1835

INVESTIGATION ON STRESS-TRANSFER MECHANISM OF SRC INTERIOR BEAM-COLUMN JOINTS

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SUMMARY

The purpose of this paper was clarify stress-transfer mechanism of SRC interior beam-column joints, then experimental and analytical studies were carried out. Valuables of the experiment were beam column depth ratio, concrete strength, and steel and concrete shape of horizontal cross-section. All the SRC specimens were failed in joint shear. Experimental results showed that shear strengths of beam-column joints depend on the beam column depth ratio and the shape of joint cross-section. Therefore the joint ultimate shear strengths calculate by AIJ-SRC standard did not close to the experimental values. Analytical results showed that shear strength of shaped steel joints was estimated with three components: a joint web plate, a joint flange frame and transverse flanges. The conclusions are followings. AIJ-SRC standard calculation can estimate well shear strength component of steel joint web. Inelastic model of the calculation overestimates that of joint flange flame. Shape of joint cross-section influences that of transverse flanges. The calculation underestimates that of RC joints. An adequate shear strength estimation for SRC joints proposed.

INTRODUCTION

Mixed frame structures consisting of reinforced concrete columns and steel beams have recently become popular in Japan. The beam-column joints of such structures are usually designed according to the Standards for Shaped Steel and Reinforced Concrete (SRC) Structures published by the Architectural Institute of Japan (AIJ). However, the authors have previously pointed out, based on the results of a database analysis, that calculation of ultimate shear strength using the AIJ-SRC standard equation is not appropriate for either RC-S mixed structures or SRC composite structures. In the present study, experimental and analytical studies were carried out in order to clarify the stress-transfer mechanism of SRC interior beam-column joints.

OUTLINE OF THE EXAMINATION

Overview of the experimental study

Nine SRC specimens were used in this study (Fig. 1). The variables examined were beam-column depth ratio, concrete strength, and the shapes of steel and concrete in a horizontal cross-section. Table 1 shows details of the specimens and material strengths.

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Table 1: The details of the specimen

Specimen Name	Column			Beam		Joint			σ_B (MPa)	Encased steel specimen	Steel yielding stress (MPa)		
	bxD (mm)	Steel L	Steel T	bxD (mm)	Steel	p_w (%)	Steel L	Steel T			PL-16	PL-9	PL-4.5
SRC-1-BW	300x300	A	C	200x300	A	0.19	A	C	31.6	S-1-BW	368	321	341
SRC-1-BWH	300x300	A	C	200x300	A	0.19	A	C	52.8	S-1-BW	368	321	341
SRC-1-W	300x300	A	C	200x300	A	0.19	A	C	34.4	S-1-BW	361	303	353
SRC-1	300x300	A	C	200x300	A	0.19	A	C*	36.7	S-1-BW	361	303	353
SRC-2-BW	300x300	A	C	200x200	E	0.19	A	C	31.5	S-2-BW	368	321	341
SRC-3-BW	300x300	A	C	200x400	F	0.19	A	C	31.0	S-3-BW	368	321	341
SRC-4-W	400x300	B	D	300x300	B	0.14	B	D	38.6	S-4-W	361	303	353
SRC-5-W	400x300	A	D	300x300	A	0.14	A	D	39.0	S-5-W	361	303	353
SRC-6-W	400x300	A	C	200x300	A	0.14	A	C	35.8	S-1-BW	361	303	353

Symbols L: Loading direction T: Transverse direction
b: column (beam) width p_w: joint shear reinforcement ratio
D: column (beam) depth σ_B: concrete strength

Specimen Name

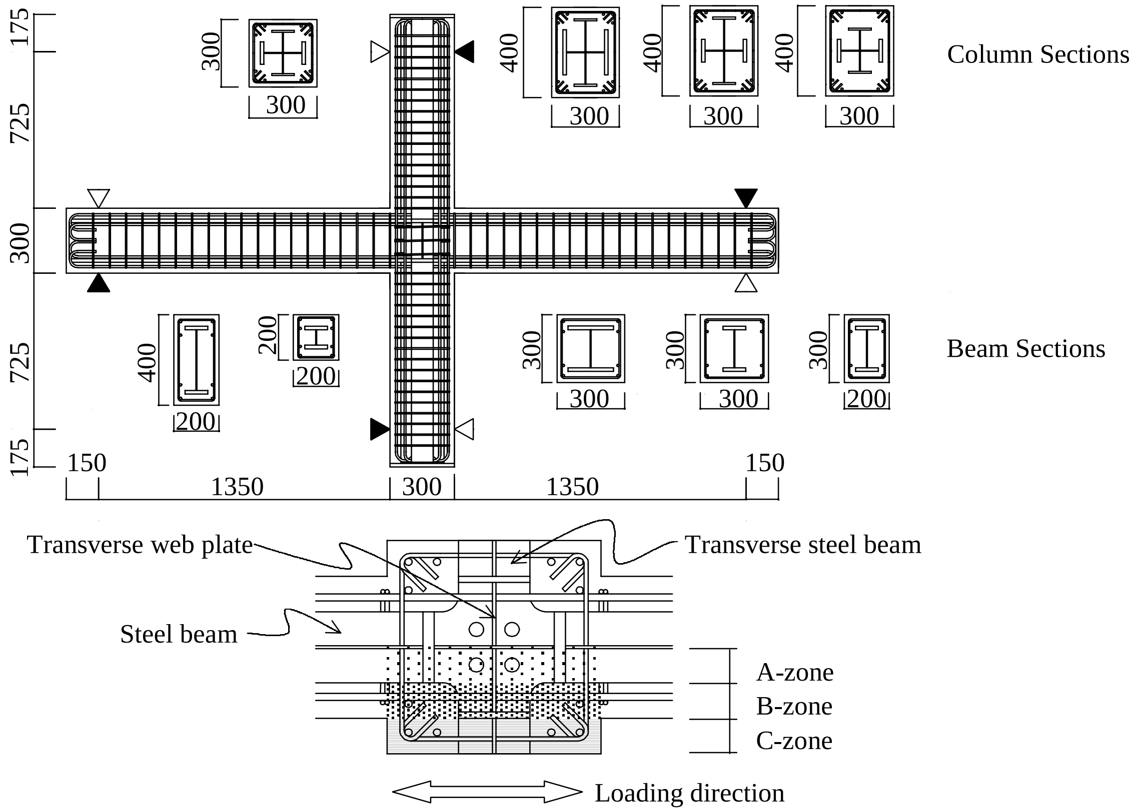
SRC: Steel encased Reinforced Concrete
S：Steel
B：Existence of transverse beam
W：Existence of transverse web plate
H：Using high strength concrete

1: Standard specimen
2: 2/3 of beam column depth ratio
3: 4/3 of beam column depth ratio
4: Double width of A-zone
5: Double width of B-zone
6: Double width of C-zone

Section of steel

A: H-200x100x4.5x16
B: H-200x200x4.5x16
C: H-200x100x4.5x9
D: H-300x100x4.5x9
E: H-130x100x4.5x16
F: H-270x100x4.5x16

* no existence of transverse web plate



Horizontal section of a joint

Figure 1: Elevation view of specimen and detail of a beam-column joint

The specimens were beam and column segments between inflection points in a frame subjected to lateral loading. Reversed cyclic loading was applied by pulling and pushing on the tops of columns, with vertical reactions provided at the ends of the beams. Steel specimens with the same configurations as those of shaped steel in the SRC specimens were also tested. All of the SRC specimens failed in joint shear. Experimental results showed that the shear strength of a beam-column joint depends on the beam-column ratio and the shape of the joint cross section.

Method of analysis

The method used for analysis was as follows. It was assumed that the shear strength of a shaped steel joint could be estimated from measurements of the shear strengths of the following three components: the joint web plate, the joint flange frame, which is a square frame consisting of two pairs of beam and column flanges surrounding a joint, and transverse flanges, which are flange plates of an H-shaped steel column arranged transversely to the lateral loading direction. The shear strength of each of these components was calculated by elasto-plasticity stress-strain analysis. Shear strength of the joint web plate was calculated by principal stress, which was measured using rosette-type strain gauges; and shear strengths of the joint flange frame and transverse flanges were calculated using a bi-linear model of moment-curvature obtained from measurements using strain gauges (Fig. 2).

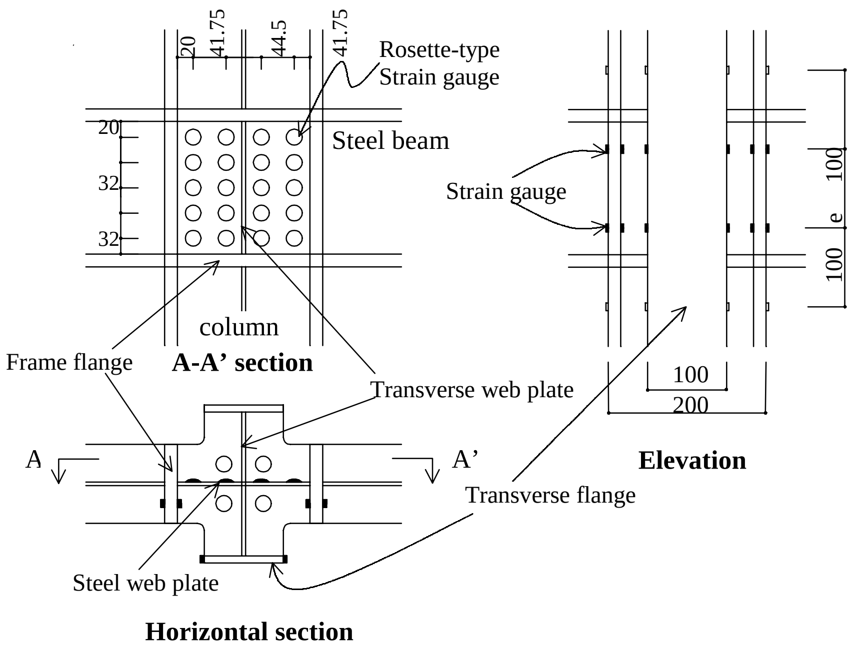


Figure 2: Strain gauge affixing position

DISCUSSION

Verification of the validity of the analytical values obtained using the steel specimen

The analytical values, which were obtained by summing the shear strengths of the above-mentioned three components, were compared with the experimental values obtained from measurements using steel specimens (Fig. 3). The vertical axes of the graphs in Figure 3 represent joint shear strengths, and the horizontal axes represent the deformation angles of beam-column joints. The deformation angle of a beam-column joint was calculated from changes in the diagonal length of the joint. The analytical and experimental values for specimens S-1-BW (the standard specimen), S-2-BW and S-3-BW were very similar, suggesting that the shear strength of a steel joint could be accurately estimated from the shear strengths of the above-mentioned three components. However, the analytical values of the specimens with a large transverse web width were only about 80% of the experimental values. Further investigation is needed to determine the reason for these discrepancies.

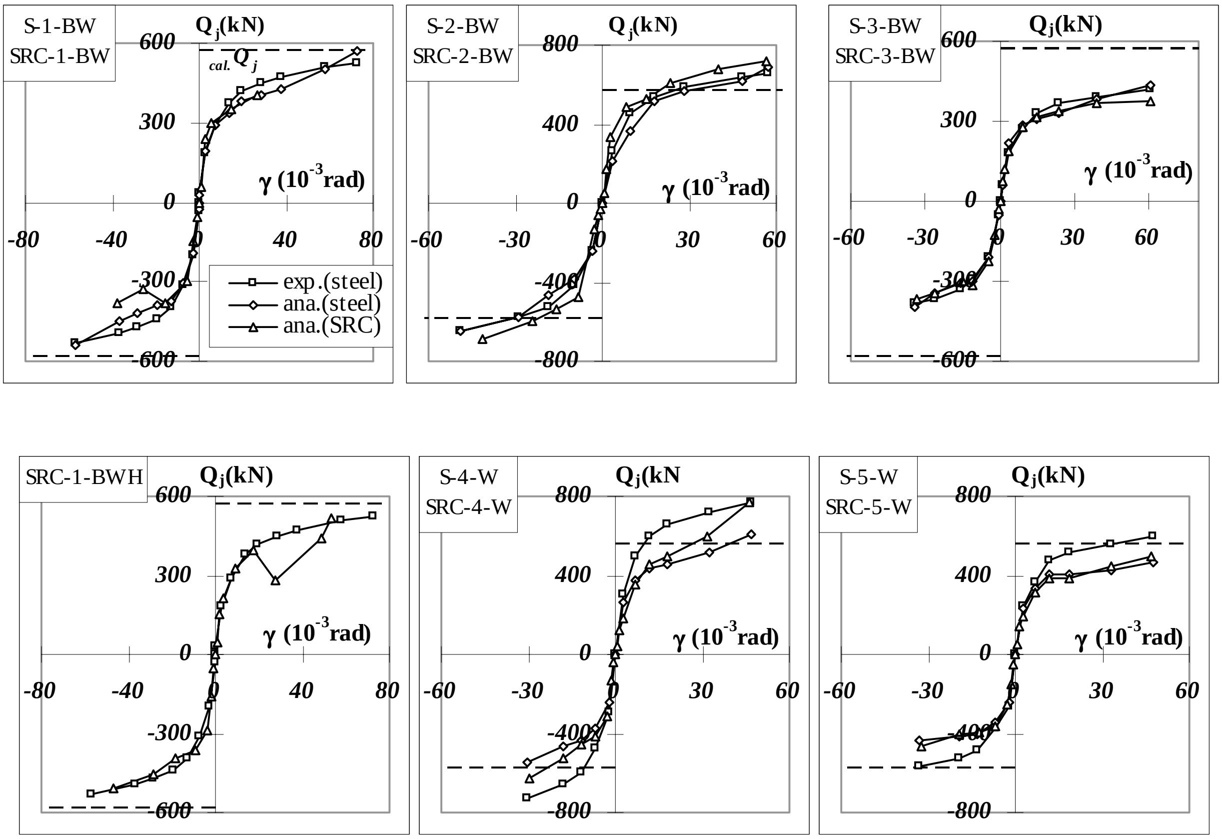


Figure 3: Analytical and experimental value of shear strength of steel specimen

Effect of beam-column joints components

Shear strength of a joint steel web plate

Figure 4 shows a comparison of the shear strengths of the joint steel web plates in the SRC specimens. The calculated values were obtained by using equation (2) (see Appendix). The analytical value of joint shear deformation at maximum strength was slightly larger than the calculated value in most of the SRC specimens. These results indicate that the shear strength of a joint steel web plate can be accurately estimated by using the AIJ-SRC standard equation.

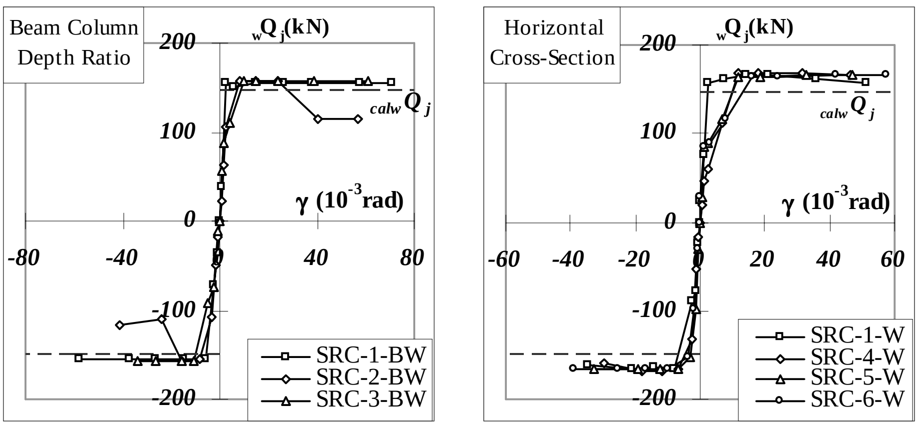


Figure 4: Analytical shear strength of steel web plate

Shear strength of a joint flange frame

Figure 5 shows a comparison of the shear strengths of joint frames calculated by using an inelastic model. The calculated values were obtained by using equation (3) (see Appendix). The shear strength of the joint flange frame in the SRC specimens increased as the beam-column depth ratio decreased. This was also the case for the steel specimens. Concrete strength, existence of a joint transverse steel web, and C-zone width did not exert any clear effects on the shear strength of the joint flange frame. The effects of the shapes of the horizontal cross section were as follows. The shear strength of the joint flange frame in the specimen with a wide A-zone (SRC-4-W) was more than twice that in the standard specimen (SRC-1-BW). However, the shear strength in the SRC specimen with a wide B-zone (SRC-5-W) was smaller than that in the standard specimen, while the shear strength in the steel specimen with a wide B-zone (S-5) was greater than that in the standard specimen. Moreover, the analytical value of ultimate shear strength was less than the calculated value in all of the SRC specimens.

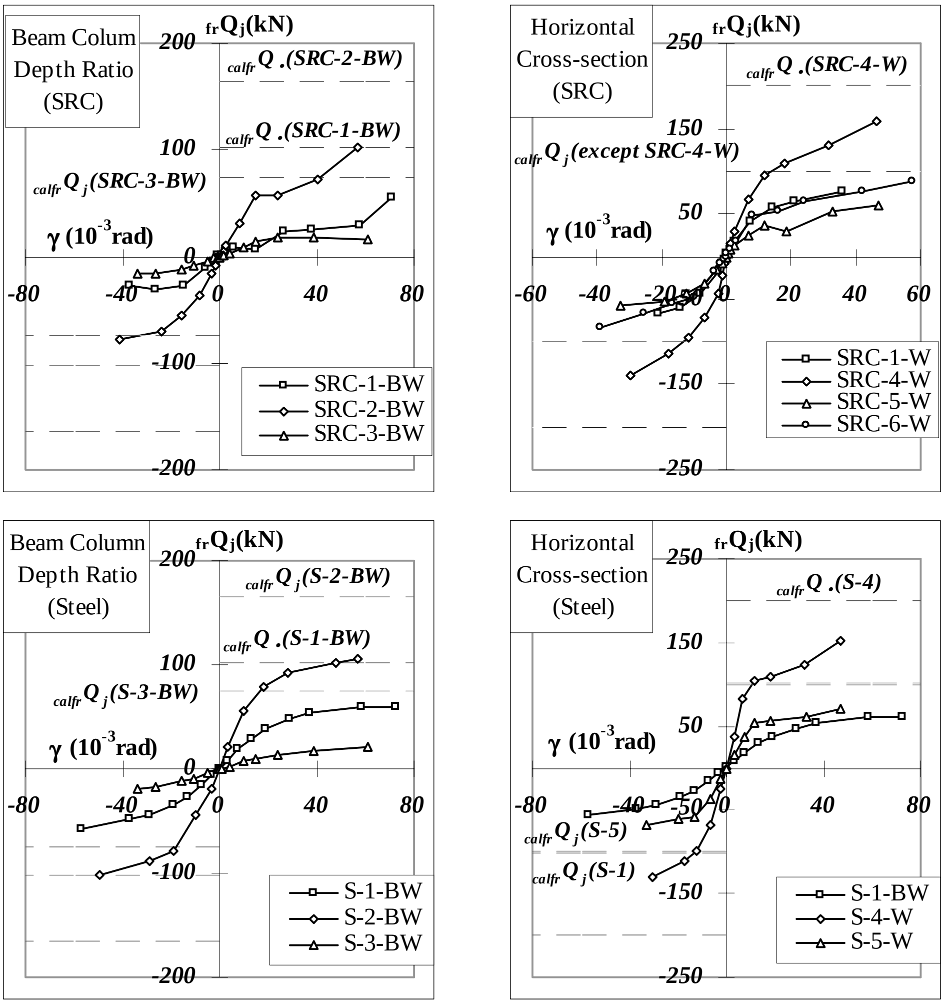


Figure 5: Analytical shear strength of a joint flange frame

Shear strength of transverse flanges

Figure 6 shows a comparison of shear strengths of the joint transverse flanges in the SRC specimens. The calculated values were obtained by using equation (4) (see Appendix). The shear strength in specimen SRC-2-BW, which had a small beam-column ratio, was almost twice that in the other specimens. Moreover, the shear strength in specimen SRC-1-BWH, which contained high-strength concrete, was slightly larger than that in the standard specimen (SRC-1-BW) in a state of large deformation. The shear strengths in the specimens with a wide A-zone or C-zone, in which the shape of the horizontal cross section was the tested variable, were larger than the calculated values. On the other hand, the shear strength of the specimen with a wide B-zone was less than that in the other specimens. This was also the case for the steel specimens. It appears that the shear load that is entered by the beam is small. The reason for this is that the transverse flange is relatively distant from the steel beam in the lateral loading direction, and the membrane stiffness of the joint steel beam flange is low.

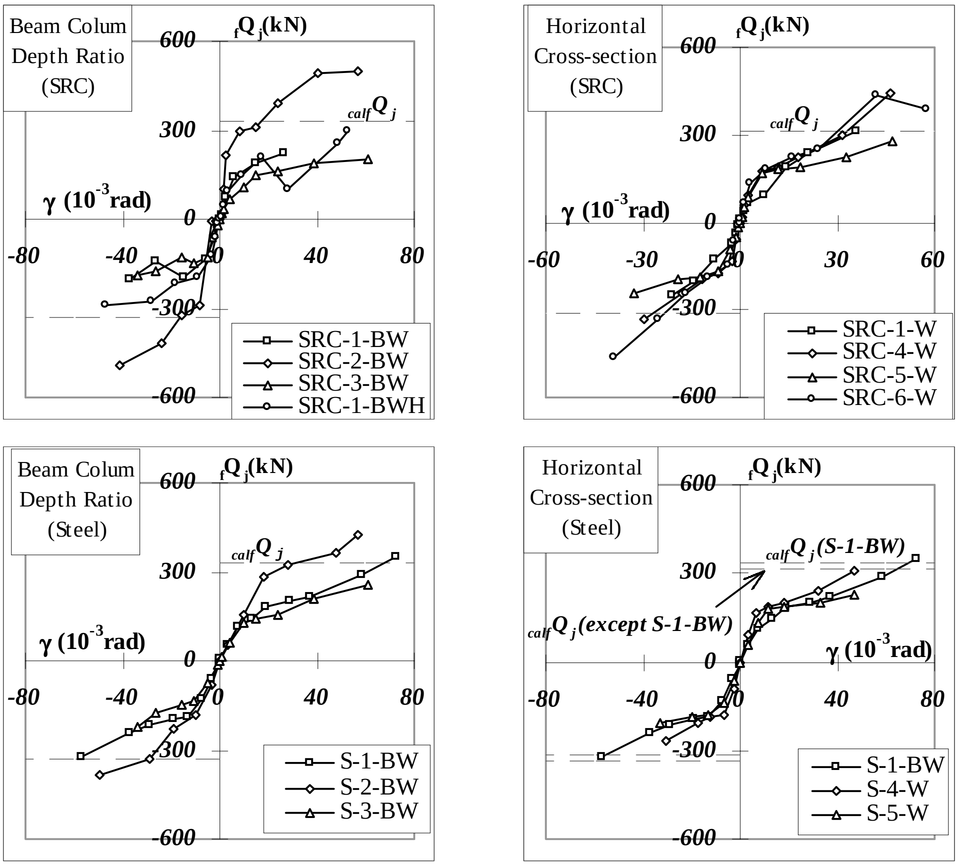


Figure 6: Analytical shear strength of a joint transverse flange

Shear strength of reinforced concrete

Except for specimens SRC-4-W and SRC-5-W, the shear strength of reinforced concrete in the SRC specimens was calculated by subtracting the analytical value of the steel from the experimental value at the time of ultimate shear strength. However, as mentioned above, since the analytical values of shear strength in the specimens with a wide transverse web (SRC-4-W and SRC-5-W) were only about 80% of the experimental values, the shear strength of reinforced concrete in these specimens was estimated by first dividing the analytical value for steel by 80% and then subtracting the resultant value from the experimental value.

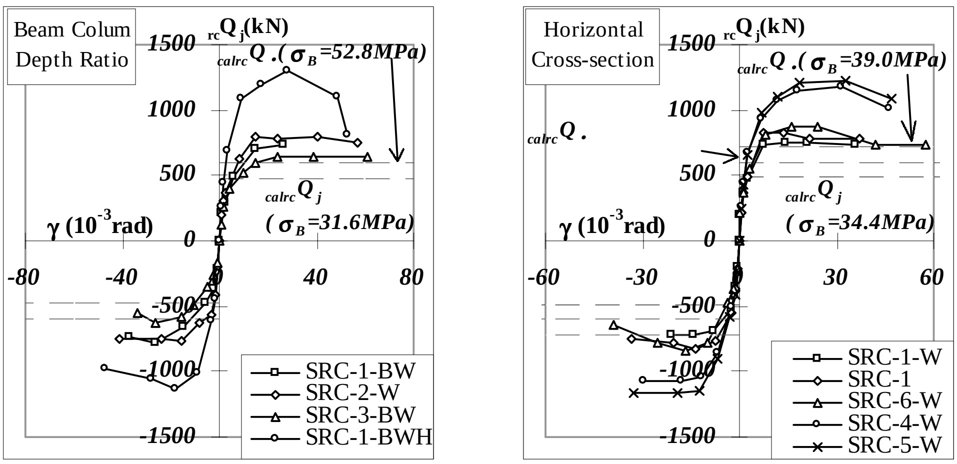
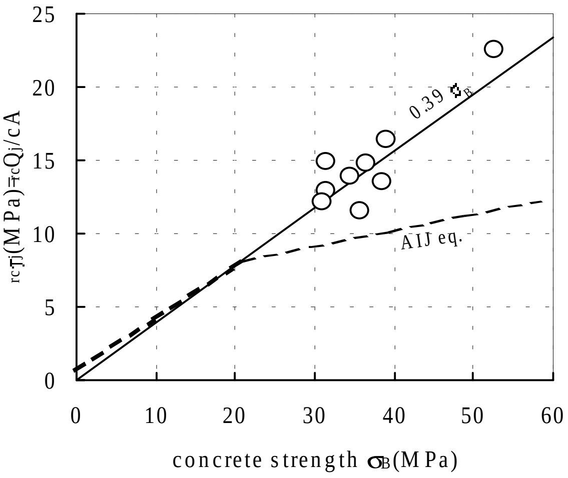


Figure 7: Analytical shear strength of reinforced concrete

Figure 7 shows a comparison of shear strengths of reinforced concrete in the SRC specimens. The calculated values were obtained by using the AIJ-SRC standard equation (see equation (5) in Appendix). The shear strength of the specimen that contained high-strength concrete (SRC-1-BWH) at ultimate strength was about 1.7-times greater than that of the standard specimen (SRC-1-BW). The concrete strength of specimen SRC-1-BWH was also about 1.7-times greater than that of the standard specimen. Therefore, the shear strength of concrete seems to be proportionally related to concrete strength in the range of 30-60 MPa (Fig.8). The shear strength of reinforced concrete increases as the beam-column depth ratio decreases. Neither the existence of a joint transverse steel web nor the width of the C-zone had any clear effect on the shear strength of reinforced concrete. However, a significant decrease in the shear strength of reinforced concrete was observed in the specimen with a wide C-zone.



Proposed equation for estimating the ultimate shear strength of an SRC beam-column joint

Based on the above results, an equation for estimating the ultimate shear strength of an SRC beam-column joint is proposed here. The shear strength of a joint steel web can be estimated by using the AIJ-SRC standard equation. Since the experimental value of shear strength of a joint flange frame was only about half of the value calculated using equation (3), the shear strength of a joint flange frame can be accurately estimated by multiplying the value obtained from equation (3) by 0.5. For the same reason, the shear strength of a joint transverse flange can be accurately estimated by multiplying the value obtained from equation (4) by 0.9. Since the coefficient of concrete shear strength was determined by the method of least squares to be 0.39, concrete shear strength can be accurately estimated by multiplying concrete strength by 0.39. The following equation is therefore proposed for estimating the ultimate shear strength of an SRC beam-column joint:

$$ {}_jQ_u = {}_CA \times 0.39\sigma_B + A_w \times {}_wQ_j + A_f \times 0.9\,{}_fQ_j + 0.5\,{}_{fr}Q_j \quad (1) $$

Figure 9 shows a comparison of the experimental values of ultimate shear strength of SRC interior beam-column joints and the values calculated by using the above equation.

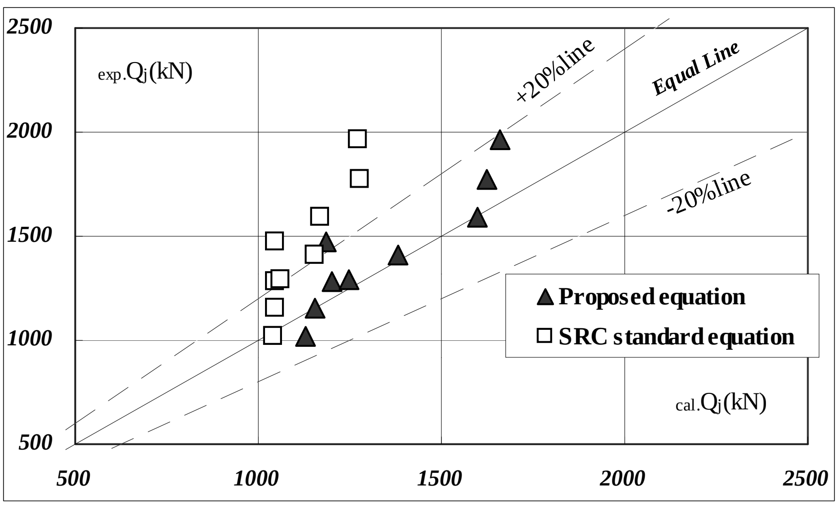


Figure 9: Comparison of experimental and calculated values of ultimate shear strength of SRC beam-column joints

CONCLUSIONS

Experimental and analytical studies were carried out in order to clarify the stress-transfer mechanism of SRC interior beam-column joints. The following conclusions were drawn from the results: 1) the shear strength of a steel joint web can be accurately estimated by using the AIJ-SRC standard equation, 2) calculation of shear strength of a joint flange frame using an inelastic model results in overestimation, 3) the shape of the joint cross section affects the shear strength of the transverse flanges, 4) calculation of shear strength of concrete reinforcement using the AIJ-SRC standard equation results in overestimation, and 5) ultimate shear strength of an SRC beam-column joint can be accurately estimated by using the proposed equation.

APPENDIX

The equations for estimating shear strength
Ultimate shear strength of a beam-column joint by AIJ-SRC standard

$$_{src}Q_j = \left\{ {}_C V_e \left({}_J F_s \cdot {}_J\delta + {}_w p \cdot {}_w\sigma_y \right) + \frac{1.2\,{}_S V \cdot {}_S\sigma_y}{\sqrt{3}} \right\} \Big/ {}_{mB}d \qquad (1)$$

Where, ${}_C V_e = \frac{{}_C b + {}_B b}{2} \cdot {}_{mB}d \cdot {}_{mC}d$, ${}_S V = {}_J t_w \cdot {}_{SB}d \cdot {}_{SC}d$, ${}_J F_s = \min\left(0.12F_c, 18 + \frac{3.6F_c}{100} \right)$

Shear strength of a joint steel web plate

$$_wQ_j = \frac{{}_{Sw}\sigma_y}{\sqrt{3}} \cdot A_w \qquad (2)$$

Shear strength of a joint flange frame

$$_{fr}Q_j = \left(\alpha \cdot b_{fr} \cdot t_{fr}{}^2 \cdot {}_{fr}\sigma_y / 4 \right) \Big/ {}_{mB}d \qquad (3)$$

where, $\alpha=8$

Shear strength of a transverse flange

$$_fQ_j = \frac{{}_f\sigma_y}{\sqrt{3}} \cdot A_f \qquad (4)$$

Shear strength of reinforced concrete

$$_{rc}Q_j = {}_C A \cdot \left({}_J F_s \cdot {}_J\delta + {}_w p \cdot {}_w\sigma_y \right) \qquad (5)$$

Symbols:

srcQj: shear strength of an SRC beam-column joint
sQj: shear strength of a steel beam-column joints
rcQj: shear strength of a reinforced concrete
jδ: form factor (interior beam-column joint=3)
wQj: shear strength of a joint steel web plate
t_w: thickness of a joint steel web plate
${}_{fr}Q_j$: shear strength of a flange frame
${}_fQ_j$: shear strength of a transverse flange
${}_{Sw}\sigma_y$: yielding stress of a steel web plate
b_{fr}: width of steel beam and column flange
t_{fr}: thickness of steel beam and column flange
${}_{fr}\sigma_y$: yielding stress of steel beam and column flange
${}_f\sigma_y$: yielding stress of transverse flange
${}_cA$: cross-sectional area of RC
A_w: cross-sectional area of a joint steel web plate
A_f: cross-sectional area of transverse flange

REFERENCE

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