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EXPERIMENTAL STUDY ON SHEAR RESISTANCE OF CONCRETE ENCASED STEEL COLUMN USED WELDING WIRE MESH

ATSUNORI KITANO

Dept of Architecture, Maebashi Institute of Technology, Maebashi, Japan

Experimental studies were carried out in order to develop the new structure system using steel and concrete with execution method that is easier than the steel and reinforced concrete (SRC) structures and with earthquake resistant performance that is equivalent to the SRC structures. The new structure was concrete encased steel (SC) structure that it removed the reinforcing bar from the SRC structure and used the welding wire mesh. Following considerations were obtained from the experimental results. Execution method using the wire mesh for the column was easier than that of conventional SRC structure. The equivalent shear strength can expect proposing SC structure using steel cross section equal to SRC structure. Steel cross section of proposing SC structures should be fundamentally enlarged in comparison with the SRC structures, and the steel would bear the flexural capacity. The shear strength of the column in the column-beam frame specimen was dependent on the degree of destruction of the bam-column joint.

Keywords: Composite Structure, Shear Strength, Steel and Reinforced Structure, Construction Method.

1 INTRODUCTION

The number of steel and reinforced concrete (SRC) structures being constructed in Japan has declined. This is because of their complicated structure design and the large number of processes required in their construction. However, their ductility is higher than that of reinforced concrete (RC) structures. For example, the damage to SRC structures was minimal in the Southern Hyogo prefecture earthquake of 1995. We have carried out experimental studies to develop a new steel and concrete (SC) structure system that is easier to construct than SRC structures and with earthquake resistance performance equivalent to that of SRC structures.

2 OUTLINE OF EXPERIMENT

2.1 Test Specimens and Materials Used

Four specimens were tested with dimensions and details in Figure 1 and Table 1. The specimen configuration represents the upper and lower beams and column segments between the inflection points in a frame subjected to lateral loading. The contraction scale of the test specimens was approximately half that of an SRC structure assuming that the column included beams and beam-column joints of a middle floor in a multi-

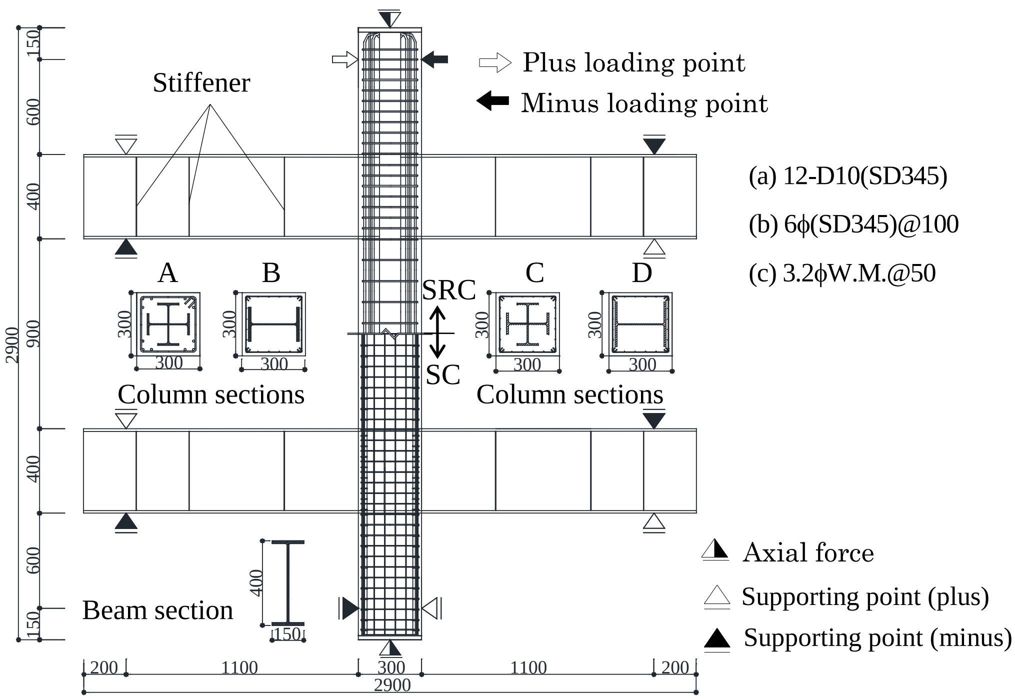


Figure 1. Test specimen dimensions.

Table 1. Details of test specimens.

Specimen		Column p_w[*2] (%)	Column Reinforcement Bar axial	Column Reinforcement Bar shear	Column Steel[*1]	Beam Steel[*1]	Joint p_w[*2] (%)	Joint Reinforcement Bar
A	SRC/S-1-27	0.19	12-D10	6ϕ@50	①	⑤	0.37	6ϕ@50
B	SC/S-4-W-27	0.11	WM3.2ϕ@50	WM3.2ϕ@50	②	⑥	0.11	WM3.2ϕ@50
C	SC/S-1-W-27	0.11	WM3.2ϕ@50	WM3.2ϕ@50	①	⑥	0.11	WM3.2ϕ@50
D	SC/S-5-W-27	0.11	WM3.2ϕ@50	WM3.2ϕ@50	③	⑥	0.11	WM3.2ϕ@50

[*2] p_w : shear rainforcement ratio

[*1] steel configration
①2H-200×100×5.5×8
②H-240×160×4.5×12
③H-240×210×4.5×9
⑤H-400×150× 9×12
⑥H-400×150×12×12

story multi-bay. To ensure that column shear failure occurs before any other failure; the column shear strength was de-signed to be smaller than the flexural and shear strengths of the beam and beam-column joints. The experimental variables were the method of shear reinforcement, the steel column cross section, and the width of steel flange in the column. All specimens had columns 2900 mm high with a 300 mm square section and beams 2900 mm long of single H-section steel. The first and second terms in the specimen name indicate the construction method of the column and beam, respectively. SRC refers to the standard SRC structure in Japan and SC to the structure constructed using welded wire mesh. The third term in the specimen name refers to the type of column steel shape and the last term refers to the specified concrete design strength. Specimen SRC/S-1-27 was prepared as a standard for comparison with other specimens. Specimens in the SC/S-_-W series were constructed using welded wire mesh instead of main and shear reinforcement bars. The steel shape of the column of specimen SC/S-1-W-27 was the same as that of specimen SRC/S-1-27. Specimens SC/S-4-W-27 and SC/S-5-W had an H-shaped steel column section.

The design strength of the concrete was set at 27 N/mm^2. The arrangement of the main column reinforcement bars was 12-D10 for the SRC column series. Other specimens had no main column reinforcement bars. The shear reinforcement of the columns in the SRC series was with 6φ and welded wire mesh of 3.2φ was used for the other specimens.

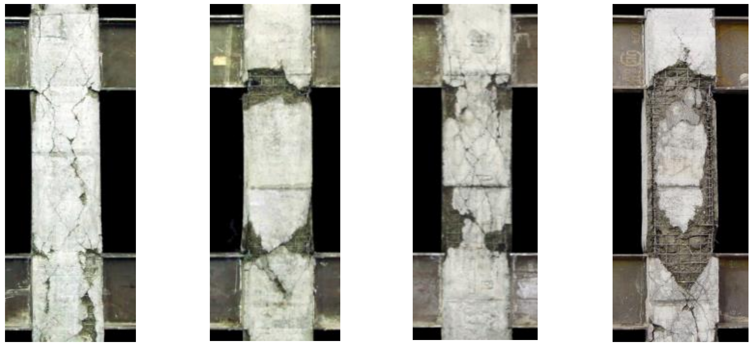
2.2 Loading and Instrumentation

The specimens were loaded with a lateral cyclic shear force by a horizontal actuator at the top of the column while a constant axial compression of $\sigma_0/6$ was applied by a vertical actuator. The upper and lower beams were kept parallel by four jacks installed at the end of the beams. The incremental loading cycles were controlled by the story drift angle, R, defined as the ratio of lateral displacement to column height, δ/h. The lateral load sequence consisted of two cycles for each story deformation angle, R of 0.002, 0.005, 0.010, 0.017, 0.026, 0.037, and 0.05 radians.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Conditions for Failure

The conditions for failure of all specimens after testing are shown in Figure 2. Specimen SRC/S-1-27 failed by shear at the end of the column. An initial shear crack appeared in the column and joints for R (story deformation angle) = 0.002 to 0.005 radians. Thereafter, the widening of the shear crack and crushing at the end of the column were intensified for R = 0.01 to 0.017 radians and the shear reinforcement bars of the column yielded. After R = 0.037 radians, the concrete covering the column flaked off. However, the maximum strength continued increasing until the last loading cycle. SC/S-4-W-27 showed a flexure fracture at the end of the column. Initial flexural and shear cracks appeared in the joints and column at R = 0.005 radians. Mostly, the flexural cracks grew and widened at the end of the column. Thereafter, however, the widening of the shear cracks at the joints was significant. After maximum strength had been achieved, the welded wire mesh was exposed at the end of the column. Buckling and cutting off of the welded wire mesh occurred and the concrete cover came off at the joints. Specimen SC/S-1-W-27 showed a combination of flexure and shear fractures. Initial flexural and shear cracks appeared in the joints and column at R = 0.005 radians. Thereafter, the horizontal and vertical bar of welded wire mesh in the middle and at the end of column, respectively, yielded. The steel web at the end of the column also yielded. The story drift angle at maximum strength was R = 0.017 radians. After maximum strength had been achieved, a widening of the shear crack width was not observed but a bending collapse occurred at the end of the column. Specimen SC/S-5-W-27 failed by bond splitting in the middle of the column and shear in the beam-column joint. An initial flexural and shear crack of the joints and column appeared at R = 0.005 radians. Thereafter, bond splitting cracks appeared over the entire column at R = 0.009 to 0.017 radians. The story drift angle at maximum strength was R = 0.017 radians. After maximum strength had been achieved, the welded wire mesh was exposed at the end of the column. Buckling and cutting off of the welded wire mesh occurred and the concrete cover came off at the joints.



SRC/S-1- SC/S-4-W- SC/S-1-W- SC/S-5-W-

Figure 2. Failure conditions.

3.2 Load versus Displacement Relationship

The interaction curves of the column shear force '${}_{C}Q$' and story deformation angle '${}_{C}R$' for SRC/S-1-27 and SC/S-1-W-27 are shown in Figure 3. Skeleton curves for all specimens, which were obtained from the interaction curves of the column shear force '${}_{C}Q$' and story deformation angle '${}_{C}R$', are shown for comparison in Figures 4. All specimens showed fusiform hysteresis of good energy absorption. Differences in the shape of the interaction curves were negligible for all specimens.

The effect of the difference in steel cross section of column can be observed by comparing SRC/S-1-27, SC/S-4-W-27 and SC/S-5-W-27 in Figure 4. The maximum strength of specimen SC/S-4-W-27 and SC/S-5-W-27 were higher than that of specimen SRC/S-1-27. Specimen SRC/S-1-27 failed by shear in the middle of the column and specimen SC/S-4-W-27 failed by flexure at the end of the column and by beam-column joint shear and specimen SC/S-5-W-27 failed by bond splitting in the middle of the column and by beam-column joint shear. Consequently, although the circumstances for failure were different, a structure that would be equivalent to the SRC structure performance during an earthquake would be possible if the reinforcement steel were welded wire mesh and the column steel cross section were enlarged.

Next, a comparison of specimens SRC/S-1-27 and SC/S-1-W-27 is shown in Figure 5 using the same column steel cross section. Both specimens showed an almost similar hysteresis at maximum strength. For specimen SC/S-1-W-27, the welded wire mesh of the column yielded at R = 0.017 radians, while the shear reinforcement of the column for specimen SRC/S-1-27 yielded at R = 0.037 radians. Therefore, the difference in shear reinforcement ratio seemed to affect the deformation at maximum strength and the conditions for failure.

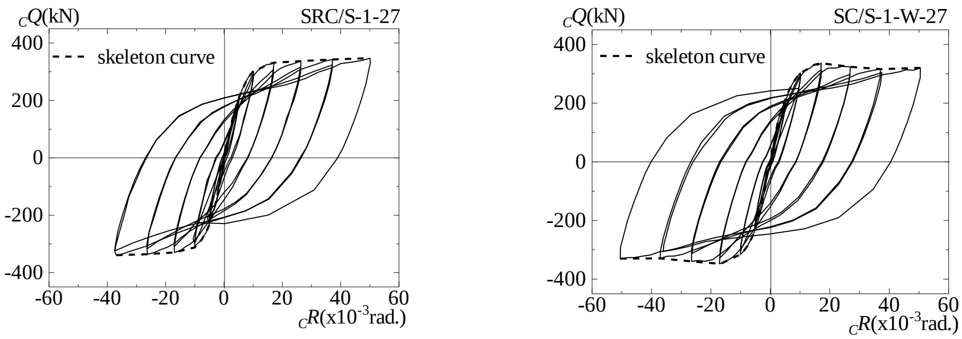


Figure 3. Relationship between column shear force '$_{C}Q$' and story deformation angle '$_{C}R$'.

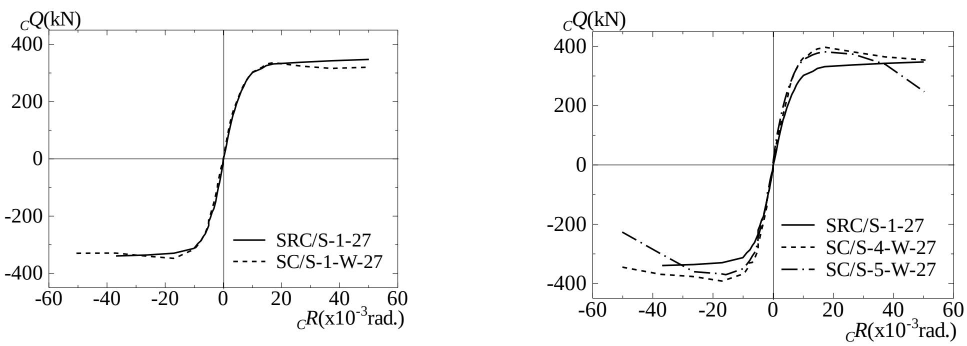


Figure 4. Comparison of skeleton curves.

3.3 Ultimate Column Shear Strength

Values for the strengths of the column and beam-column joints for all specimens were calculated from the AIJ (Architectural Institute of Japan) SRC standard equations. The experimental and calculated values are shown in Table 2 and were compared for the column shear force. In the strengths of the column calculation, the strength of welding wire mesh is considered in the shear strength, and it is not considered in the flexural strength.

A comparison of the calculated and experimental values showed that the experimental value for column shear using the SRC standard equation was overestimated slightly in all test specimens except specimen SC/S-5-W-27. The following two points are considered to be the reason for this observation. Firstly, the calculated value of the shear strength shared by the RC of the SRC standard was derived from an experimental equation that applied the RC standard. This condition was required in the column shear experiment with the conventional loading stub and is different from the specimen in this study. Secondly, it has been reported that the column shear strength is reduced by the difference between the circumstances that caused damage to the beam-column joint. Therefore, by examining the effect of the shear capacity magnification factor of the beam-column joint on the column shear capacity calculation equation, it was proven that the experimental value had been overestimated, as the shear capacity magnification factor of the beam-column joint is small specimen. Therefore, the shear capacity magnification factor of the beam-column joint must be considered when the shear strength of the column is evaluated. Still, it has been clarified that there is no effect of joint damage on the column shear capacity if the joint shear margin exceeds 1.40.

Table 2. Experimental and calculated values of ultimate strength.

Specimen		maximum strength (kN)	calculate ultimate strength by AIJ-SRC standard(kN)			$_{exp.C}Q_u / _{cal.*}Q_{**}$		shear capacity magnification factor
			joint shear	column shear	column flexural	joint shear	column shear	$\frac{_{cal.J}Q_{su}}{_{cal.C}Q_{su}}$
		$_{exp.C}Q_u$	$_{cal.J}Q_{su}$	$_{cal.C}Q_{su}$	$_{cal.C}Q_{bu}$	$_{cal.J}Q_{su}$	$_{cal.C}Q_{su}$	
A	SRC/S-1-27	347	506	361	506	0.69	0.96	1.40
B	SC/S-4-W-27	397	483	431	544	0.82	0.92	1.12
C	SC/S-1-W-27	347	555	371	377	0.63	0.94	1.08
D	SC/S-5-W-27	382	500	360	520	0.76	1.06	1.39

4 CONCLUSIONS

The following observations were made from this experimental study of SRC structures.

1. Construction method of the column using welded wire mesh was easier than that for the conventional SRC structure.
2. Though the conditions for failure differed, a structure with equivalent earthquake performance to the SRC structure is possible when the reinforcement steel is changed to welded wire mesh and the column steel cross section is enlarged.
3. An equivalent shear strength can be expected if an SC structure with the same steel cross section as the SRC structure is used.
4. The shear strength of the column in the column-beam frame specimen was dependent on the degree of destruction of the bam-column joint.

Acknowledgments

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