in Fig.3, are tabulated in Table 2. The test piece with two passes and no pre-heat obtained the lowest HV among them.

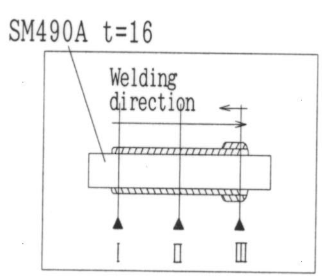

Fig.3 Test piece of hardness

Table 2 Hardness of weldness

Test piece	HV I	HV II	HV III
D19 (2 pass welding, no pre-heat)	-	-	260
D25 (2 pass welding, no pre-heat)	265	222	243
D32 (2 pass welding, no pre-heat)	-	-	231
D25 (1 pass welding, no pre-heat)	-	248	300
D32 (1 pass welding, no pre-heat)	-	-	274
D25 (1 pass welding, pre-heat)	-	245	260

(Vickers hardness test)

Results of tensile tests of welds The shape of the tensile test specimen is illustrated in Fig.4. All specimens were broken at the center of reinforcing bars, that is, neckings occured in all bars under tensile forces. The maximum tensile stresses are 55 - 60 kgf/mm ^{2}, which are almost same as those of the base metals of bars, which is shown in Fig.5.

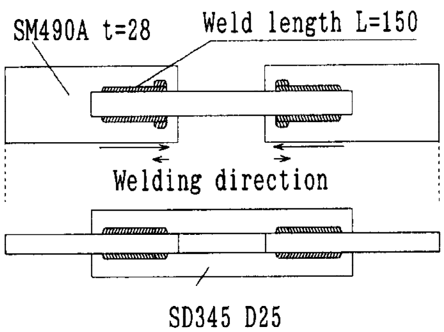

Fig.4 Tensile test specimens

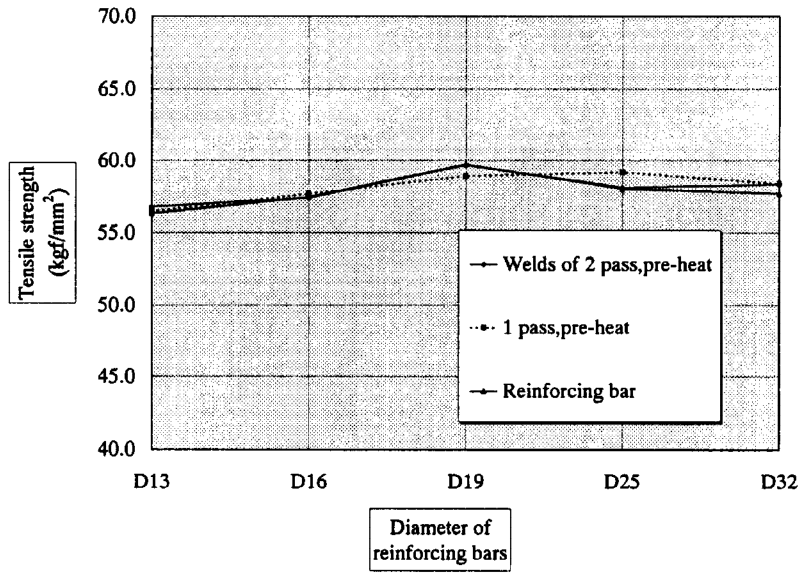

Fig.5 Results of tensile test

Results of fatigue tests of welds The fatigue strengths of one pass welds and one pass-partially two pass welds are almost same, however, that of multi-layer welds is lower than those of the formers. The S-N curves for all kinds of welds became straight shown in Fig.6.

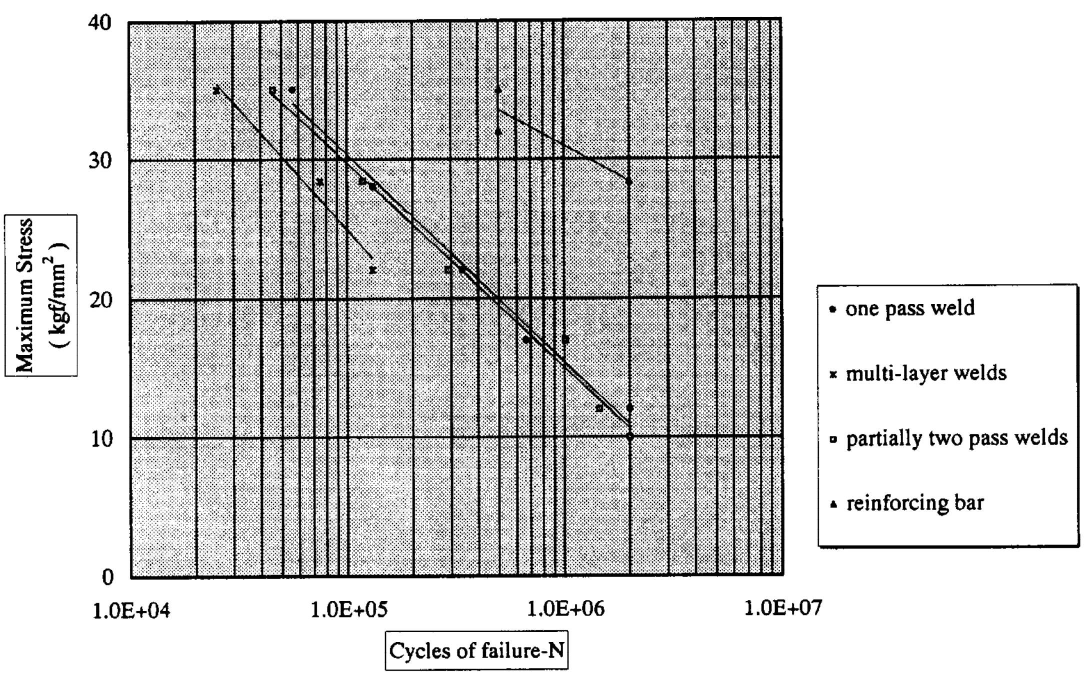

Fig.6 S-N Curve for welds

Experiments of beam end connections

For the above-mentioned construction method, it is necessary to assure that the plastic hinge forms at the connection of reinforcing bars and steel plates of beam ends.

Test specimens Test specimens are shown in Fig.7 and listed in Table 3. Mechanical properties of used materials are shown in Table 4. They are subjected to pure bending loads. The beam sections are b × d = 25cm × 45cm. Stub columns are B × D = 40cm × 85cm, and columns loaded directly are B × D = 40cm × 40cm. The experimental parameters are the number of connection plates and the existence of concrete placing joints. In this construction method, concrete placing joints exist because of using precast concrete members for beams.

Loading schedule They are alternately loaded with electric oil jacks. Firstly, 2/3Qy tonf (Qy: yield strength of Bending) is loaded. Thereafter, the joint translation angle shall be set to be 1/200 radian twice, 1/100 radian twice, 1/50 radian twice, 1/33 radian twice, 1/25 radian once and finally 1/20 once.

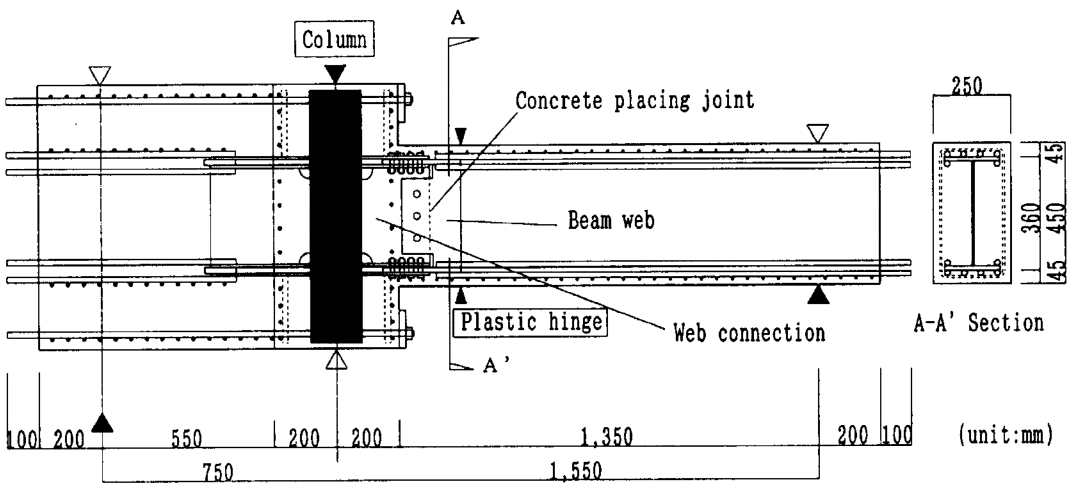

Fig.7 Shape of specimen

Table 3 Test specimens

(unit:mm)

Test specimens	Reinforcing bar (SD345)	Connection plate (SM490A)	Concrete placing joint	Tube column (STK400)
No.1 BS-1	top 3-D16	PL-9	none	165.2φ×4.5
No.2 BS-2	bottom 3-D16 (Pt=0.58%)	PL-9	exists	165.2φ×4.5
No.3 BD-1	top 6-D16	2PL-9	none	165.2φ×4.5
No.4 BD-2	bottom 6-D16 (Pt=1.19)%)	2PL-9	exists	165.2φ×4.5

Table 4 Mechanical properties of used material

Concrete

Test specimen		Compressive strength $c\sigma B$ (kgf/cm^2)	Tensile strength $c\sigma t$ (kgf/cm^2)	Young modulus cE (10^5 kgf/cm^2)
No.1 BS-1		287	24.3	2.58
No.2 BS-2	First placement	319	24.0	2.69
	Second placement	287	24.3	2.59
No.3 BD-1		287	24.3	2.59
No.4 BD-2	First placement	336	25.7	2.72
	Second placement	308	22.2	2.56

Steel plate and tube

	Yield stress $s\sigma y$ (kgf/cm^2)	Yield strain $s\varepsilon y$ (x 10^{-6})	Tensile strength $s\sigma u$ (kgf/cm^2)	Rupture elongation δ (%)	Young modulus sE (10^5 kgf/cm^2)
PL6 (SM490A)	4554	2650	5740	19.8	2.15
PL9 (SM490A)	4085	1993	5539	24.3	2.19
PL16 (SM490A)	3645	1760	5227	29.3	2.05
165.2ϕ×4.5					
(SM490A)	3517	1817	4248	24.9	1.95

Reinforcing bar

		Yield stress $s\sigma y$ (kgf/cm^2)	Yield strain $s\varepsilon y$ (x 10^{-6})	Tensile strength $s\sigma u$ (kgf/cm^2)	Rupture elongation δ (%)	Young modulus sE (10^5 kgf/cm^2)
Shear reinforcing bar	D6 (SD345)	4289	2082	5610	22.8	1.72
	U6.4	14039	6860	15433	9.3	1.87
Main reinforcement	D16 (SD345)	4105	2288	5834	24.8	1.79
	D19 (SD345)	3900	2201	5802	22.6	1.89

Experimental results

Yield and ultimate strengths Experimental results are listed in Table 5. The bending yield strengths of all specimens were 0.98 - 1.18 times the predicted ones respectively. The ultimate strengths for bending were approximately 1.2 times the yield strengths for bending, and scatterness on strengths of beams for experimental parameters could not be observed.

Table 5 Experiment results of beam end connection

Test speciments	Initial stiffness (tonf/cm)			Yield strength (tonf)			Maximum strength of experiment (tonf)
	Exp.value	Cal.value	Exp./Cal.	Exp.value	Cal.value	Exp./Cal.	
No.1 BS1	5.88	6.79	0.87	8.50	7.95	1.07	10.89
No.2 BS2	8.00	7.02	1.14	8.30	7.95	1.04	10.63
No.3 BD1	14.29	7.14	2.00	15.70	15.47	1.01	19.22
No.4 BD2	8.00	7.70	1.04	15.10	15.47	0.98	17.82

Flexural failure The final shapes of specimens after flexural failure were illustrated in Fig.8. Concrete cracks occured at the face of the column firstly at the shearing forces Q = approximately 6tonf for beams and consecutively, cracks in concrete occured in the vicinity of the welded connection of reinforcing bars and steel plates. Afterwards, many cracks developed inside of the region of 2.0 D (D:Beam depth) for BD type from the face of the column. As the alternate loading increased, cracks around the connection of reinforcing bars and steel plates opened and closed getting larger gradually, and it is evident that the yield hinge was formed at this location. For the loading cycle of R = 1/25 radian, top reinforcing bars buckled in compressive force. However, no cracks were obsereved at all at the welded beam-column joints. The failure shapes for BS type and BD type were almost same shown in Fig.8.

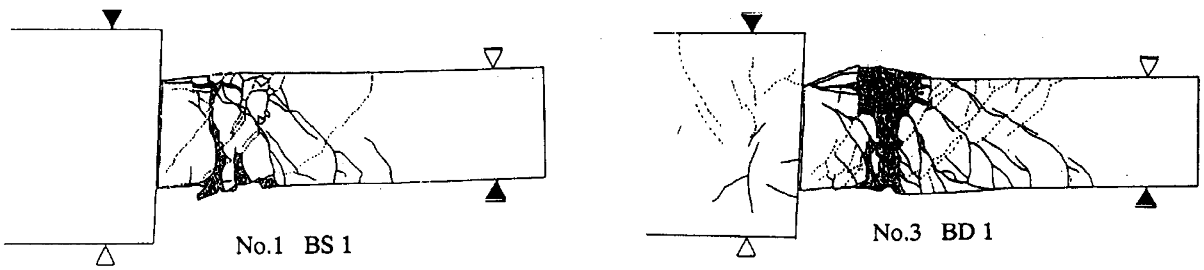

Fig.8 Flexual failure of beam-column joints

Hysterisis characteristic The shearing force (Q) - the displacement curve for No.3 specimen is shown in Fig.9. At the 1/20 radian displacement, the shearing force dereased due to buckling of main reinforcements, however, up until rotational angle R = 1/25 radian specimens had shown excellent deformability. All specimens behaved in the same way.

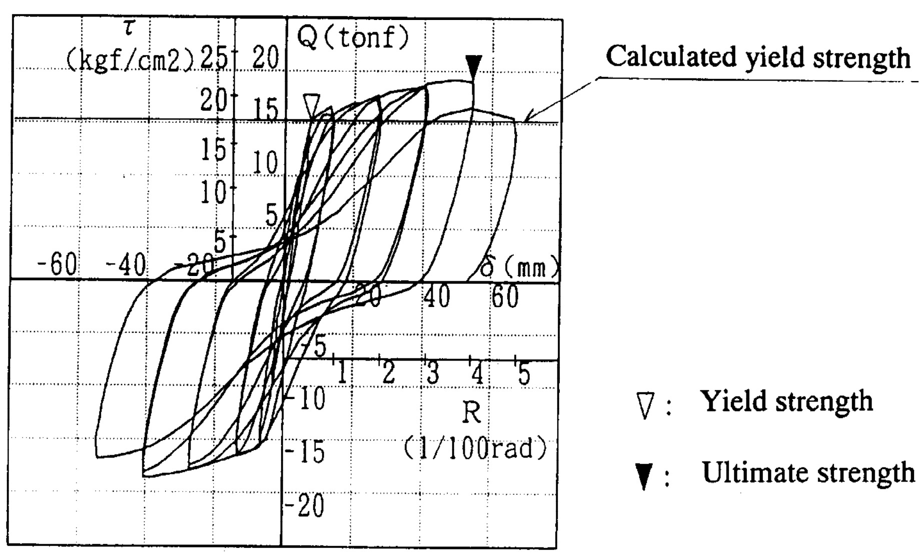

Fig.9 Shearing force (Q) - Displacement (δ) curve for No.3

Deformation capability The rotational angle of a beam at the face of the column is defined as illustrated in Fig.10. Those of four specimens are shown in Fig.11.

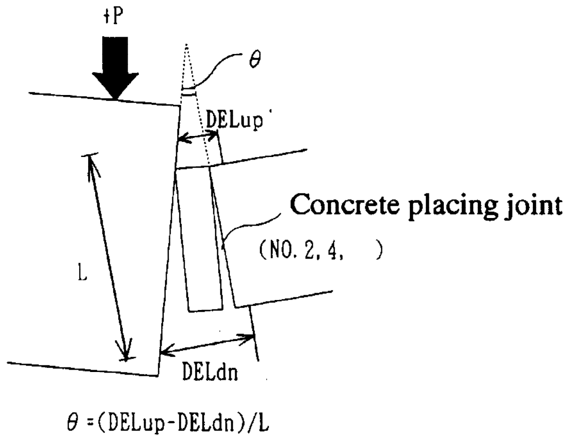

Fig.10 Rotational angle at beam end

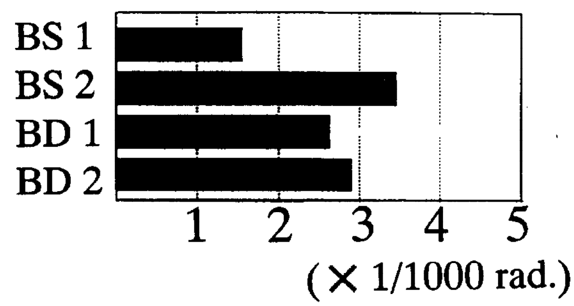

Fig.11 Rotational angle of specimens

Strain distribution Strain distribution of the bottom of the stiffener ring of No.3 specimen is illustrated in Fig.12. Strain distribution around the steel tubular column is very smoothe and the column plays an important role for auchoring the beam.

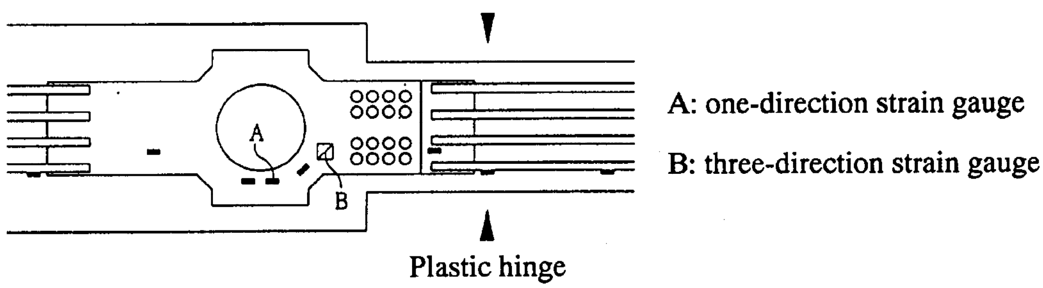

Fig.12 Strain distribution of bottom stiffener ring of No.3 specimen

CONCLUSIONS

(1) The flare-bevel-groove welding method for reinforcing bars and steel plates in mixed structural system was established through many studies and tests.
(2) In the experiments of bending of beams, the yield hinge of the beam-column connection surely occured at the expected location of the beam ends.

REFERENCES

Architectural Institute of Japan (1973). Design Standard for Steel Structures.

Architectural Institute of Japan (1991). Standard for Structural Calculation of Reinforced Concrete Structures.

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

Architectural Institute of Japan (1987). Standard for Structural Calculation of Steel Reinforced Concrete Structures.