STRUCTURAL PERFORMANCE OF MIXED MEMBER COMPOSED OF STEEL REINFORCED CONCRETE AND REINFORCED CONCRETE

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SUMMARY

On the assumption that the member in which the structural form changes from steel reinforced concrete (SRC) structure to reinforced concrete (RC) structure, two kinds of experiments were carried out in relation to concrete member with steel which was cut on the way of the member. One was development of composite beam that consisted of SRC structure in both ends of the beam and RC structure with diagonal reinforcements in the middle of beam. Another was a research concerning the shear properties of RC column where the steel extended from column base to the way of the height of the column. This was assumed the column where the structural form changed SRC to RC in the middle floor. However, there are few studies concerning the shear properties of RC column including the steel at the column base side. In the composite beam of which the steel was cut on the way of the member, yield hinges were formed at both ends of the beam, and the flexural strength exhibited higher than the calculated value from the general superposed strength method when both the setting the device for anchorage in the steel and the adequate arrangement of additional bars were provided. The shear strength of the columns with steel that existed below the half of height of the column was lower than that of the column without steel.

INTRODUCTION

Timber structure, reinforced concrete structure, steel frame structure, and steel reinforced concrete structure, etc. are enumerated as a typical structural form of building. Designers are able to choose the structural form that is made use of each characteristic according to the usage and the scale of the building. These structural forms have distinguishing characteristic respectively, and if it is possible to combine only good points of the structural form, it will be ideal and economical.

This paper is composed of two experimental studies for the member in which the structural form changes from steel reinforced concrete (SRC) structure to reinforced concrete (RC) structure on the way of the length of a member. One is development of composite beam that consists of SRC structure in both ends of the beam and RC structure with diagonal reinforcements in the middle of beam. A general view of this beam is shown in Figure 1a. The distinguishing characteristics of the composite beam is to be composed of SRC at the both beam ends where the stress is high at the earthquake and RC with diagonal reinforcements (X-shape bars) in the middle of beam.

The objectives are that a structural performance of this beam is equal to that of SRC beam, and that the flexural strength exceeds the calculated value from the general superposed strength method [1].

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Another study is a research concerning the shear properties of RC column where the steel extends from column base to the way of the height of the column. In the building of about eight stories, there is occasionally what a lower floor is composed of SRC, and the upper layer floor is composed of RC. The column in which the structural form changes SRC to RC at the way of the height is shown in Figure 1b. In such the column, it is general to cut the steel that is extended from the column base at the center of the height of the column. In the Hyogo-ken Nanbu earthquake, it was reported that a lot of destruction of columns in the middle floor of the buildings was seen. The change of the structural form of the columns in the middle floor was thought as one of the causes.

However, there are few studies concerning the shear properties of RC column including the steel at the column base side. The objectives of this experiment are to clear the effect of the steel existing on the way of the RC member on the shear properties. In this paper, these experimental results were introduced. It is expected to become one material that should correspond to the composite structural forms that seem to be diversified in the future.

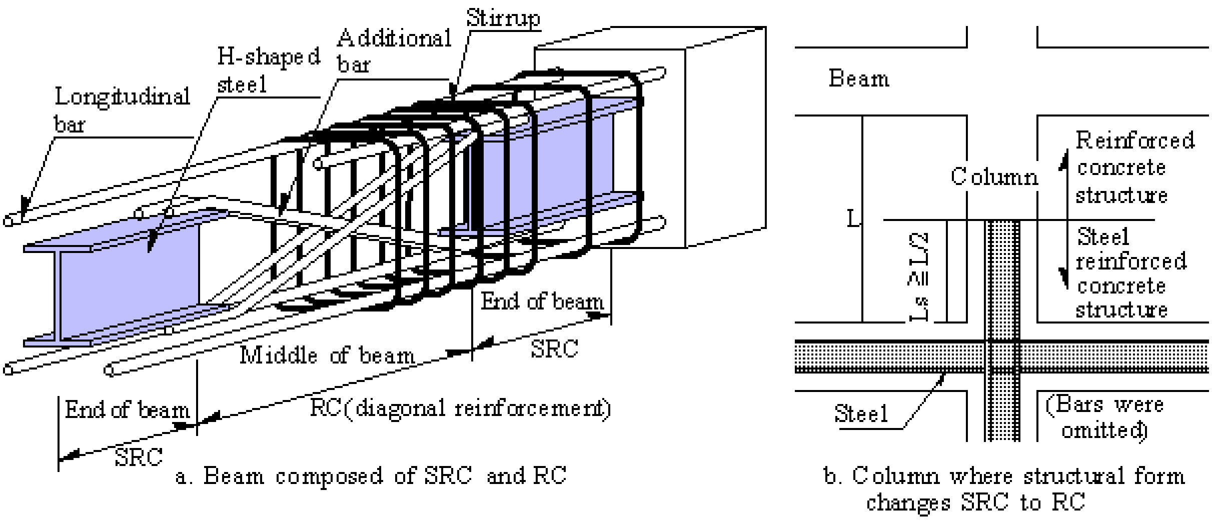

Figure 1: The member composed of SRC and RC

THE COMPOSITE BEAMS CONSISTING OF SRC IN THE BEAM-ENDS AND RC IN THE MIDDLE OF THE SPAN

Test specimens and parameters

Table 1 shows specimen list, and the bar arrangements and dimensions are shown in Figure 2. The specimens consisted of SRC structure in both ends of the beam and RC structure in the middle of beam. The steels that extended from both ends of the test section were cut in the length of a quarter of inside span length of beam. The position where this structural form changed was defined as " J-point ". The bars arranged at four corners of stirrup penetrated the stubs connected to the both sides of test section, namely, the bars were longitudinal bars which contribute to flexural strength at the end of the beam. On the other hand, the additional bars must be anchored in SRC region or be welded to steel flange and not be anchored in the stubs because the additional bars supplemented flexural strength at the vicinity of J-point where the steel was cut.

The principal factors of the specimens were stirrup ratio, figure and anchoring method of additional bars and figure of the beam. For each specimen, the stirrups about twice amount in other parts were arranged at the vicinity of J-point. The additional bars of the P-ST and P-PL beams were straight, while for the other specimens, diagonal reinforcements were used as the additional bar. Anchoring methods of the additional bars for the specimens of which final mark of specimen name was [PL] were plate anchorage, [WE] were flare welding to steel flange (welding length was 200 mm), and the other were bond of additional bar.

To prevent the steel being pulled out from the test section, the stiffeners were attached to the steel vicinity of J-point for all specimens. Seven stud bolts with 13 mm in diameter and 60 mm in length were welded to the each steel flange of the specimens of which final mark of specimen name was [ST]. The base specimens had a cross-

Table 1: Specimen list

series	Specimen name	Figure of section (mm)	L/D	Longitudinal bar	Steel (SS400)	Stirrup J-point	Stirrup Other	Additional bar Figure	Additional bar Bar	Additional bar Anchorage	Stud bolt 13 ϕ L=60mm
1	P-ST	b x D= 320x400	5	2-D22 (SD345)	H200·130 ·8·12	2-D6 pw =0.32%	2-D6 pw =0.16%	Straight	2-D22 (SD345)	Bond of bar	7 per flange
	X-N							Diagonal			None
	X-ST										7 per flange
	X-WE									Welding	none
2	P-PL					2-D6 pw =0.61%	2-D6 pw =0.34%	Straight		Plate	
	X-PL							Diagonal			
	XT-WE	Slab width =600								Welding	
	X33-PL	b x D= 255x300	6.6	2-D16 (SD345)	H125·100 ·6.5·9	2-D6 pw =0.45%	2-D6 pw =0.23%		2-D16 (SD345)	Plate	

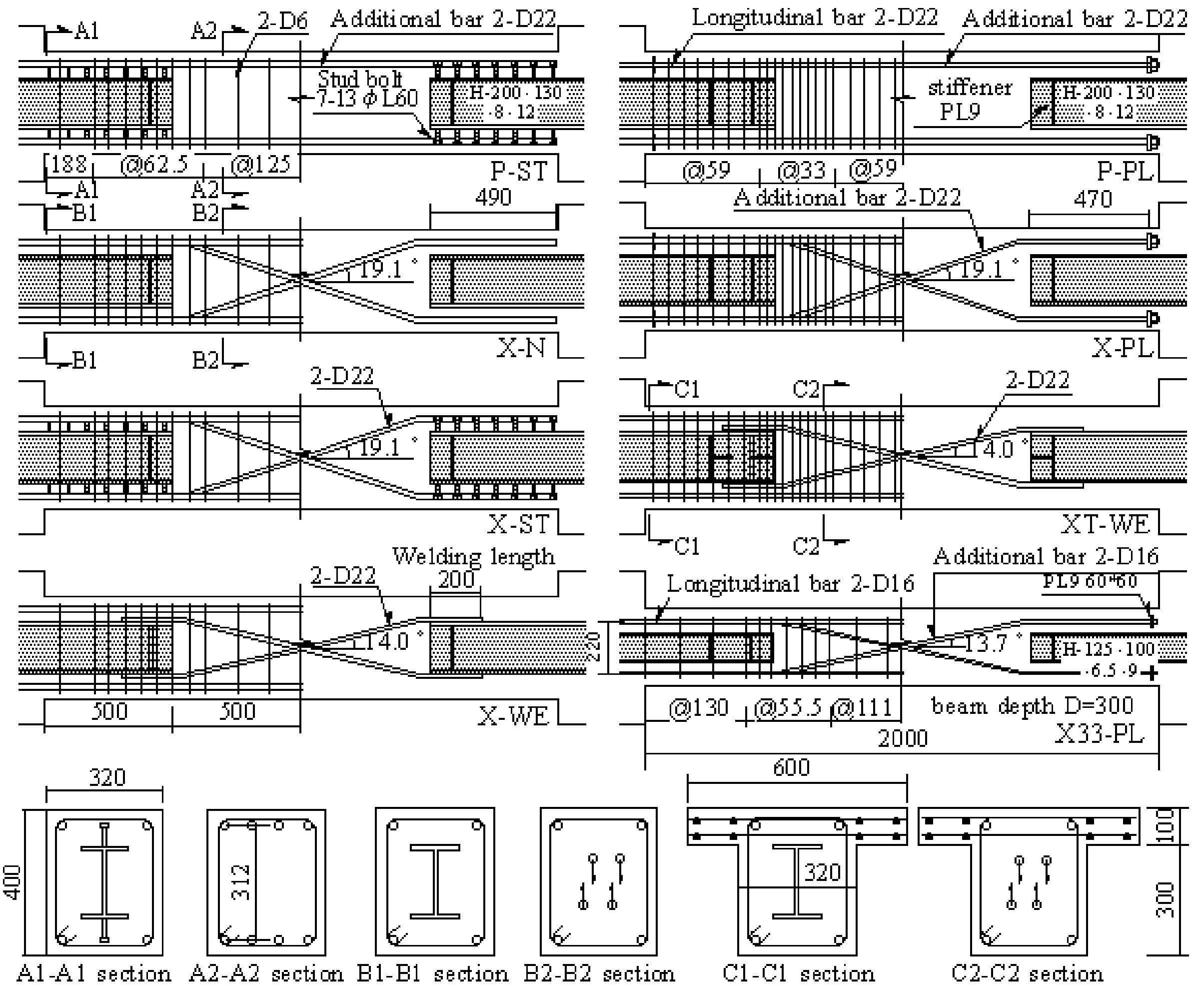

Figure 2: Bar arrangements and dimensions (beam)

section of 320 x 400 mm, and clear span depth ratio (L/D) was 5.0. While the clear span length of the X33-PL beam was the same as that of base specimen, the size of cross-section, steels and longitudinal bars were smaller than that of base specimen, and so L/D of the X33-PL beam was 6.6. The XT-WE beam had T-figure cross-section. The mechanical properties of concrete, bars and steels are shown in Table 2.

Table 2: Mechanical properties of materials

Series	Material		Yield strength fy (MPa)	Elastic modulus sE (GPa)	Concrete
1	D22A*1	Longitudinal & additional	393	196	fc'=29.1 (MPa)
	PL12	H-200・130・8・12	274	207	cE=25.9 (GPa)
2	D16	Longitudinal & additional	393	193	fc'=23.7 (MPa)
	PL12	H-200・130・8・12	318	208	cE=22.8 (GPa)
	PL9	H-125・100・6.5・9	287	209	
Common	D22B	Longitudinal & additional	366	194	fc' : Compressive strength
	D6	Stirrup & slab	433	189	cE: Elastic modulus
	*1 Used for X-WE. D22B was used for others				

Loading method

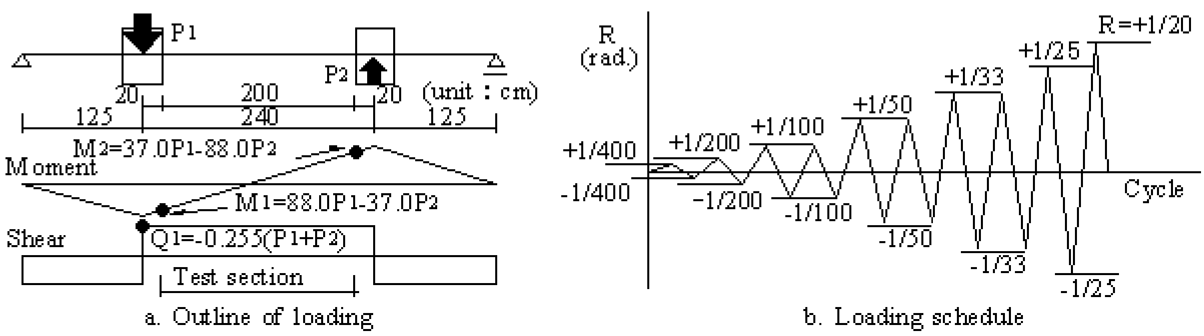

Figure 3: Loading method (beam)

Figure 3a shows the outline of the loading method. Both ends of specimen were supported with pin and roller system, respectively, and the load was supplied to the specimen at P1 and P2 in Figure 3a by push-pull type oil jack. The load was supplied by control that displacement of right and left stubs became reverse-symmetry. The reversed cyclic load was supplied at each drift angle according to loading schedule shown in Figure 3b.

Test results

Table 3 shows test results, Figure 4 shows the final destruction state and Figure 5 shows the relationship between shear force and drift angle of the test section. In all specimens, bending cracks occurred at the beam-ends and then bend-shear cracks and shear cracks occurred in the SRC region. The longitudinal bars and steel flanges yielded between 1/200 rad. and 1/100 rad. of drift angle. Up to this time, the difference of the crack state by the experiment factors was not seen, and the cracks did not concentrate at the J-point or the RC region that was middle of the test section. In the P-ST, X-N and X-ST beams, the maximum strength was recorded at the same time as shear failure occurred between 1/100 rad. and 1/50 rad. of drift angle because the shear crack which extended from the J-point to the RC region widened. In the beam with straight additional bars that were anchored by plates (P-PL), bond-splitting failure occurred in the RC region at cyclic loading of 1/50 rad. of drift angle.

Table 3: Test results (beam)

Specimen name	P-ST	X-N	X-ST	X-WE	P-PL	X-PL	XT-WE	X33-PL	f-yield: Flexural yield shear: Shear failure bond: Bond splitting failure anchor: Anchorage failure of additional bar
Yield of longitudinal bar	190	189	209	210	178	188	224	84.8	
Yield of steel flange	199	234	209	233	230	261	262	89.8	
Maximum strength	237	238	250	292	265	271	329	104	
State of failure	f- yield ↓ shear	f- yield ↓ shear	f- yield ↓ shear	f- yield	f- yield ↓ bond	f- yield ↓ anchor	f- yield	f- yield	

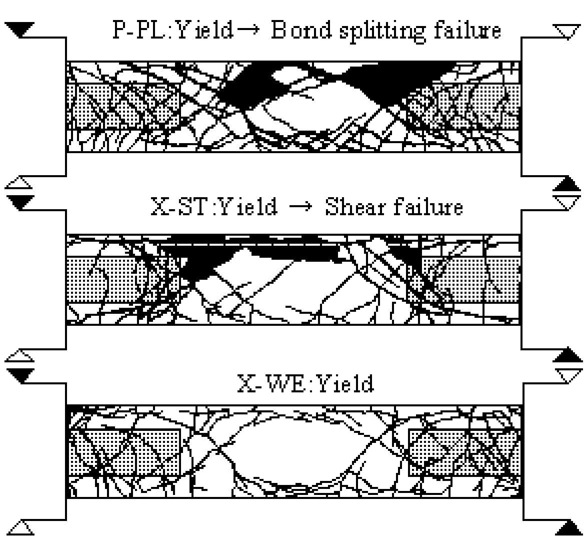

Figure 4: Final destruction state (beam)

The X-PL beam was the same as the P-PL beam except the figure of the additional bars. In the X-PL beam, bond crack along the bars did not occurred in middle of the span, yield hinges were formed at both ends of beam, and the hysteresis characteristic was stable after flexural yielding. However the strength decreased finally owing to

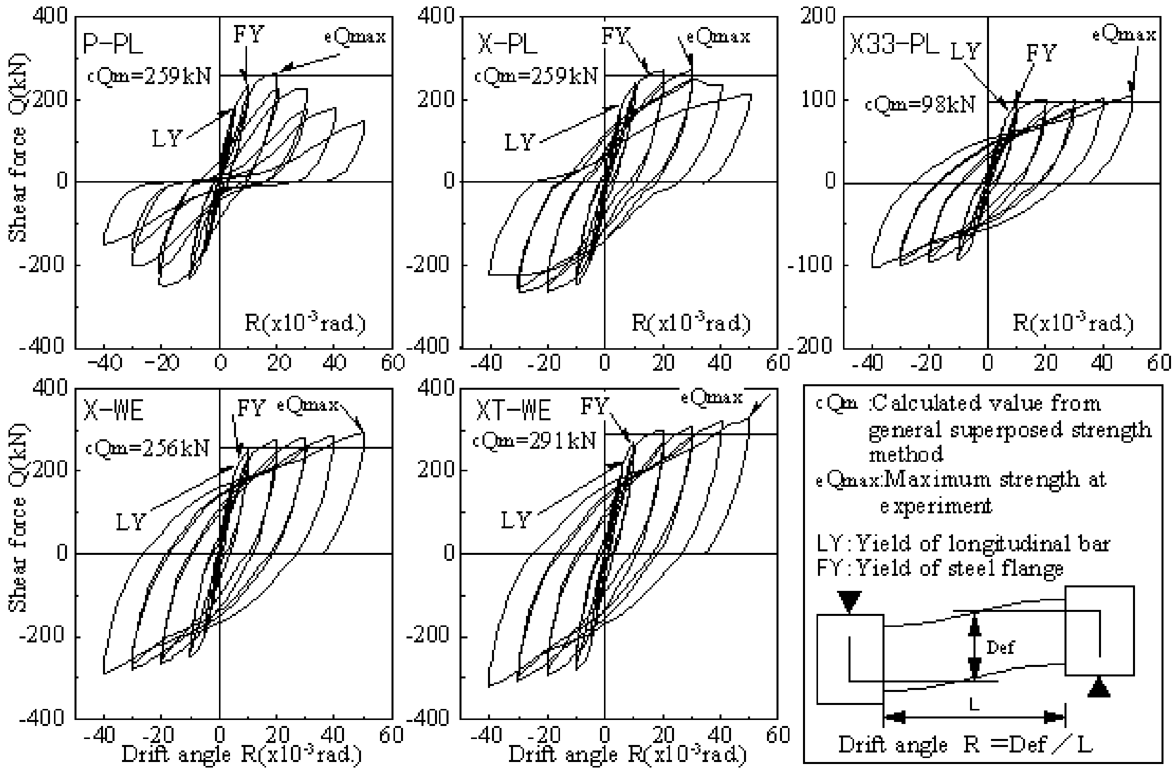

Figure 5: Relationship between shear force (Q) and drift angle (R)

the anchor failure occurred in the part of anchor plate of additional bars before the time of 1/25 rad. of drift angle.

In the specimens with straight additional bars, bond splitting failure is caused easily because of the bars are arranged in the direction of the beam width. It is thought that the effective width of concrete per bar increases by changing straight additional bars to diagonal reinforcement. As a result, it was effective to prevent from bond splitting failure and shear failure to use diagonal reinforcement as additional bar. It was necessary for the diagonal reinforcement to be anchored in SRC region suitably. In the X-WE and the XT-WE beams of which the diagonal reinforcements were welded to the steel flange and in the X33-PL beam of which L/D was 6.6, there was no decrease of strength and the hysteresis characteristics were stable up to final loading. In the specimens that did not occurred fatal destruction with decrease of strength, the flexural strength higher than the calculated value from the general superposed strength method.

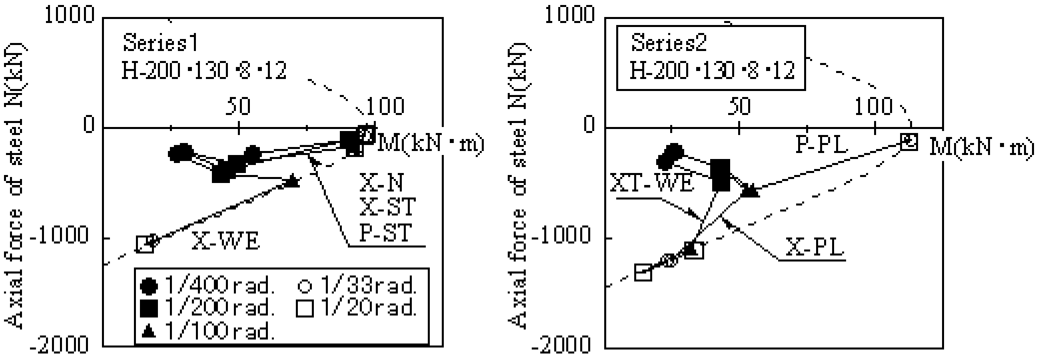

Figure 6: Moment - axial force interaction curves of steel at end of beams

Figure 4: Final destruction state (beam)

Figure 6 shows moment - axial force interaction curves of the steel at end of the beams. In this figure, the moment and the axial force of the steel were estimated from strain that was measured by strain gages put on the steel face. According to Figure 6, in the specimens that did not occurred fatal destruction with decrease of strength, the steel bore tension force in the direction of the member axis.

THE COLUMNS WHERE THE STRUCTURAL FORM CHANGES FROM SRC TO RC

Test specimens and parameters

Table 4 shows specimen list, and the bar arrangements and dimensions are shown in Figure 7. The column in the middle floor of eight stories general office construction composed of rigid frame structure was modeled with a scale of about 1/2 as specimen. Four specimens were prepared in this experiment, three of them had steel in the column base side, another was normal reinforced concrete without steel. The specimens were rectangular columns with a cross-section of 400x400 mm and with inside span length (test section length) of 1200 mm (L/D=3.0). In Figure 7, the side including steel was defined as column base side and the other was defined as capital side. The steel included in the specimen was H-shaped steel with dimension of 204 x 200 x 12 x 12 mm,

Table 4: Specimen list and test results (column)

Specimen name	Steel (SS400)	Steel length including test section Ls(mm)	Diagonal tension style crack eQdc(kN)	Maximum strength		State of failure
				Shear force eQmax(kN)	Drift angle R(x10^{-3}rad.)	
S3-00	none	0	none	431	9.3	Shear failure
S3-30	H-200・204・12・12	300	401	401	6.1	
S3-60		600	325	400	8.4	
S3-90		900	312	446	9.7	

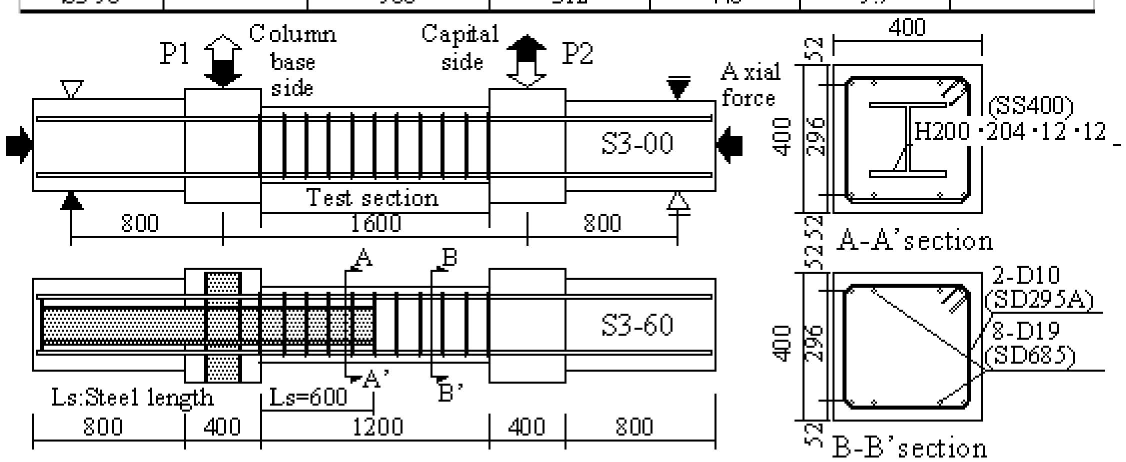

Figure 7: Bar arrangements and dimensions (column)

Table 5: Mechanical properties of materials				
Material		Yield strength fy (MPa)	Elastic modulus sE (GPa)	Concrete
D19	Longitudinal	755*1	200	fc'=25.9 (MPa)
D10	Stirrup	363	181	cE=24.5 (GPa)
PL12	H-200･204･12･12	228	209	fc': Compressive strength
	*1 0.2% offset yield strength			cE: Elastic modulus

and was arranged in the strong-axis bending direction for simplification. High strength bars (8-D19: SD685) were used for all specimens as longitudinal bars to prevent yielding of longitudinal bars before shear destruction, and hoops (2-D10: SD295A) were arranged with 120 mm spacing. The principal parameter was the length of the steel that extended from the column base. The S3-00 column was normal RC column. In the S3-30, S3-60 and S3-90 columns, the bar arrangement was same as the S3-00 columns, and the steel length anchored in the test section was varied, that is, the length was 300 mm, 600 mm and 900 mm, respectively. The mechanical properties of concrete, bars and steel are shown in Table 5.

Loading method

The outline of the supplied load method is shown in Figure 7. The shear loading method was same as shown in 2.2 section. The axial stress, which was 0.15 times as much as compressive strength of concrete, was supplied constantly. The reversed cyclic load was supplied at 1/200, 1/100, 1/50 and 1/25 rad. of drift angle of the test section respectively except when the destruction progressed rapidly.

Test results

Table 4 shows test results, Figure 8 shows the final destruction state and Figure 9 shows the relationship between shear force and drift angle of the test section. In all specimens, the maximum strength was recorded at the same

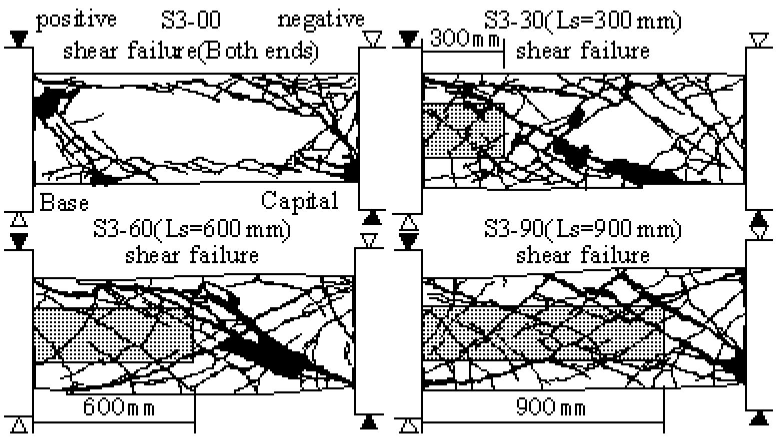

Figure 8: Final destruction state (column)

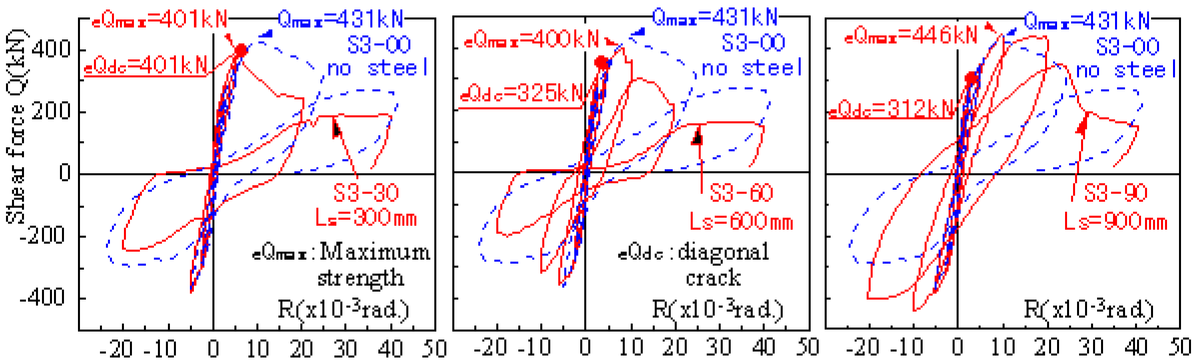

Figure 9: Relationship between shear force (Q) and drift angle (R)

time as shear destruction before yielding of the longitudinal bar. In the specimens with steel at column base side, a big oblique crack occurred from the part where the steel was cut to the compression region of the column capital. This crack is similar to diagonal tension crack that is often observed in short column, and is named " diagonal tension style crack "[4]. At the same time as the occurrence of the diagonal tension style crack, the maximum strength was recorded in the S3-30 column, moreover in the S3-60 column, shear destruction occurred immediately after the rapid declination of stiffness. The occurrence strength of this crack had a tendency to decline as the steel that was anchored in test section extended. On the other hand, in the S3-00 column without steel, no diagonal tension crack occurred, and the destruction concentrated at the both ends of the test section. In the specimens with steel, the destruction concentrate in the region from the steel was cut to the column capital.

In the S3-30 and S3-60 columns of which the ratio of the steel length including test section to test section length (Ls/L) were 0.25 and 0.50, respectively, the maximum strength was lower than the S3-00 columns which had no steel. In the S3-90 column of which Ls/L equal to 0.75, the maximum strength was higher than the S3-00 columns slightly. On the test results, it is presumed that the steel existing on the way of the column influences on the state of destruction and the shear strength in the reinforced concrete region.

CONCLUSIONS

Two kinds of experiments were carried out in relation to concrete member with steel that was cut on the way of the member. One is a suggestion of rationalization that the amount of steel used will be decreased without deterioration of the structural performance. Another is a caution against the structural form that is used generally. The objectives of both experiments were different respectively, however, fundamental characteristics of composite structure that consisted of reinforced concrete and steel reinforced concrete were grasped. The elucidation of stress transfer mechanism is the subject for a future study. The observations obtained from this study were as follows.

Experiment of composite beams consisting of SRC in the beam-ends and RC in the middle of the span

1) In the composite beam of which the steel was cut on the way of the member, yield hinges were formed at both ends of the beam, the hysteresis characteristics were stable, and the flexural strength exhibited higher than the calculated value from the general superposed strength method when both the setting the device for anchorage in the steel and the adequate arrangement of additional bars were provided.

2) The diagonal reinforcements arranged in RC region were effective for flexural reinforcement at the changing point of structural forms, for shear reinforcement and for restraint of bond splitting failure in RC region.

Experiment of the columns where the structural form changes from SRC to RC

1) In the specimens with steel at column base side, "the diagonal tension style crack" occurred from the part where the steel was cut to the compression region of the column capital. This crack affected the structural performance considerably

2) The shear strength of the columns with steel that existed below the half of height of the column was lower than that of the column without steel.

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