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STATICAL CHARACTERISTICS OF WF BEAM TO RHS COLUMN CONNECTIONS USING VERTICAL STIFFENERS

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ABSTRACT

At WF beam to RHS column connections diaphragms (horizontal stiffeners) are commonly used to the column at the level of beam flanges. In this paper statical characteristics of a new type connecting method without diaphragms were experimentally investigated. In this method the side of flanges of the beam ends were welded to vertical stiffners, and the ends of the stiffners were welded to the corners of RHS columns. By means of full scale bending tests the maximum strength and the deformation capacity of this type connections were certified to be good enough in case the design of vertical stiffner plates and the design of the welding of the stiffener plates and beam flanges are appropriate.

KEYWORDS

Steel structure; RHS column; Beam to column connections; Welded joint; Full scale bending test
Cyclic loading test; Ultimate bending moment; Plastic deformation capacity

INTRODUCTION

In Japan steel structures of multi-story buildings are usually designed as earthquake resisting moment frames using RHS columns and WF section beams. At the beam-to-column connections diaphragms (horizontal stiffeners) are generally located at the flange level of beams in order to prevent local deformation of RHS columns. But the installation work of diaphragms to the RHS columns are very complicated. Severe damages at this part were obseved in many steel buildings at 1995 Hyogo-ken Nanbu Earthquake. New type of moment resisting beam-to-column connection of such steel frames without diaphragms are developed and the statical chracteristics are investigated experimentally. At this new type connections vertical stiffeners are used to connect the beam flanges to RHS columns (Fig.1). The stress transfer mechanism of the new type beam-to-column connections is defferent from that of usual connections (Fig.2). In this new type connecting methods the ends of beam flanges do not be connected to the faces of RHS columns. The beam flange stresses can be transfered to the column panel zones through the vertical stiffeners. The behaviors of new type connections under cyclic loading tests are reported in this paper.

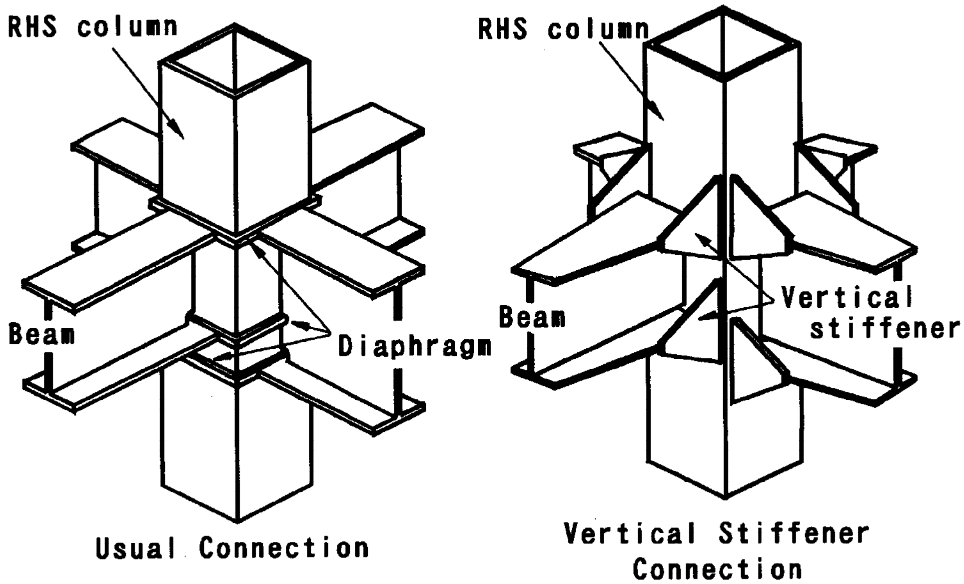

Fig. 1. WF beam to RHS column connection

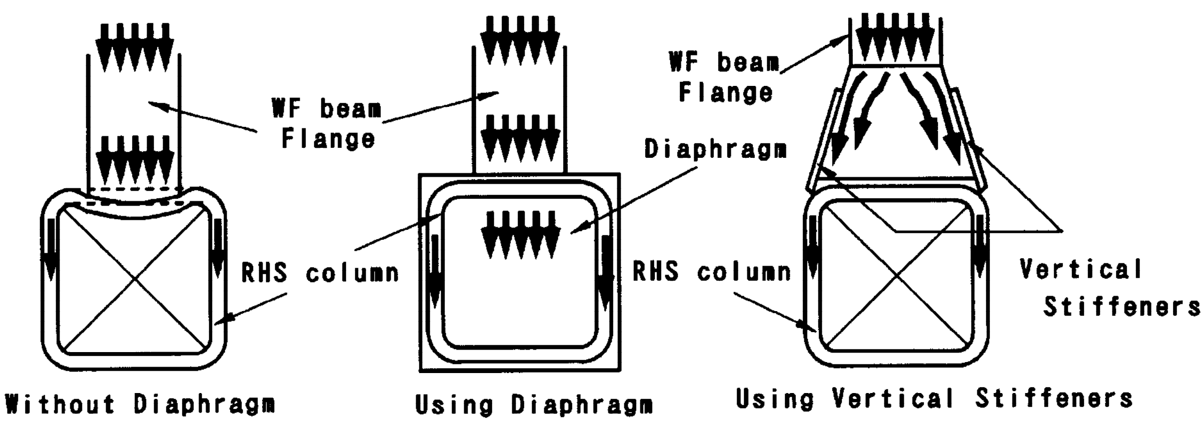

Fig. 2. The Mechnism of stress transmission

HARDNESS TESTS AND IMPACT TESTS OF THE CORNER OF RHS COLUMNS

At this new type connecting method the ends of vertical stiffeners were full penetration welded to the corner parts of cold formed RHS columns. The mechanical properties of these parts were investigated by means of hardness tests and impact tests. For hardness tests one test piece was sliced off from the welded part (Fig.3) and the other was sliced off from unwelded part. The tests were Vickers hardness tests with 1kgf loading. The size of RHS columns were 400x400x12 and 400x400x19. Hardness distributions are shown in Fig.4. As the test results hardness at the welded part was lower than that of unwelded part at the center area of the corner, in case the thickness of the column (tc) was 12mm. It is considered that annealing effect by heat affecting occurred by welding. Hardness of the welded part was almost on a same level with that of unwelded part, in case the column thickness was 19mm.

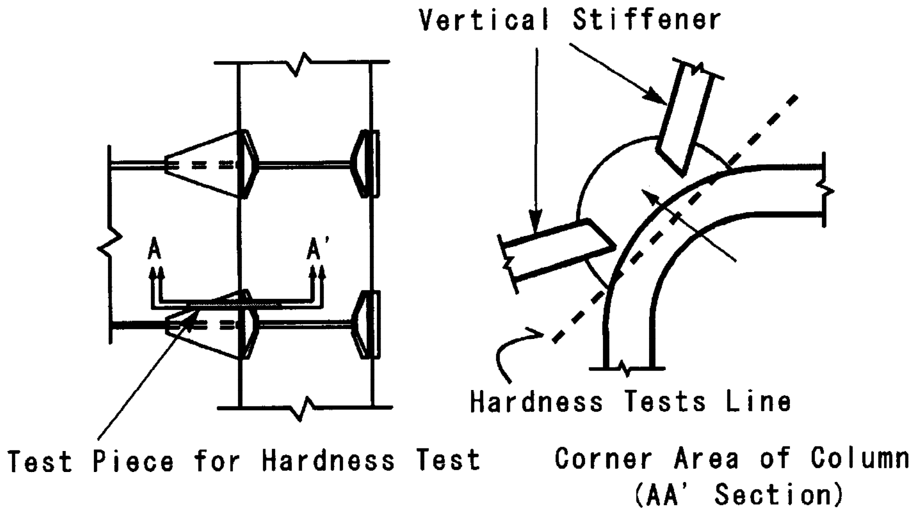

Fig. 3. Hardness test specimen

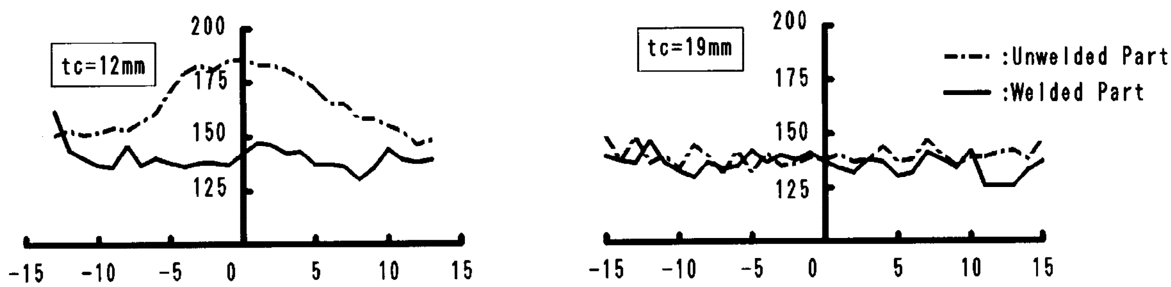

Fig. 4. Hardness distributions (vertical axis unit : Hv, horizontal axis unit : mm)

For the Charpy impact tests three specimens were taken from the welded part and the unwelded part at the corner of columns (Fig.5). Fig.6 shows the test results. Some impact values at the welded part were better than the impact values at the unwelded part. But generally speaking the impact values at the welded part ware almost same as those of unwelded part. From those hardnes tests and impact test, it becomes clear that the mechanical properties of the welded parts of the corner of cold formed RHS columns were not worse than that of the unwelded parts of the column.

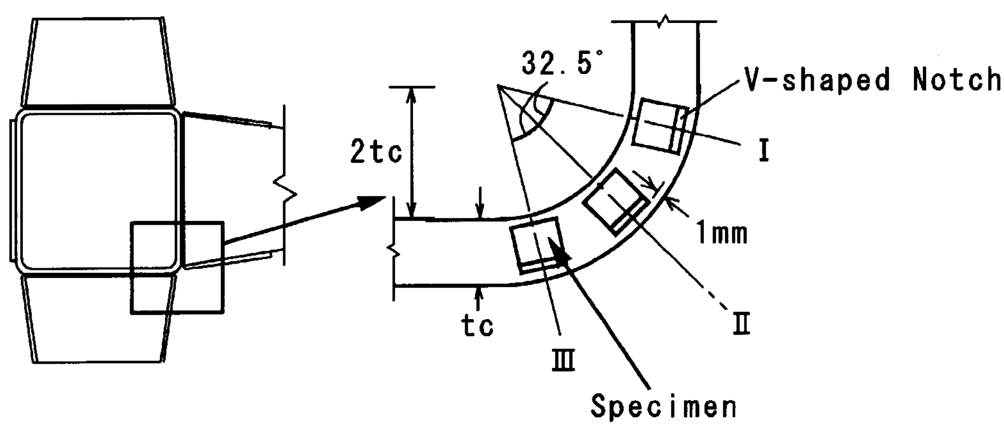

Fig. 5. Specimen of Charpy impact test at the corner of RHS column

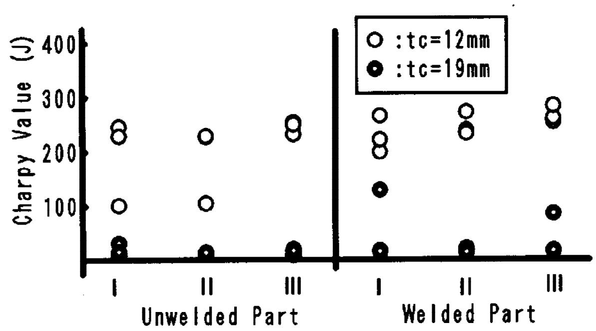

Fig. 6. Results of impact test

CYCLIC-LOADING TESTS OF BEAM-TO-COLUMN CONNECTIONS

Experimental Setup and Test Specimens

The figure of test specimens was shown in Fig.7. Cyclic loads were applied to specimens by hydraulic jack. A total of seven specimens were tested, as summarized in Table 1. Beams and columns of Grade 400 (N/mm ^{2}) steel were used for all specimens. Connection details of test specimens are illustrated in Fig.8. Steel plates with thickness of 12mm and 16mm were used for vertical stiffeners respectively. Length of vertical stiffener (Ls) were 220mm and 440mm respectively. Only for the specimen C-16-1, vertical steffeners were full penetration welded to the beam flanges. At the other specimens vertical stiffners were fillet welded at the both side to the beam flanges. The ends of the beam flanges were not connected to the column face, and there were gaps between the ends of the beam flanges and the colmun face. The beam web was directly fillet welded to the column face. The specimen C-0-1,which has usual welded type of beam to column connection with diaphragms, was used for the comparison with the behavior of the specimens with new type connections. Mechanical properties of the materials were summarised in Table 2.

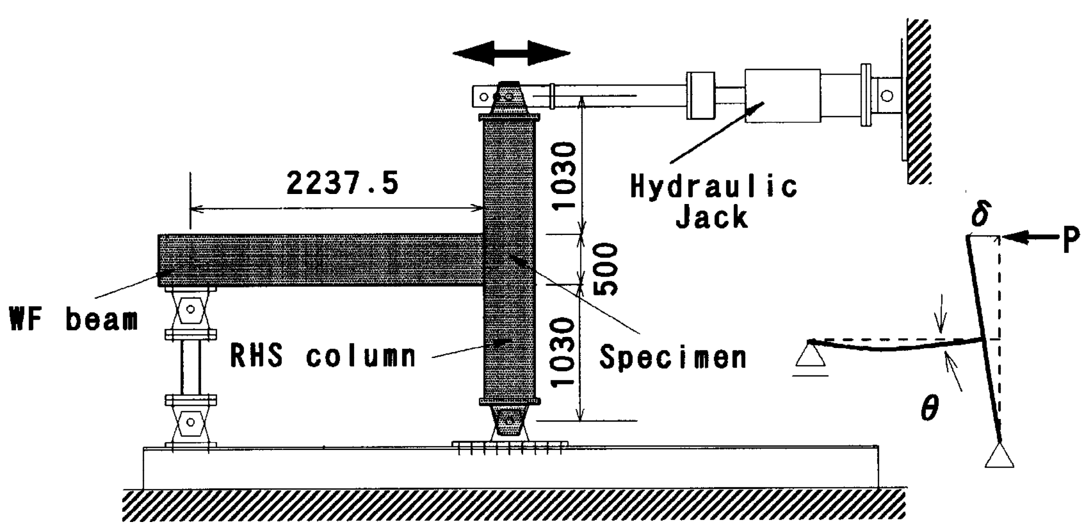

Fig. 7. Loading setup

Table 1. Test specimens

Specimen	Thickness of Stiffener	Length of Stiffener	Member for Beam	Member for Column	
C- 0-1	-----------	------------	H-500x200x10x16	☐ -400x400x12	(cold formed)
C-12-1	12mm	220mm	H-500x200x10x16	☐ -400x400x12	(cold formed)
C-16-1	16mm	220mm	BH-500x200x12x22	☐ -400x400x19	(cold formed)
C-12-2	12mm	440mm	H-500x200x10x16	☐ -350x350x16	(cold formed)
C-16-2	16mm	440mm	H-500x200x10x16	☐ -350x350x16	(cold formed)
H-12-2	12mm	440mm	H-500x200x10x16	☐ -350x350x16	(hot formed)
H-16-2	16mm	440mm	H-500x200x10x16	☐ -350x350x16	(hot formed)

Table 2 Mechanical properties of materials

		C-0 -1, C-12-1, C-16-1			C-12-2, C-16-2, H-12-2, H-16-2		
		Y.P.	T.S.	El.	Y.P.	T.S.	El.
Stiffener plate	12mm	2.97	4.38	21.8	3.00	4.30	27.3
	16mm	2.67	4.21	20.5	3.10	4.60	28.4
Beam flange	16mm	2.88	4.70	18.1	3.10	4.60	26.3
	22mm	2.56	4.14	33.9	-----	-----	-----

Y.P. : Yield Point (tf/cm ^{2}) T.S. : Tensile Strength (tf/cm ^{2}) El. : Elongation (%)

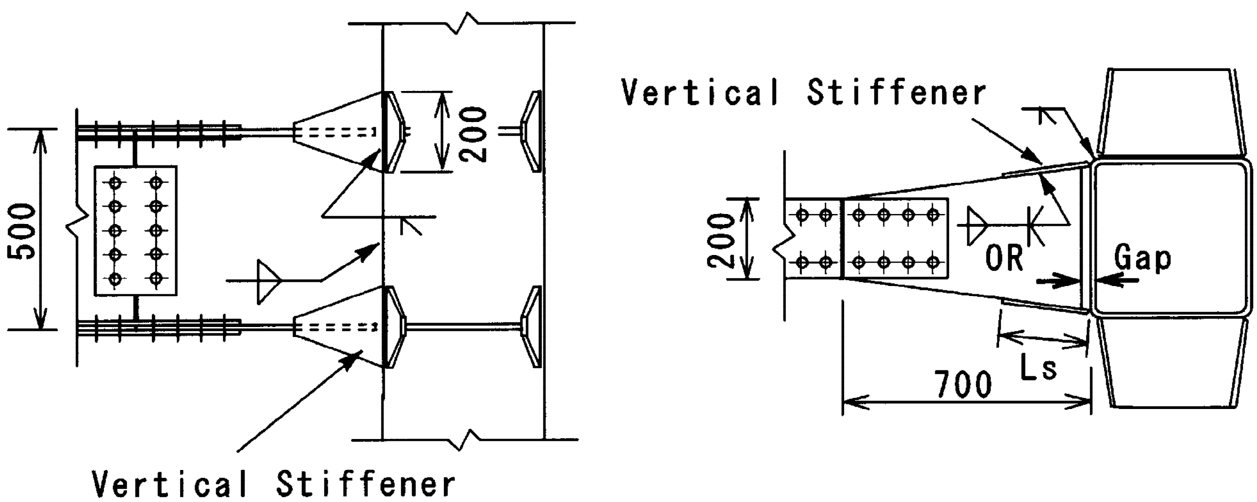

Fig. 8. Detail of beam to column connection using vertical stiffeners

Test Results

All specimens were subjected to statically applied cyclic loads up to failure. Loading was basically controlled by the column top deformation, ± 2δp, ± 4δp ± 6δp. δp is the calculated column top deformation corresponding to the full plastic moment of each beam. At the specimen C-0-1 fracture of beam flange occurred at the part of cope hole for welding at ultimate stage (F.M.0). At specimen C-12-1, C-12-2 and H-12-2 , fracture occurred near the end of vetital stiffener (F.M.1), as shown in Fig.9. At specimen C-16-1, fracture occured along the welding seam of the beam flange (F.M.2), as shown in Fig.9. At specimen C-16-2, splice plate at the beam joint broke ultimately (F.M.3). At specimen H-16-2, local buckling at the beam flange occured near the tip of vertical stiffeners (F.M.4).

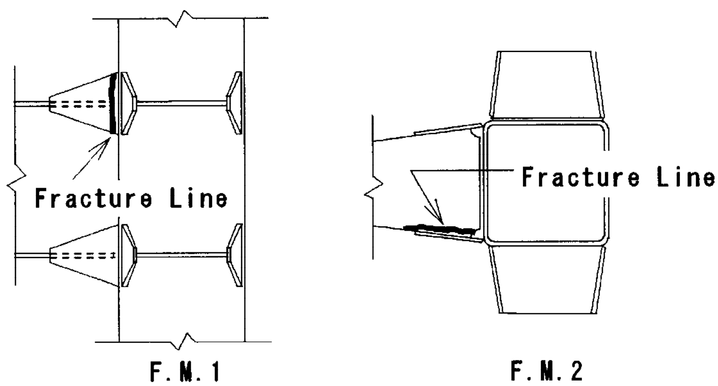

Fig. 9. Failure mode

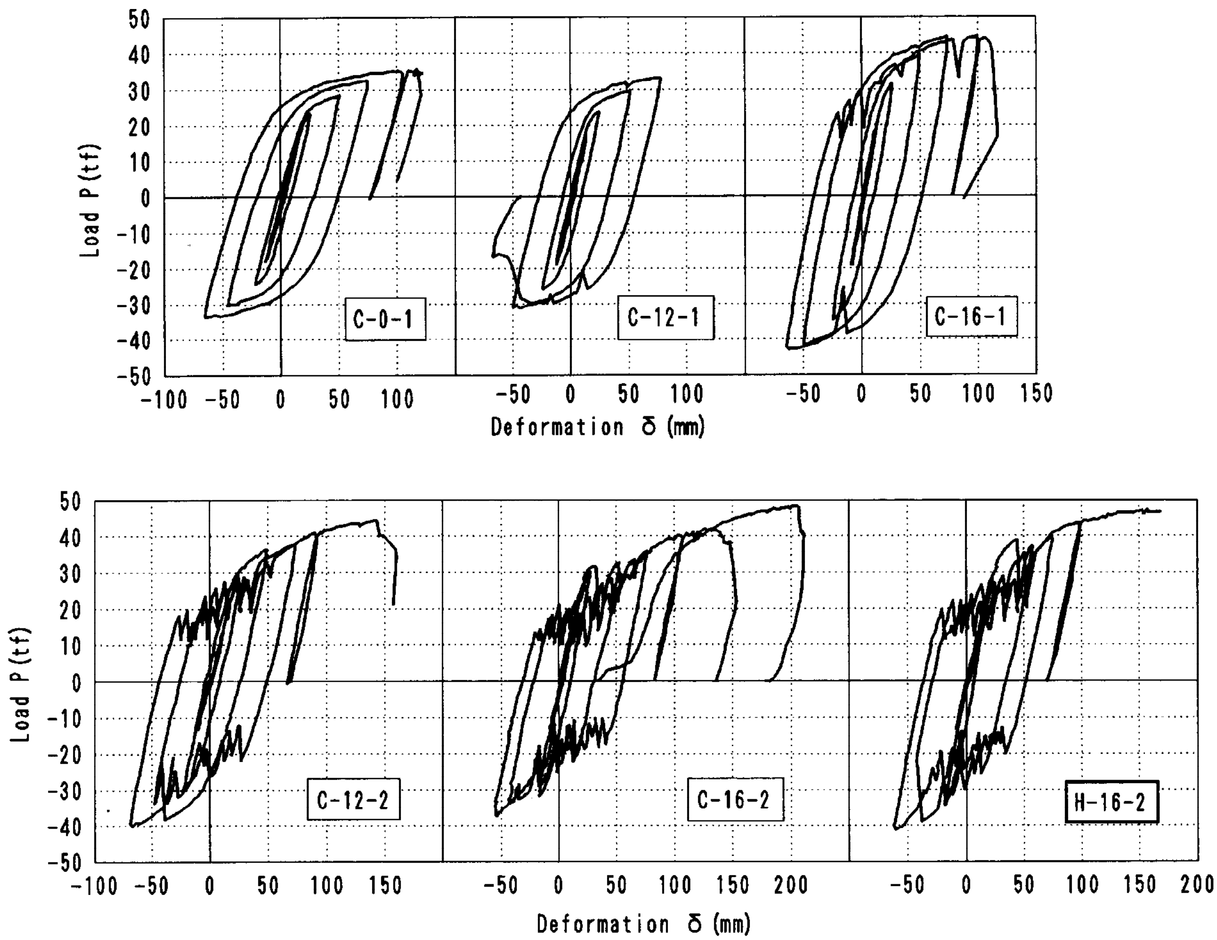

Fig.10. Load (P) - deformation (δ) relationship

The typical restoring force characteristics of specimens are shown in Fig.10. Results are plotted as horizontal load (P) versus the column top deformation (δ) relationship. The skeleton curves of moment at the beam end (M) versus beam end rotation (θ) relationship are shown in Fig.11 and Fig.12. The value Mp is full plastic moment of each beam, and the value of θp is the calculated rotation corresponding to Mp. In case the length of vertical stiffener was 220mm the behavior of the specimen with vertical stiffener connections were worth than that of the specimen with usual welded connection (C-0-1). This phenomenon caused by the failure either at the end of stiffener plate or at the welding seam between beam flange and vertical stiffener. In case the length of vertical stiffener was 440mm the behavior of the specimens with vertical stiffner connection were better than that of the specimen C-0-1. This behavior was ensured by the verical stiffners with appropriate length. Different behaviors could not be observed between the specimens using cold formed RHS column and the specimens using hot formed RHS column.

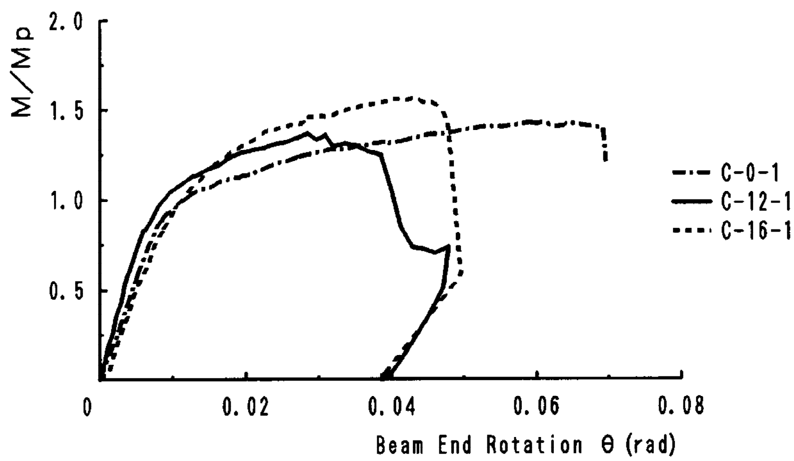

Fig.11 Skeleton curves of M/Mp - θ relationship (Ls=220mm)

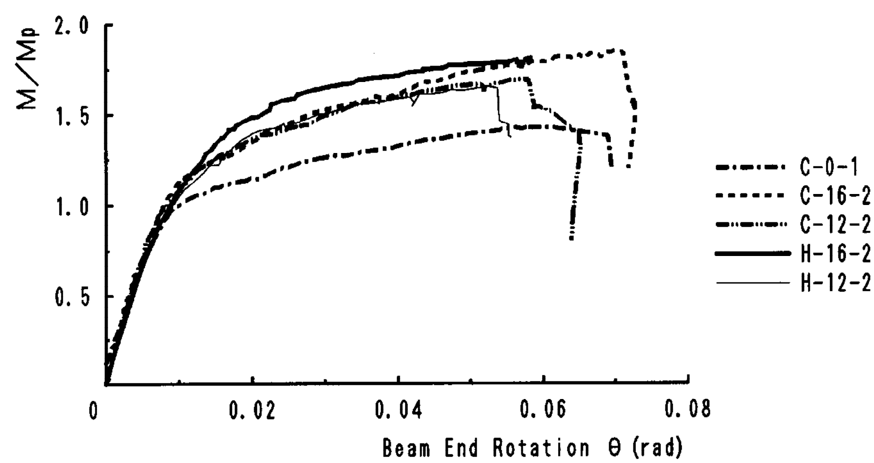

Fig.12 Skeleton curves of M/Mp - θ relationship (Ls=440mm)

Table 3 Test results

Specimen	Pmax (tf)	eMu (tf·cm)	Mp' (tf·cm)	α	ηs	Failure Mode
C- 0-1	35.5	9055	6278	1.44	14.2	F.M.0
C-12-1	33.2	8468	6928	1.22	9.2	F.M.1
C-16-1	44.6	11376	7688	1.48	13.0	F.M.2
C-12-2	44.0	11249	8309	1.35	14.1	F.M.1
C-16-2	49.0	12527	8309	1.51	18.7	F.M.3
H-12-2	43.4	11096	8309	1.34	11.1	F.M.1
H-16-2	48.6	12425	8309	1.50	15.2	F.M.4

The test results, computed values, and failure mode of each specimen are summarizes in Table 3. The maximum load (Pmax) , the maximum bending moment at the beam end (eMu), the moment at the beam end corresponding to the full plastic moment of the beam at the tip of vertical stiffeners (Mp') are shown in this Table. The value of α is the ratio of eMu to Mp'. The value of ηs is accumulated plastic deformation ratio ($\eta s = Ws/(Mp \cdot \theta p)$, Ws : larger total absorption energy of skeleton curve of possitive or negative loading direction). α-ηs relationship of each specimen is shown in Fig.13. This figure shows that the ultimated strength and the plastic deformation capacities increase with increase of the thickness and the length of the vertical stiffners. It means that the beam ends area welded with the vertical stiffeners of this type connections work as rigid zone and good stress transfer from beam to column connection is achieved, in case the design of vertical stiffeners and those welded joints are appropriate. Consequently the formation of the plastic hinge at the tip of vertical stiffeners is assured.

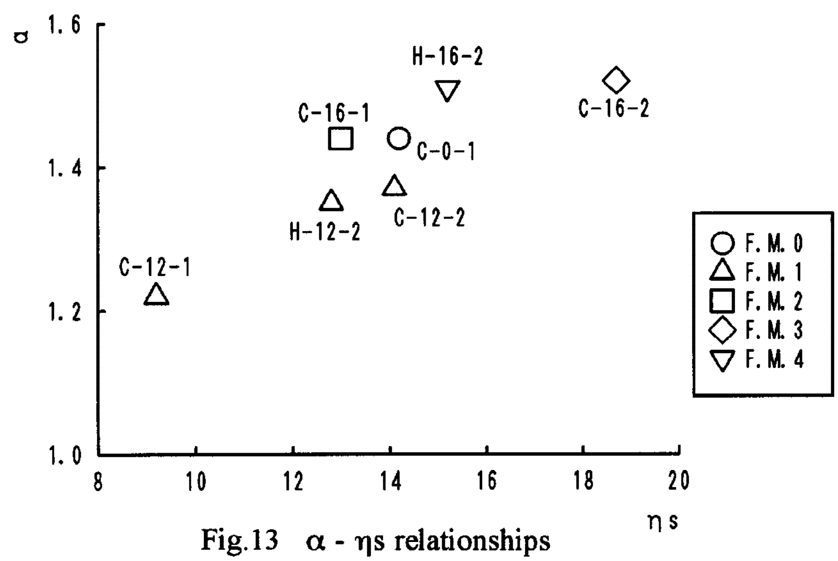

Fig.13 α - ηs relationships

CONCLUSIONS

From the cyclic loading tests of the beam-to-column connections it becomes clear that the new type of WF beam to RHS column connections using vertical stiffeners behave well in comparison with the usual welded beam-to-column connections, when the design of the vertical stiffeners and the design of welding joints of vertical stiffeners and beam flanges are appropriate. The results of the hardness test and the impact test about the welded parts at the corner of cold formed RHS column revealed no bad influence of heat affection.