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EXPERIMENTAL STUDY ON THE SEISMIC RESISTANCE OF THE JOINTS COMPOSED OF THE REINFORCED CONCRETE COLUMNS AND STEEL BEAMS

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ABSTRACT

The object of this study was to investigate and evaluate the structural properties of joints between reinforced concrete columns and steel beams with frame members. To accomplish the object of this study, experiments were conducted to examine the seismic performance of joints between reinforced concrete columns and steel beams. Joint details are internally constructed of vertical stiffeners, face bearing plates and do not contain web steel.

The hysteresis characteristics model with regard to the joint shear strength and shear deformation was proposed. In this model, the joint shear strength - shear deformation relationships of steel and concrete portions were superposed. This model gave good agreements to the hysteresis characteristics of the experimental results.

KEYWORDS

Joint; Joint Shear Strength; Seismic Performance; Stress Transfer Mechanisms;

INTRODUCTION

Recently, the mixed structure composed with reinforced concrete columns and steel beams have been developed in Japan. Reinforced concrete columns were advantaged for axial load and story stiffness, and steel beams were advantaged for a long span structure. The mixed structure was available to use the various structural members and increase the flexibility of design.

The principal subject of the mixed structure was clarification of the joint composed with reinforced concrete columns and steel beams. Many researchers have been discuss the joint shear strength and seismic performances of joints in mixed structures.

In this study, in order to investigate the seismic performances and stress transfer mechanisms of the joint, the loading test of cross shaped beam-column joints with developed joint details was carried out.

Based on the investigation results of the cross shape tests, the loading test of two story - two span frame type specimens was also carried out to investigate the influence of joint behavior on the frame behavior.

OUTLINE OF JOINT TESTS

In order to investigate the seismic performances of the developed a new type of joint details composed of reinforced concrete columns and steel beams, the test of cross shape specimens was carried out. Dimension of the specimens was shown in Fig. 1, and joint details were shown in Fig. 2.

The joint details were a through beam type (B1) with a steel beam penetrating the reinforced concrete column and a through column type (C1) composed of vertical stiffeners. The dimension of the column section was 300*300mm and the beam section was H-200*100*12*16. The specimens were about 1/3 models for the real size. Test parameters were shown in table 1, and material properties were shown in Table 2. Concrete strength of the column was about 280kgf/cm2, and yield strength of the beam flange was about 2700kgf/cm2.

Expected failure type of the specimens was the joint shear failure after beam yielding. Therefore, the strength and dimension of columns and beams were decided by the expected joint shear failure type.

The constant axial force was applied at the column top of the specimen at fast, and the cyclic load was applied to the both beam end using the actuators.

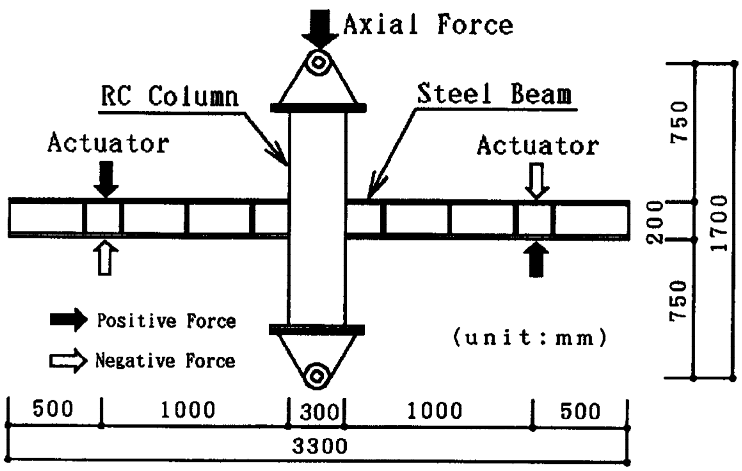

Fig. 1 Dimension of Test Specimens

Table 1 Test Parameters

Column	Section	B×D=300×300 (mm)
	Main Bar	12−D19 (p_t=1.28%)
	Lateral Bar	4−D10@50 (p_w=1.9%)
	Axial Force	0.2BDσ_B
Beam	Section	H−200×100×12×16 (mm)
Joint Lateral Bar		4−D6@50 (p_w=0.85%)

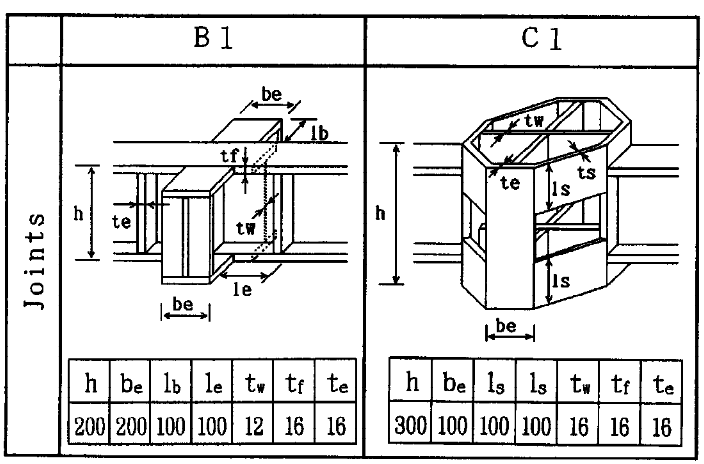

Fig. 2 Joint Details

Table 2 Material Properties

Concrete		Conpressive Strength (kgf/cm²)	Tensile Strength (kgf/cm²)	Young's modulous (×10⁵kgf/cm²)
B1		298	25.8	2.50
C1		265	24.9	2.47
Steel		Yield Strength (kgf/cm²)	Tensile Strength (kgf/cm²)	Young's modulous (×10⁶kgf/cm²)
Bar	D6	3175	4820	1.89
	D10	3863	4924	1.82
	D19	4142	6116	2.03
Plate	12mm	2700	4360	2.18
	16mm	2717	4516	2.24

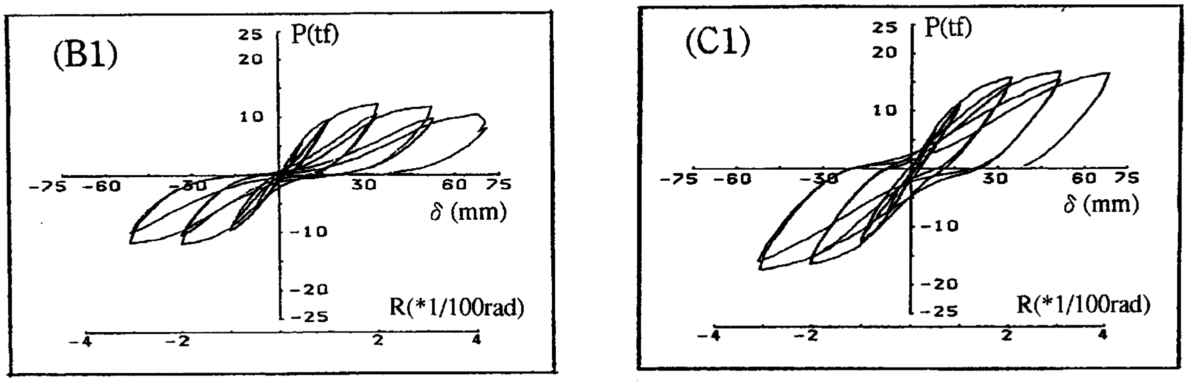

Fig. 3 Story Shear Force - Story Deformation Relationships

TEST RESULTS

Story shear force - story deformation relationship of the experimental results were shown in Fig. 3.

For the story shear force - story deformation relationships, through column type specimen (C1) with the new type of joint details indicated good hysteresis loops and maintained the strength until the test end. On the other hand, as for the through beam type specimen, the strength decay was observed after the rotation angle 2/100rad., and contra-S shape hysteresis loops were observed. From the test results, it was recognized that the through column type with the new joint detail showed better excellent seismic performances for the strength and ductility than the through beam type.

Joint shear strength - joint shear deformation angle relationship were shown in Fig. 4, and comparisons with experimental and calculation results were shown in Table 3.

Through column type showed large capacity for the joint shear strength and gave large energy absorption capacity in the hysteresis loop shape. As for the through beam type, the joint shear strength was less than that of the through column type, and energy absorption capacity was less than that of the through column type.

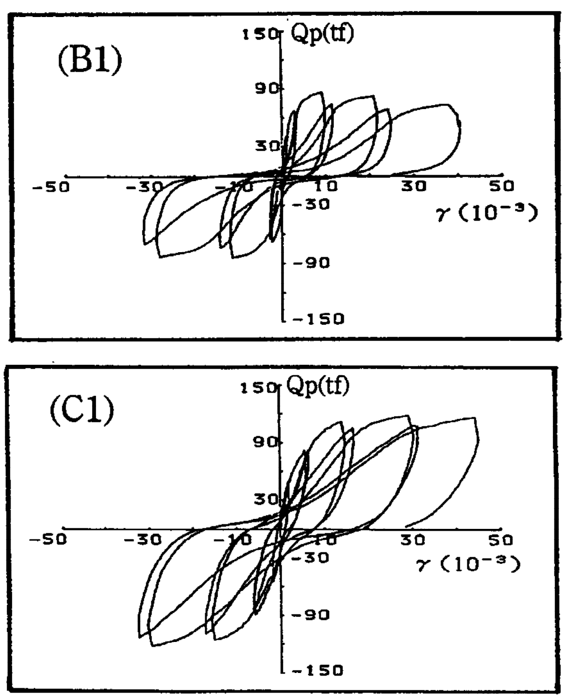

Fig. 4 Joint Shear Strength - Joint Shear Deformation Angle Relationships

Table 3 Comparisons with Test Results

	B 1	C 1
Experimental Q_p (tf)	87.5	121.3
Calculation Equation (1)	87.0	88.5
Calculation Equation (2)	90.6	69.4
Calculation Equation (3)	87.0	101.2

The joint shear strength of the test results was compared with the calculation value using two equations. Equation (1) is from the standard for steel reinforced concrete structure in Japan, and equation (2) is from the proposed formula of Japan Concrete Institute.

The calculation results using eq. (1) and eq. (2) gave a good agreement with the test results for the joint shear strength of the through beam type specimen (B1). The calculation results were smaller than the test result for the joint shear strength of the through column type specimen (C1), because the calculation results were not considered the confined effect by the vertical stiffener. Therefore, the experimental results of the through column type specimen was not considered sufficiently in eq. (1) and eq. (2).

The joint shear strength formula of the through column type was discussed. Proposed joint shear strength formula is as follows.

$$Qp=ksrc*0.3\,\sigma b*B/2*D+As*\sigma y/\sqrt{3} \quad (3)$$

Where, Qp:joint shear strength, ksrc:a coefficient for confined effect 1.8, σ b:concrete compressive strength, B:column width, D:column depth, As:cross section of lateral end plate, σ y:yield strength of lateral end plate.

It was assumed that the joint shear strength of the through column type is obtained from the summation of the shear strength of a concrete portion and a steel portion. As for the concrete portion's shear strength, the confined effect of concrete was considered and the effective section for the steel portion's shear strength was defined as the lateral end plate in the joint. Calculation results using proposed joint shear strength formula gave good agreement with the experimental result of the through column type.

HYSTERESIS CHARACTERISTICS OF THROUGH COLUMN TYPE JOINT

From the hysteresis shape of test results, joint shear strength - joint shear deformation angle relationships were defined as the summation of a concrete portion and a steel portion. Assumed joint shear strength - joint shear deformation angle relationships are shown in Fig. 5.

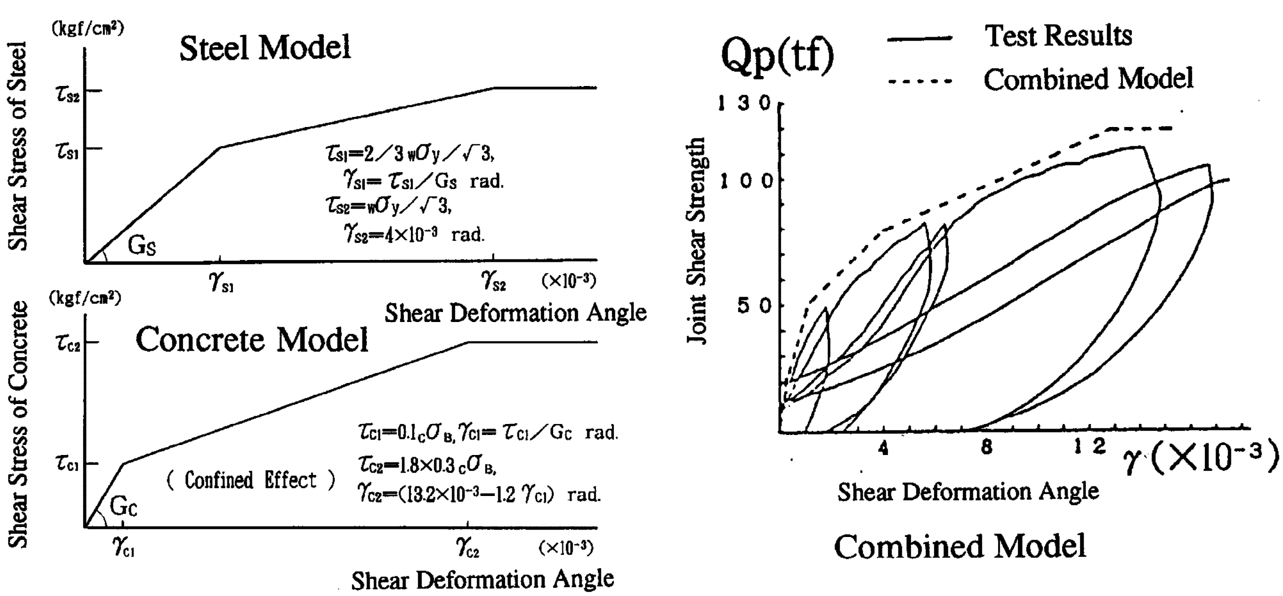

Fig. 5 Hysteresis Characteristic Model of Through Column type Joint

Hysteresis characteristics of a concrete portion and a steel portion were modeled using tri-linear curves. The turning points of concrete portion's hysteresis characteristics were defined by the cracking strength and yield strength, and the turning points of steel portion's hysteresis characteristics were defined by 2/3 yield strength and yield strength.

Joint shear strength - joint shear deformation angle relationships were obtained by combining the concrete portion and steel portion. The calculation result gave a good agreement with the test result.

OUTLINE OF FRAME TEST

The number of the tests of frames with reinforced concrete columns and beams were not so many in Japan. Moreover, the frame tests to investigate the influences of joint seismic performance on the frame behavior have been scarcely carried out. In order to investigate the influence of reinforced concrete columns and steel beams structural frame behavior for difference of joint seismic performance, two - story and two - span frames model structures with different joint details were tested.

The detail of specimens was shown in Fig. 6. Test parameters and material properties of specimen were shown in Table 4 and Table 5, respectively. The dimension of column section was 300*300mm and beam section was H-200*100*12*16, columns and beams of specimens were the same scale as those of the cross shape specimens.

Concrete compressive strength of columns was 270kgf/cm2 and yield strength of steel beam was 3000kgf/cm2. Axial load of exterior and interior columns were 0.1 σ b BD and 0.2 σ b BD, respectively. The difference of two frame type specimens was only a joint detail for through beam type (TB) and through column type (TC). Other parts except for the joints had the same details and the same strength for column and beam numbers.

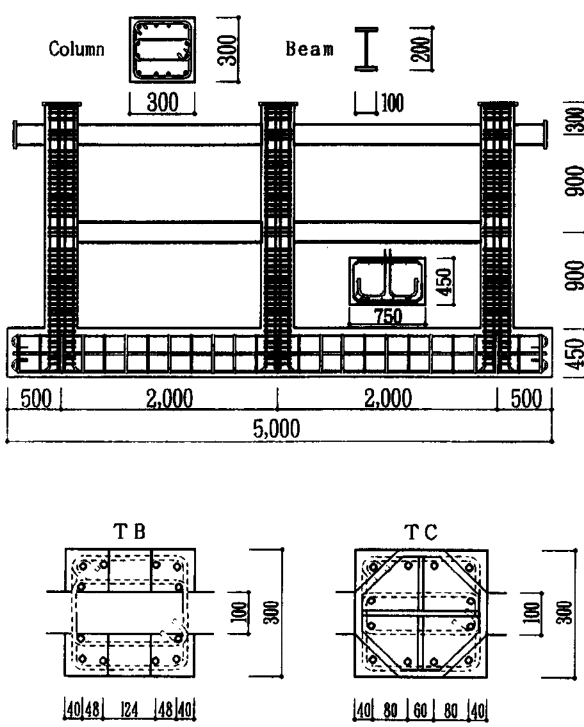

Fig. 6 Detail of Test Specimens

Table 4 Test Parameters

Column	Section	B×D=300×300 (mm)
	Main Bar	12−D19 (p_t=1.28%)
	Lateral Bar	4D−10@50 (p_w=1.9%)
	Axial Force	(Exterior Column) 0.1BD σ_B (Interior Column) 0.2BD σ_B
Beam	Section	BH−200×100×12×16 (mm)
Joint Lateral Bar		4D−6@50 (p_w=0.85%)

Table 5 Material Properties

Concrete		Compressive Strength (kgf/cm²)	Tensile Strength (kgf/cm²)	Young's modulous (×10⁵kgf/cm²)
Column		269	19.1	2.21
Base		294	26.2	2.19
Steel		Yield Strength (kgf/cm²)	Tensile Strength (kgf/cm²)	Young's modulous (×10⁶kgf/cm²)
Bar	D6	3860	5435	1.79
	D10	3753	5163	1.69
	D19	3854	5560	1.77
Plate	12mm	3124	4639	1.97
	16mm	2998	4254	1.95

The joint seismic performance of the through beam type (TB), which to realize the results of cross shape type test, was less ability for joint shear strength and hysteresis loop shape than the joint seismic performance of through column type (TC).

For the loading procedure, lateral force was loaded by actuators at the third floor level after constant axial load at each column. In order to investigate the stress transfer mechanism for internal and external joints at the second floor, lateral force was alternately loaded only at third floor level.

RESULTS OF EXPERIMENT

A summary of the frame test results was shown in table 6. Story shear force - story drift deformation relationships of the test results were shown in fig. 7.

There was not a big difference in the loads of flexural cracking and steel yielding between the through column type and through beam type. The test results of the maximum shear forces were 101.4tf for the through column type and 88.5tf for the through beam type, respectively. It was considered that the difference of the maximum shear force for the frame test specimens came from the difference of the joint seismic performances.

From the test results of story shear force - story drift deformation relationships, the difference of hysteresis loops was observed between the through column type and the through beam type. For the through column type, hysteresis loops showed a spindle shape and maintained the strength of the frame structures until the end of the test. For the through beam type, however, hysteresis loops showed a contra - S shape from the slippage and the strength decreased after the rotation angle 1/33rad..

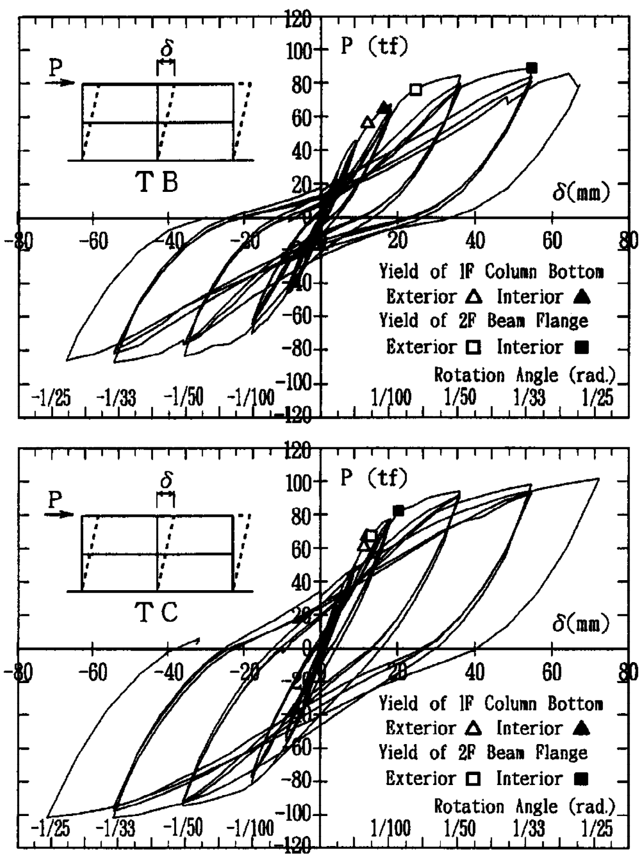

Fig. 7 Story Shear Force - Story Drift Deformation Relationships

Table 6 Frame Test Results

		TB		TC		Analytical Results	
		Exterior	Interior	Exterior	Interior	Exterior	Interior
Flexural Crack	1F Column Bottom	26.5	40.1	26.6	28.7	16.3	20.3
		1/450	1/257	1/514	1/450		
	1F Column Top	67.1	——	77.1	74.7	41.1	33.4
		1/100	——	1/100	1/113		
	2F Column Bottom	54.3	67.1	63.7	77.1	42.3	30.2
		1/150	1/100	1/150	1/100		
	2F Column Top	59.7	67.1	39.0	33.5	27.5	21.1
		1/128	1/100	1/300	1/360		
Steel Yielding	1F Column Bottom	54.3	63.9	63.7	69.9	92.1	92.2
		1/150	1/113	1/150	1/128		
	2F Column Top	78.7	78.7	91.4	91.4	——	93.4
		1/25	1/25	1/43	1/43		
	2F Beam Flange	75.8	88.5	69.9	81.8	62.2	74.4
		1/75	1/33	1/128	1/90		
	3F Beam Flange	84.3	——	84.9	92.2	84.4	——
		1/50	——	1/75	1/56		
Maximum Strength		88.5		101.4		93.4	

Upper : Load (tf), Lower : Rotation Angle (rad.)

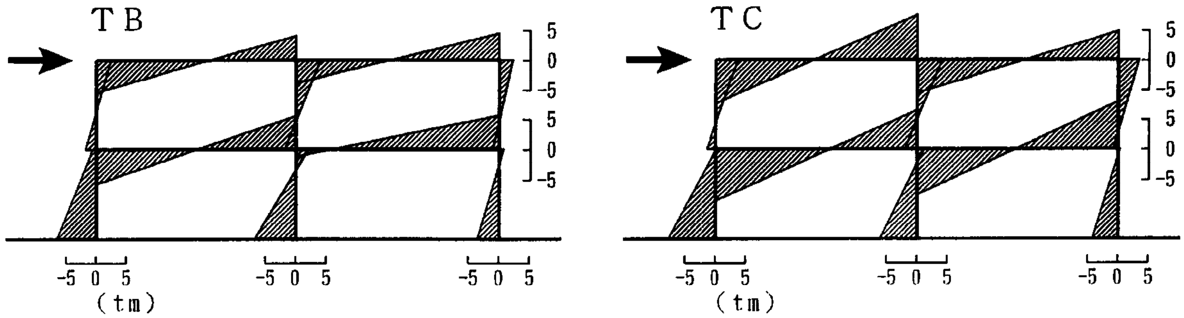

Fig. 8 Moment Distributions of Test Results (1/400rad.)

The test results of moment distributions of the frame specimens at the rotation angle of 1/400rad. were shown in Fig. 8. The moment distributions of specimen with through beam type was similar to that with the through column type.

The position of inflection points at the first floor column existed near to the top of columns. It was considered that this phenomenon came from the difference of the stiffness between reinforced concrete columns and steel beams.

DISCUSSION OF JOINT BEHAVIOR

Joint shear strength - joint shear deformation angle relationships of the interior and exterior joints at the second floor level for both specimens were shown in Fig. 9. Where the joint shear strength was calculated from the stress of beam flanges and lateral force. As for the exterior joints, joint shear deformations of both specimens were small and beam deformations were dominant. On the other hand, as for the interior joints, joint shear deformations were large, and the difference of joint seismic performance appeared between the through beam type and the through column type.

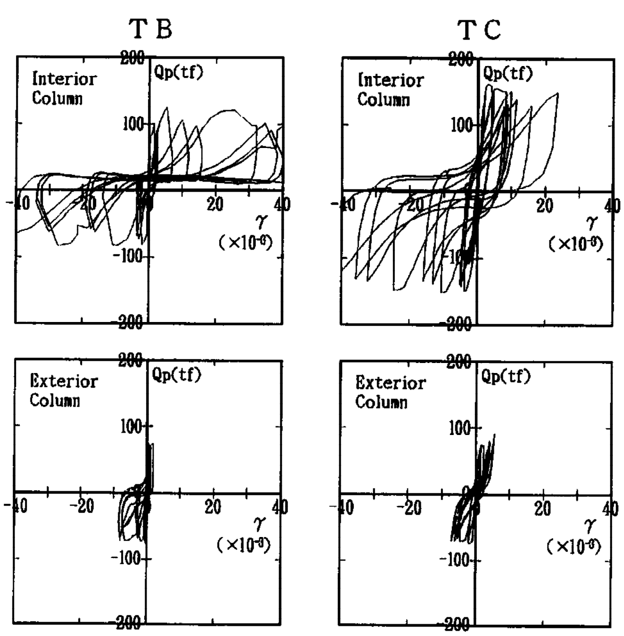

Fig. 9 Joint Shear Strength - Joint Shear Deformation Angle Relationships (at the second level)

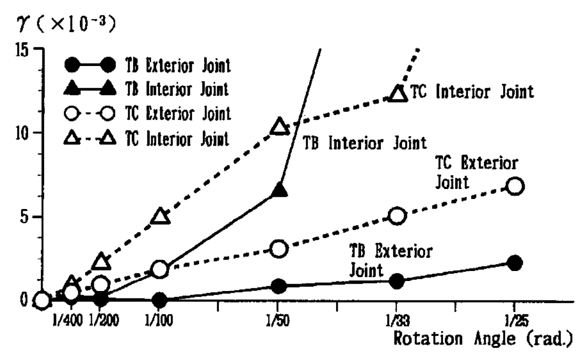

Fig. 10 Joint Shear Deformation Angle - Story Rotation Angle Relationships

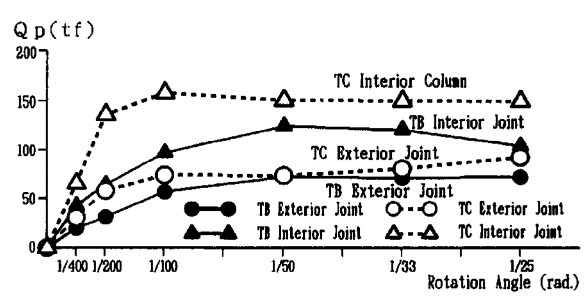

Fig.11 Joint Shear Strength - Story Rotation Angle Relationships

In the through beam type, joint shear deformation angle was large after the story rotation angle of 1/50rad. and the hysteresis loops showed a extreme contra S - shaped with slippage. In the through column type, on the other hand, hysteresis loops maintained stable shape.

Joint shear deformation angle - story rotation angle relationships was shown in Fig. 10. Though, the joint shear deformation angle of the exterior joint was small, joint shear deformation angle of the interior joint increased after the story rotation angle of 1/50rad.. It was considered that the joint shear strength was achieved after the story rotation angle of 1/50rad..

Joint shear strength - story rotation angle relationships was shown in Fig. 11. The joint shear strength of through column type was maintained joint shear strength after the story rotation angle as 1/100rad. On the other hand, the joint shear strength of through beam type decreased after 1/50rad..

CONCLUSIONS

For the joint composed of reinforced concrete column and steel beam structures, the joint shear strength and frame seismic performances using the two type joints difference of joint seismic performance were discussed.

The following items were observed in this research.

1. From the test results of cross shape specimens, the joint shear strength formula of the through column type was proposed. Calculation results using proposed joint shear formula gave good agreement with the test result of the through column type.
2. For the through column type, the hysteresis characteristics model with regard to the joint shear strength and shear deformation was proposed. In this model, the joint shear strength - shear deformation relationships of concrete and steel portions were superposed. This model gave good angle agreements to the hysteresis characteristics of the experimental results.
3. From the frame test results, it was recognized that the difference of the maximum strength for the frame test specimens came from the difference of the joint seismic performance.

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REFERENCES

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

Report of Steel - Concrete Structures Committee (1991). Japan Concrete Institute

S. Iizuka, T. Kasamatsu and H. Noguchi (1994). Experimental Study on the Strength and the Stiffness of Joints in Mixed Structures. J. Struct. Constr. Eng., AIJ, No.461, 143-152.