Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VIII)

SG-4

EXPERIMENTAL STUDY OF REINFORCED CONCRETE BEAMS AND COLUMNS LATERALLY CONFINED BY HIGH TENSILE STRENGTH SHEAR REINFORCEMENTS

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SUMMARY

To obtain design guide-lines for reinforced concrete (RC) 15~19-stories building, we made experiments of (RC) beams and columns reinforced by high tensile bars as shear reinforcement. Experimental results are summarized as follows: The specimens reinforced by high tensile shear reinforcement behaved more ductile than those reinforced by ordinary reinforcement. The confining coefficient Cc^1 and the concrete effective coefficient[2] ν seem to have some relation to the ductility of RC members. The shear design formulas based on truss and arch shear transfer mechanisms give satisfactory results of ultimate deformation.

INTRODUCTION

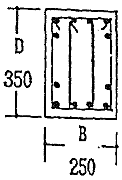
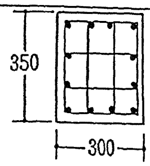
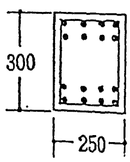
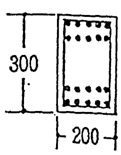
To make RC frame structure aseismic, the structure must be designed in such a way that the plastic hinges of columns and beams have sufficient ductility. For making the plastic hinges more ductile, it is an effective method to confine concrete by lateral reinforcement. We anticipated that RC members should have sufficient ductility if they are reinforced by high tensile shear reinforcement in the plastic hinge zone, and conducted an experimental study to confirm the effects of such reinforcement. In this study shear reinforcement with about 8.0 ft/cm^2 yield strength was used because reinforcement with such yield strength level can be easily bent and butt-welded.

EXPERIMENT

Test specimens consist of 3 series. In Series I and III specimens are beams and in Series II those are columns. Each specimens are 1/2~1/3 model sizes of actual members. For simulating earthquake load, lateral cyclic alternating load are given for each specimens. Table 1 is the list of all specimens.

Series I H1~H3 are reinforced by high tensile shear reinforcement (8.2 ft/cm^2) in the plastic hinge zone (each 1D D:depth of beam) and by ordinary reinforcement (3.83 ft/cm^2) in the other zone. Fig.3 shows envelopes of hysteresis curves. H2 and N2 have the same shear reinforcement ratio in the hinge zone, but N2 is reinforced by ordinary reinforcement. H2 have more lateral load capacity than N2 in large deformation ranges. H1 and H2 have the same shear reinforcement ratio in the plastic zone, but the shapes of reinforcement are different as shown in Fig.1. In this series there are two types (A and B) of shear reinforcement shapes used. Type B is used in the hinge zone of H2 and H3 only. All the other

Table 1 the list of specimens

Specimens		Section Shear Span Ratio L/D	Main Bars Pt % σy tf/cm²	Shear Reinforcements: Hinge Zone Pw %	Hinge Zone σwy tf/cm²	Center Zone Pw %	Center Zone σwy tf/cm²	Fc kgf/cm²	N/BDFc
I	N1		6-D16 1.64 % 3.92 tf/cm²	0.32 % (7φ□−@100) 3.83 tf/cm²				347	0.0
	N2		6-D19 2.37 %	1.16 % (7φ田−@55) 3.83 tf/cm²				317	
	H1			1.16	8.2	1.16	3.83	339	
	H2			1.16	8.2	0.80 (7φ田−@88). 3.83 tf/ cm²		317	
	H3	L/D=6.57	3.72 tf/cm²	0.61 (7φ□−@105) 8.2 tf/cm²		0.61	3.83		
II	CN1		2-D13 2-D10 0.38 % 3.50 tf/cm² (8-D13) (4-D10)	1.07 % (D6田−@40) 3.63 tf/ cm²				285	
	CH1			1.04 % (5φ田−@25) 8.03 tf/ cm²					0.33
	CH3	L/D=3.71							0.50
	CN2	L/D=2.00		1.07 % 3.63 tf/ cm²					0.33
	CH2			1.04 % 8.03 tf/ cm²					
III	No.1		8-D13 1.59 % 4.57 tf/cm²	0.33 % (6φ□−@70) 3.12 tf/ cm²				271	0.0
	No.2			0.33 % 8.46 tf/ cm²					
	No.3			0.66 % (6φ田−@70) 8.46 tf/ cm²					
	No.4							375	
	No.5	L/D=3.66		0.91 % (10φ□−@70) 8.62 tf/ cm²					
	No.6		10-D13 2.49 % 4.22 tf/cm²	0.41 (6φ□−@70) 3.12 tf/ cm²		0.41 % (6φ□−@70) 3.12 tf/cm²		351	
	No.7			0.41	8.46				
	No.8			0.82 (6φ田−@70) 8.46 tf/ cm²					
	No.9							441	
	No.10			1.14(10φ□−@70) 8.62 tf/ cm²					
	No.11	L/D=7.1	4.47 tf/cm²	1.13 (6φ田−@50) 8.46 tf/ cm²				206	

L=Length of Specimen Pt=100×At/Bd At=Area of Tension Main Bar

σy=Yield Strength of Main Bar Pw=Aw/BS Aw=Area of Shear Reinforcement

S=Spacing of Shear Reinforcement N=Compressive Axial Load σwy=Yield Strength of Shear Reinforcement

Fc= Compressive Strength of Concrete

reinforcement is Type A (general type). The hooks of Type A were placed in right and left side of beam alternately. Fig.2 indicates the strain progresses and distributions of the shear reinforcement in the hinge zone. H1 shows a zigzag strain distributions. The strain measurements at the hooked side are lower than that of the other side, so it indicates that hooked side of shear reinforcement slips and hooked side bars aren't effective. The general hooked type isn't adequate for high tensile shear reinforcement. It can be seen in Fig.3, H1 is less ductile than H2.

Series II In this series, columns were tested, whose experimental variables are shear span ratio, axial stress ratio and tensile strength of shear reinforcement. Shear reinforcements are all butt-welded with enclosed shape, as shown in Fig.1. From Fig.4, it follows that specimens (CH1 and CH2) reinforced by high tensile shear reinforcement are more ductile than those (CN1 and CN2) by ordinary shear reinforcement, and CH3 reinforced by high tensile shear reinforcement are ductile in spite of high axial stress.

Series III The main experimental variables are shear span ratio, shear reinforcement ratio, concrete compressive strength, and tensile strength of shear reinforcement. And butt-welded bars are used the same as series II. No.7~11 have high tensile shear reinforcement in plastic hinge zone (each 1.5 D). The failure pattern of No.1, No.2 and No.11 with less shear reinforcement is the splitting bond failure along main bars. The bond failure of No.11 occured in the center zone. On No.6, diagonal shear cracks developed in hinge zone, and then bond failure occurred. From Fig.5, it follows that if bond failure dosen't occur, specimens are ductile, but in this case it isn't clear that ductility improvement is influenced by the difference of concrete strength.

In these series, it is supposed that any high tensile shear reinforcement didn't yield under the strain measurement. In Table 2, experimental results are shown. Yield displacement Ry is defined as the displacement at which main bars yield for the first time. And the ultimate displacement Ru is defined as the displacement on the envelopes at which lateral load decreases to 0.8 times of maximum lateral load Qmax.

DISCUSSION

The ultimate displacement Ru and the ductility μ given from these experiments are exameind as follows.

Fig.6 shows the relation between the ductility and the confining coefficient Cc. The confining coefficient Cc shown in reference 1 is as follows:

$$Cc=\rho_s \cdot \frac{\sqrt{f_y}}{f_c'} \cdot (1-0.5 \cdot \frac{S}{W}) \qquad (1)$$

Fig.7 shows the relation between the ductility and Pw σwy, which indicats the effects of shear reinforcement in the hinge zone. In Fig.6 and Fig.7, the specimens in which bond failure occured and shear span ratio is espesally small (CH2 and CN) are ommitted. From Fig.6 and Fig.7, it followed that specimens are more ductile with increase in Cc and $Pw \cdot \sigma wy$.

The design formula of ultimate shear strength which is based on truss and arch mechanisms, shown in reference 2, is as follows:

$$Q=b \cdot jt \cdot Pw \cdot \sigma wy \cdot Cot\phi + \alpha \cdot (1-\beta) \cdot b \cdot d \cdot \nu \cdot Fc \qquad (2)$$

truss mechanism   arch mechanism

In the formula, it is assumed that the concrete strut crushes when its compressive stress reaches ν Fc. On these experiments, it is supposed that shear force is transferred by this truss and arch mechanisms. The shear transfer

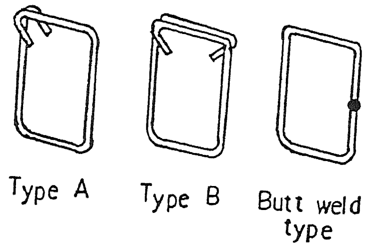


Fig.1 Shape of Shear Reinforcements

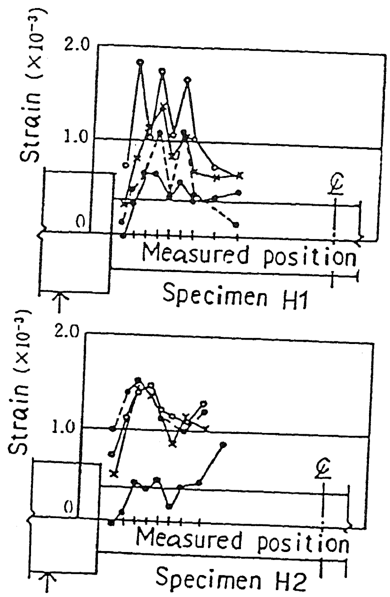


Fig.2 Progress of Strain of Shear Reinforcements

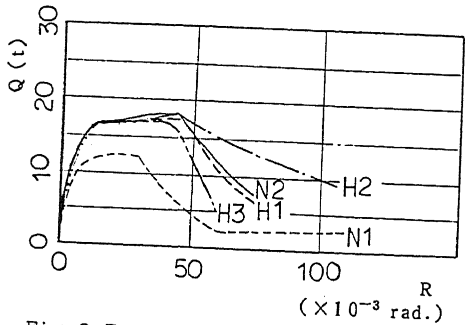


Fig.3 Envelopes of Series I Hysteresis Curves

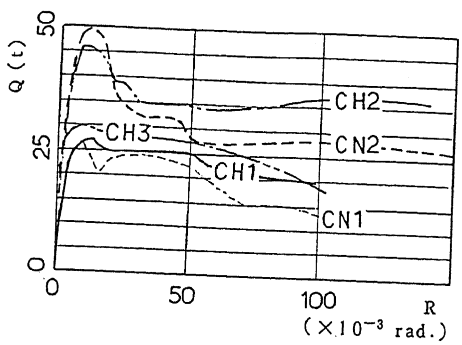


Fig.4 Envelopes of Series II Hysteresis Curves

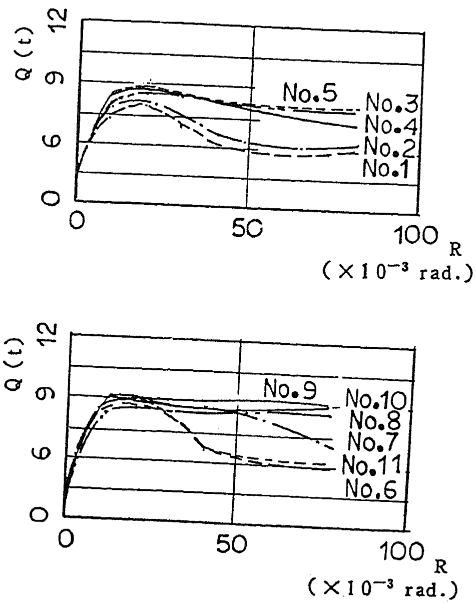


Fig.5 Envelopes of Series III Hysteresis Curves

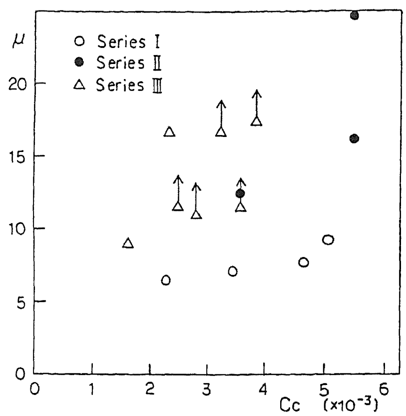


Fig.6 Ductility Factor μ
- Confining Coefficient Cc Relationship

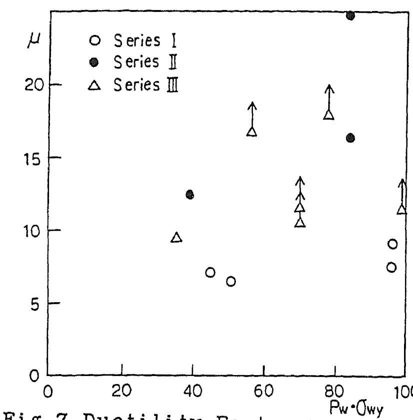


Fig.7 Ductility Factor μ
- Pw·σwy Relationship

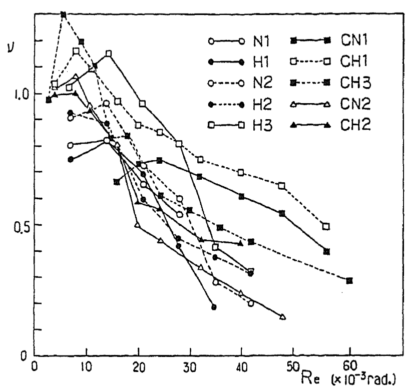


Fig.8 Concrete Effective Coefficient ν
- Displacement R Relationship
(Test Series I , II)

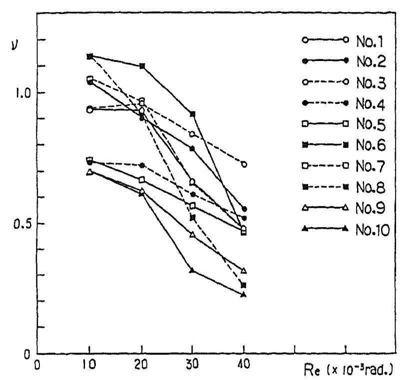


Fig.9 Concrete Effective Coefficient ν
- Displacement R Relationship
(Test Series III)

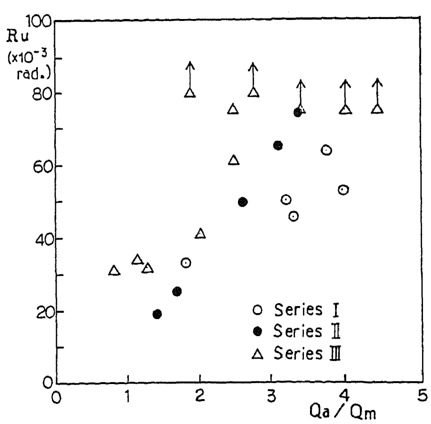


Fig.10 Displacement Ru
- Qa/Qm Relationship

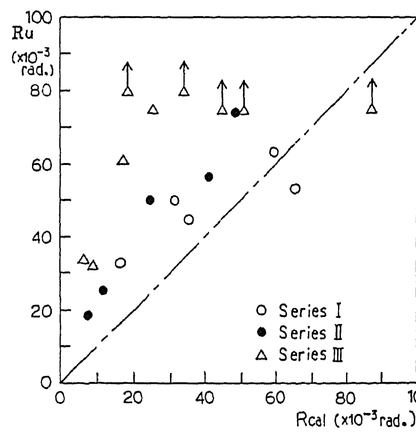


Fig.11 Ru- Rcal Relationship

Table 2 Test Results

	Series I					Series II					
	N1	N2	H1	H2	H3	CN1	CH1	CH3	CN2	CH2	
Qmax tf	12.3	17.9	17.6	18.4	17.4	27.1	27.5	29.5	50.2	46.4	
Ryx10^{-3}rad.	7.0	7.0	7.0	7.0	7.0	4.0	4.0	3.0	4.0	4.0	
Rux10^{-3}rad.	33.0	50.0	53.0	63.5	45.5	50.0	65.3	74.1	18.5	24.9	
μ = Ru/Ry	4.7	7.1	7.6	9.1	6.5	12.5	16.3	24.7	4.6	6.2	
Failure	F	F	F	F	F	F	F	F	F	F	
	Series III										
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11
Qmax tf	19.6	20.8	23.3	23.5	23.1	11.5	11.6	11.4	12.2	12.1	12.0
Ryx10^{-3}rad.	4.8	4.8	4.8	4.5	4.5	6.8	6.8	6.8	6.5	6.5	8.0
Rux10^{-3}rad.	31	32	above 80	75	above 80	34	61	above 75	above 75	above 75	33
μ = Ru/Ry	6.5	6.7	above 16.7	16.7	above 17.8	5.0	9.0	above 11.0	above 11.5	above 11.5	4.1
Failure	B	B	F	F	F	B	F	F	F	F	B

F : Flexural failure B : Splitting bond failure

mechanisms in the plastic displacement range in which the main bar already yielded are examined here. At each displacement level, the part of shear force transferred by truss mechanism is calculated by the design formula (2), in which the measured stress σw of shear reinforcement is used instead of σwy, and ϕ is taken as 45°. Fig.8 and 9 show the calculated results at each displacement level. These figures show that the calculated results ν decreases with the displacement increase. It can be supposed that ultimate displacement is the function of the concrete effective factor ν.

Fig.10 shows the relation between the ultimate displacement Ru and the ratio of the ultimate shear strength calculated by formula (2) to the shear force Qm at the yield of main bar. In this calculation, ν and cot ϕ shown in formula (2) are taken as 0.6 and the minimum value (2.0, $jt/(D \cdot \tan\theta)$, $\sqrt{Fc/(Pw \cdot \sigma wy)-1}$) respeclively, which are suggested in reference 2. The figure shows that the ultimate displacement increases with the ratio of shear strengths.

Fig.11 shows the relation between ultimate displacement Ru of experiments and the results Rcal calculated by the following formula suggested in reference 2. From Fig.11, it follows that the calculated ultimate displacement Rcal satisfactory for design.

CONCLUSION REMARKS

1) The high tensile shear reinforcement increases the ductility of RC beams and colums.
2) The confining coefficient Cc and the concrete effective factor ν seem to have some relation to the ductility of columns and beams.

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