FLEXURAL BEHAVIOR OF RM CONCRETE BLOCK WALL GIRDERS WITH LARGE SIZE REINFORCING BARS

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INTRODUCTION

In order to develop new earthquake resistant masonry structural systems, the U.S.-Japan Coordinated Research Program on Reinforced Masonry (RM) Building has been started since 1984 [Ref. 1]. Seismic tests of RM concrete block wall girders, which formed a part of the program, have been carried out under cyclic bending and shear loading condition since 1985. Four wall girders were tested in 1985 with the test parameters of the amounts of shear reinforcement and shear span ratios [Ref. 2], other four wall girders were tested in 1986 with the test parameters of lap splices of flexural reinforcing bars at the wall girder ends and spiral reinforcement to confine the grout concrete around the splices [Refs. 3, 4], and the rest four were tested in 1988 with the test parameters of diameters of flexural reinforcing bars and the details of bar arrangement [Refs. 5, 6]. The main purpose of the tests was to provide data for the development of a new masonry structural system without reinforced concrete beams required strongly in the existing Masonry Building Codes in Japan.

Nominal diameters of eight wall girders except the last test series in 1988 were 19 mm; #6, whereas the maximum nominal diameter of flexural reinforcing bars is determined as 25 mm; #8, in the draft Seismic Design Guidelines for Low/Medium Rise Reinforced Concrete Masonry Buildings in Japan. In order to use large size reinforcing bars for flexural reinforcement, it is important to clarify influences of the details of bar arrangement to failure mechanism, particularly, bond splitting failure. In this paper, the influences to strength, ductility and failure mechanism obtained through the last test series are described.

OUTLINE OF TEST WALL GIRDERS

Amounts of reinforcement, bar arrangement and spiral reinforcement of test wall girders are shown in Table 1. The test parameters of three wall girders named as GF7, GF8 and GF8S are the details of bar arrangement (i.e., bundling of flexural reinforcing bars and spiral reinforcement). Table 2 shows material properties of reinforcing bars, and Table 3 shows results of compression tests of joint mortar, RM assemblage; prism test, and grout concrete. The dimensions of test wall girders; GF7, GF8 and GF8S, are shown in Fig. 1. Depth, width and clear span length, which are

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common to all girders, are 790 mm, 190 mm and 2000 mm long, respectively, and shear span ratio is 1.27. The wall girders, which consist of three layers of concrete RM units and concrete at the top, were grouted in its position of the real practice in Japan.

The nominal diameter of flexural reinforcing bars is 25 mm which is the maximum value determined in the draft Seismic Design Guidelines for Low/Medium Rise Reinforced Masonry Buildings in Japan. The flexural and shear reinforcement ratios are 0.75 and 0.34 in percent, respectively. In the case of GF7, two flexural reinforcing bars are not bundled with 100 mm spacing, whereas the two bars are bundled in the cases of GF8 and GF8S. As was the case for GF8S, spiral reinforcement, which is set around flexural reinforcing bars at the ends of the wall girder, is 790 mm in length, which is the same value as the depth of the wall girders.

TEST METHOD

All wall girders were loaded to cause inverse symmetric bending moment distributions by the equipment shown in Fig. 2. The reinforced concrete end stubs were fixed to the test floor and a L-shaped loading beam, respectively. Cyclic loading was applied by the following schedule in principle: 1 cycle at the average deflection angle of the both ends of a wall girder of $\pm 1/2000$ rad., 2 cycles at $\pm 1/400$ rad., $\pm 1/200$ rad., $\pm 1/100$ rad., 1 cycle at $\pm 1/50$ rad., and a monotonic loading until severe strength deterioration occurs. Relative displacement between the both ends, shear deformation, slip and elongation of flexural reinforcement from the end stubs, and strains of flexural, shear and spiral reinforcing bars were measured. The locations of displacement transducers are shown in Fig. 3.

TEST RESULTS

As was the case for GF8S, during the first loop of the scheduled deflection angle of the both ends of -1/200 rad., deflection over -1/100 rad. was applied due to the trouble of loading system. The schedule of cyclic loading was, therefore, slightly changed for the wall girder.

Initial Stiffness

Initial stiffness of wall girders was estimated by the A.I.J. formula for reinforced concrete structures, where the strength Fm obtained by the prism tests was used for compressive strength of concrete Fc. Initial stiffness was calculated by the beam theory considering both flexural and shear deformation as follows;

$$K = 1 \Big/ \left\{ \frac{\ell^3}{12 \cdot Em \cdot I} + \frac{\kappa \cdot \ell}{Gm \cdot A} \right\} \quad (\text{tonf/cm}) \qquad (1)$$

where, ℓ : clear span length (cm)

Em : Young's modulus of RM assemblage (kgf/cm^2)

$$Em = 1.68 \times 10^5 \sqrt{Fm/180}$$

Fm : prism strength (kgf/cm^2)

I : geometrical moment of inertia (cm^4)

κ : section ratio (=1.5)

Gm : shear modulus (kgf/cm^2)

$$Gm = \frac{Em}{2(1+\nu m)} \quad (kgf/cm^2)$$

νm : Poison's ratio of RM assemblage (=1/6)

A : section area (cm^2)

Secant stiffness of shear force-deflection relationships at the initial flexural crack was used for estimating the initial stiffness by the test. The experimental and calculated values are shown in Table 4. The experimental values are 0.49-0.55 times of the calculated values.

Crack Patterns

Crack patterns of the wall girders at the average deflection angle of the both ends of 1/50-1/60 rad. are shown in Fig. 4. Initial flexural cracks were observed along vertical mortar joints at the ends, when the average shear stress was 2.7-5.7 kgf/cm^2, and shear cracks also occurred, when the average shear stress was about 6.9-11.7 kgf/cm^2 as shown in Table 5. Yielding in bending was observed, when the average shear stress was 15.7-19.0 kgf/cm^2, and the average stress at the ultimate stages was 17.0-19.6 kgf/cm^2 as shown in Table 6. As was the case for GF8 with non-reinforced bundled flexural reinforcing bars of large size, the wall girder failed finally in bond splitting after bending. In the cases of GF7 with large size reinforcing bars with spacing and GF8S with spirally-reinforced flexural reinforcing bars of large size, the wall girders failed in shear after bending. The wall girder GF7, however, failed finally in bond splitting with development of shear cracks.

Observed Strengths

Strengths and deflection angles at flexural and shear cracking stages are shown in Table 5. Those at yielding and ultimate stages are shown in Table 6. The strengths are expressed as average shear stress. The flexural, and shear cracking strengths and shear force at flexural yielding, and shear strengths were calculated using the following A.I.J. (Architectural Institute of Japan) formulas (2)-(5), respectively for reinforced concrete beam.

Flexural Cracking Strength:

$$Q_{Mc} = 1.8\sqrt{Fm} \cdot Z \cdot 2/\ell \quad (tonf) \qquad (2)$$

where, Fm : prism strength (kgf/cm^2)

Z : section modulus (cm^3)

Shear Cracking Strength:

$$Q_{Sc} = \frac{0.085 \cdot kc(500+Fm)}{M/(Q \cdot d)+1.7} A \quad (tonf) \qquad (3)$$

where, kc : section ratio (=0.72)

M/(Q•d) : shear span ratio ($1 \leq M/(Q \cdot d) \leq 3$)

M : maximum bending moment

Q : shear force

d : effective depth of wall girder

Shear Force at Yielding:

$$Q_{Mu} = 0.9 \cdot At \cdot \sigma y \cdot d \cdot 2/\ell \quad \text{(tonf)} \qquad (4)$$

where, At : area of flexural reinforcing bars (cm^2)
σy : yield strength of flexural reinforcing bars (kgf/cm^2)
d : effective depth of wall girder (cm)

Shear Strength:

$$Q_{Su} = \left\{ \frac{0.053 \cdot pt^{0.23}(180+Fm)}{M/(Q \cdot d)+0.12} + 2.7\sqrt{pw \cdot \sigma wy} \right\} b \cdot j \quad \text{(tonf)} \qquad (5)$$

where, pt : flexural reinforcement ratio (%)
pw : shear reinforcement ratio
σwy : yield strength of shear reinforcing bars (kgf/cm^2)
b : width of wall girder (cm)
j : distance between centroids of tensile and compressive forces in section (cm) (=7/8•d)

Observed maximum strengths are 1.16-1.27 times as large as the calculated flexural strength, and 0.93-1.02 times of shear strength. It is assumed that all wall girders took yielding by bending. Final failure mechanisms of the wall girders; GF7 with spacing of flexural reinforcing bars, and GF8S with spirally-reinforced bundled flexural reinforcing bars, was shear failure and the wall girder; GF8 with bundled flexural reinforcing bars without spiral reinforcement, seemed to fail in shear leading to bond splitting failure.

Ratio of Flexural Deformation to Total Deformation

Flexural deformation to total deformation relationships are shown in Fig. 5. Broken lines in the figure shows the relationships of flexural deformation to total deformation based on reinforced concrete beam elastic theory. In the cases of GF7 and GF8 without spiral reinforcement, after the average deflection angle was over 1/150 rad., flexural deformation decreased according to increase of total deformation. As was the case for GF8S with spiral reinforcement, the share of the flexural deformation to the total deformation was almost constant at the average deflection angle over 1/100 rad.. Hence, it is obvious that spiral reinforcement is extremely effective to keep high deformation capacity in the case of large size reinforcing bars used for flexural reinforcement.

Overall Behavior of Load-Deformation Characteristics

Since the discrepancy between the deflections measured at the both ends was observed in large deformation range due to the rotation of loading beam, each relationship at each end is shown in Fig. 6. Behavior of the restoring force characteristics were almost equivalent to those of reinforced concrete beams, and had a large energy absorption within the deflection angle of about 1/100 rad..

Deformation Capacity

Deformation capacity are shown in Table 7. Maximum deflection angle before strength deterioration to 80% of the maximum strength occurs is defined as deformation capacity. When the maximum deflections at both ends are different, the larger value is used. The estimated values in Table 7 correspond to deflection angles at the marks v in Fig. 6. Deformation capacity of the all wall girders were over 1/100 rad. in terms of deflection angle. The spiral reinforcement is effective to improve deformation capacity.

CONCLUDING REMARKS

Strengths and deformation capacity of RM concrete block wall girders with large size reinforcing bars yielded in bending were similar to those of reinforced concrete beams. Strength could be estimated by reinforced concrete theory. The wall girder with bundled flexural reinforcing bars of large size failed finally in bond splitting. One with large size reinforcing bars with spacing failed in shear after bending, and finally failed in bond splitting with development of shear cracks. Deformation capacity in terms of deflection angle is supposed over 1/100 rad.. In the case of using large size reinforcing bars, it is effective to use spiral reinforcement or spacing between the bars to avoid bond splitting failure and to improve the ductility.

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REFERENCES

[1] S. Okamoto and J. Noland, "U.S.-Japan Coordinated Program on Masonry Research ," Proceedings of the Third Conference on Dynamic Response of Structures, EM Div., ASCE, pp. 55-70, 1986.

[2] Okada, T. and Kumazawa, F., "Flexural Behavior of Reinforced Concrete Block Beams," The First Joint Technical Coordinating Committee on Masonry Research (JTCCMAR), U.S.-Japan Cooperative Research Program, August 26-27, 1985, Tokyo, Japan.

[3] Okada, T. and Kumazawa, F., "Flexural Behavior of Reinforced Concrete Block Beams with Lap Splices and Spiral Reinforcement," The Second JTCCMAR, September 8-10, 1986, Keystone, Colorado, U.S.A..

[4] Okada, T. and Kumazawa, F., "Flexural Behavior of Reinforced Concrete Block Beams with Spirally-Reinforced Lap Splices," The Third JTCCMAR, October 15-17, 1987, Tomamu, Hokkaido, Japan.

[5] Okada, T. and Kumazawa, F., "Flexural Behavior of Reinforced Concrete Block Beams," The Fourth JTCCMAR, October 17-19, 1988, San Diego, California, U.S.A..

[6] Kumazawa Fumitoshi et al., "U.S.-Japan Coordinated Earthquake Research Program on Reinforced Masonry Building (74), Seismic Capacity of Reinforced Masonry Walls and Beams, Part 28. Flexural Behavior of Reinforced Concrete Block Beams with Large-Diameter Tensile Reinforcing Bars," Proceedings of The Annual Convention of A.I.J., Vol. C, pp. 1695-1696, October 1989 (in Japanese).

Table 1 : Properties of test wall girders (unit ; mm)

Specimen	Clear Span	Flexural Reinforcement			Shear Reinforcement
		Amount	Bundled	Spiral	
GF7	2000 [1.27]	2−D25 (0.75)	×	×	1−D13 @200 (0.34)
GF8			○		
GF8S				○	

Note ; A value in brackets is a shear span ratio.
Values in parentheses are reinforcement ratios.
Spiral reinforcement ; 4φ, D100, @40, ℓ=790

Table 2 : Material Properties of Reinforcing Bars

	Strength (kgf/cm^2)		Tensile Strain (%)
	Yield	Tensile	
D13	3,619	5,346	18.7
D16	3,672	7,152	23.1
D25	3,567	5,404	25.0
4φ	5,984	6,047	——

Table 3 : Results of Compression Tests (kgf/cm^2)

Specimen	Joint Mortar	Grout Concrete	RM Assemblage
GF7	453.4	319.8	282.7
GF8			
GF8S			

Table 4 : Initial Stiffness (tonf/cm)

Specimen	Exp. Value	Cal. Value	Ratio of Exp/Cal
GF7	81.8	159.5	0.51
GF8	78.0		0.49
GF8S	87.5		0.55

Table 5 : Cracking Strength (kgf/cm^2)

Specimen	Flexural Crack			Shear Crack		
	tτmc	Exp/Cal	tRmc	tτsc	Exp/Cal	tRsc
GF7	4.34	1.09	0.35	8.65	0.80	1.31
	5.30	1.33	0.28	9.45	0.87	1.28
GF8	5.68	1.43	0.44	9.18	0.76	1.05
	3.28	0.82	0.05	11.70	0.97	1.54
GF8S	3.30	0.83	0.19	6.93	0.57	0.84
	2.70	0.68	0.09	7.86	0.65	1.03

Note ; τ : Average Shear Stress (kgf/cm^2), R : Deflection Angle ($\times 10^{-3}$ rad.)
Upper values are observed in positive loading, lower values are in negative.

Table 6 : Yield and Ultimate Strength (kgf/cm^2)

Specimen	Yielding			Ultimate			
	tτy	Exp/Cal	tRy	tτu	Exp/Cal1	Exp/Cal2	tRu
GF7	16.14	1.13	4.92	17.03	1.19	0.98	6.69
	17.61	1.23	3.90	17.61	1.23	1.02	3.90
GF8	17.22	1.12	3.77	17.90	1.16	0.93	8.02
	19.00	1.23	3.96	19.62	1.27	1.02	7.20
GF8S	16.40	1.07	4.39	18.67	1.21	0.97	7.90
	15.74	1.02	4.62	18.22	1.18	0.95	19.84

Note ; τ : Average Shear Stress (kgf/cm^2), R : Deflection Angle ($\times 10^{-3}$ rad.)
Cal1 : Calculated shear force at yield, Cal2 : Calculated shear strength
Upper values are observed in positive loading, lower values are in negative.

Table 7 : Deformation Capacity in Deflection Angle ($\times 10^{-2}$ rad.)

Specimen	Observed Value				Estimated Value		
	Left		Right		+	−	Average
	+	−	+	−			
GF7	0.712	0.763	1.65	0.835	1.65	0.835	1.24 (1/80)
GF8	0.927	1.12	1.07	0.851	1.07	1.12	1.09 (1/91)
GF8S	1.56	1.24	1.83	2.03	1.83	2.03	1.93 (1/52)

Note ; Values in ▒▒ are estimated deformation capacity.

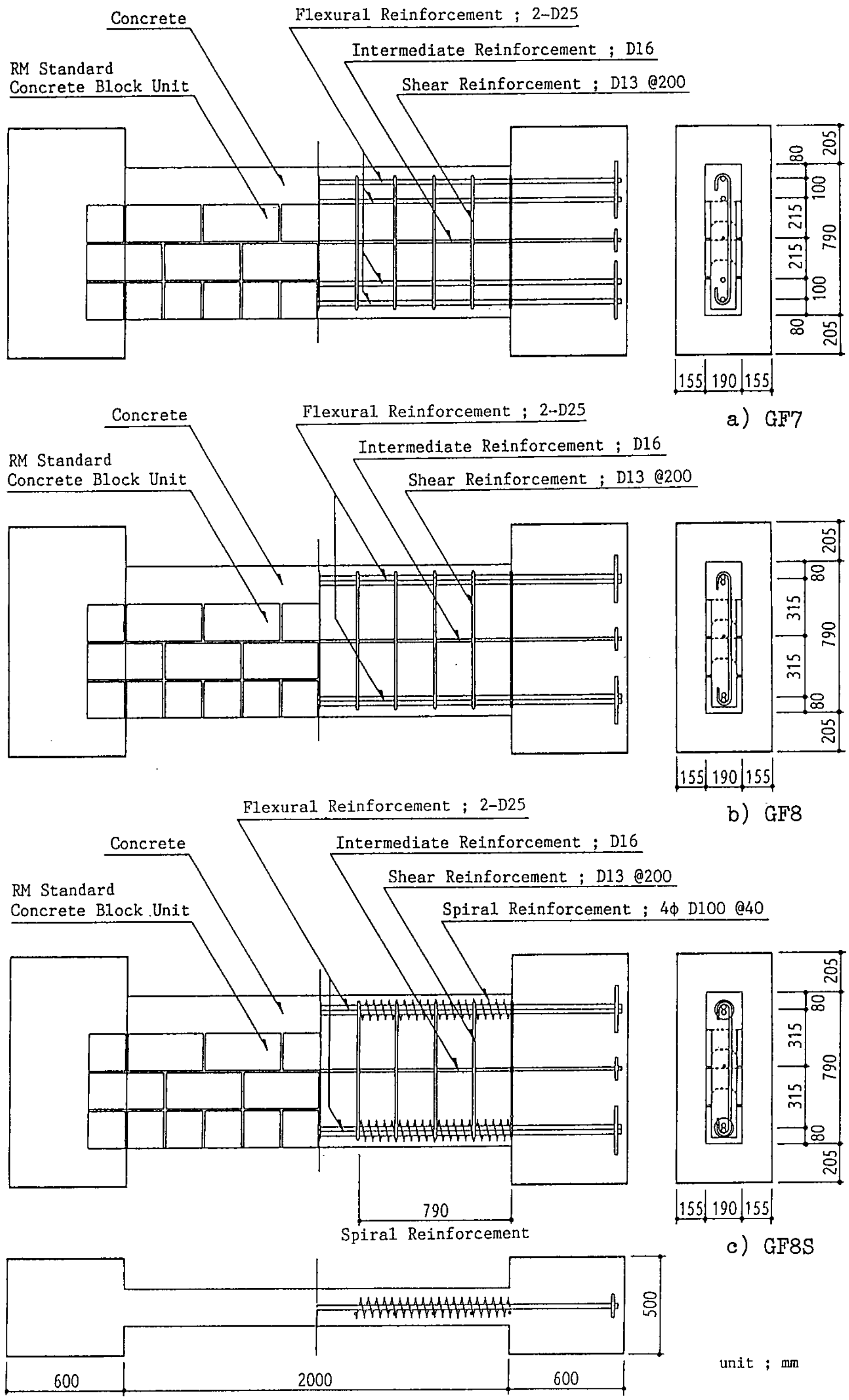


Fig. 1 Dimensions of Wall Girders

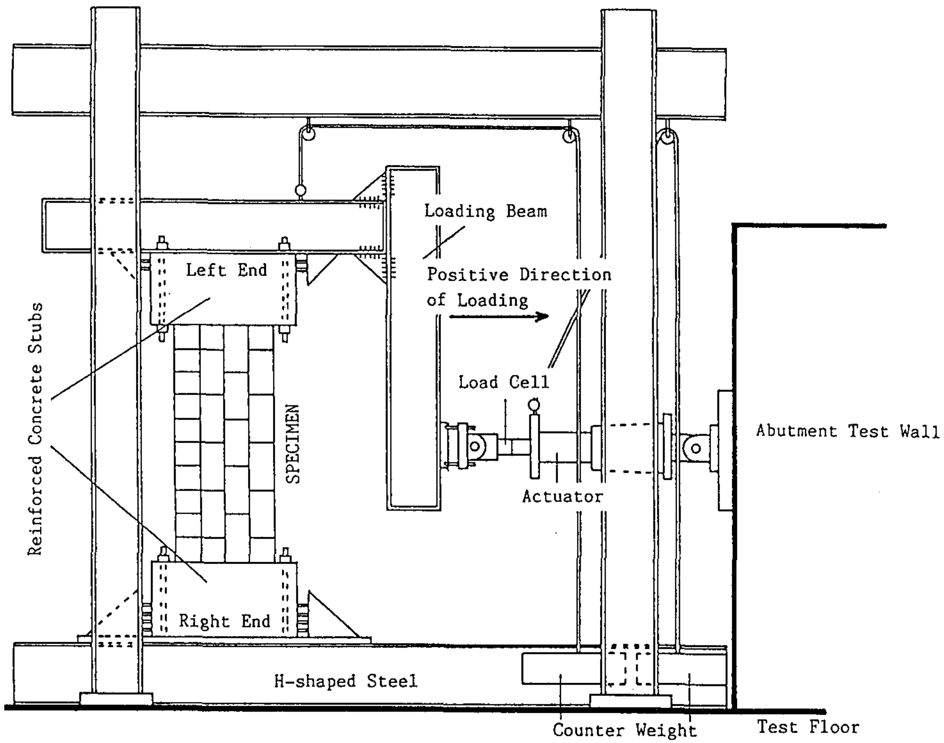


Fig. 2 Loading System

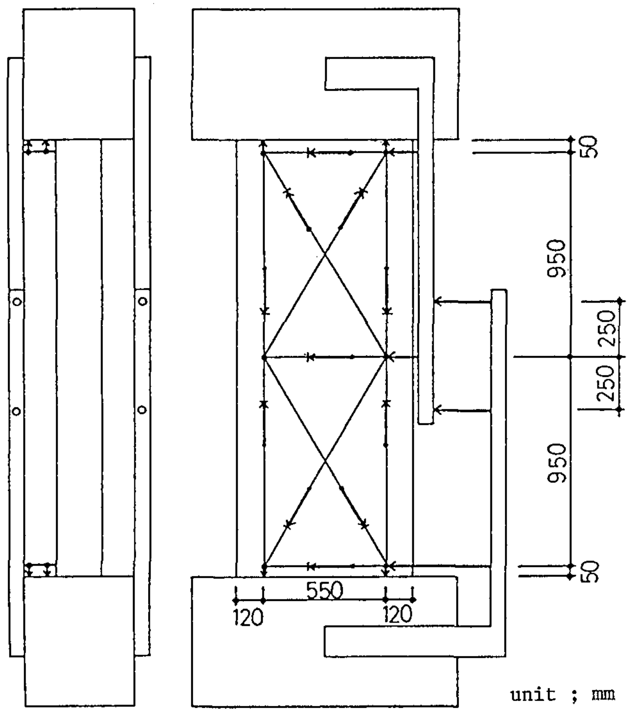
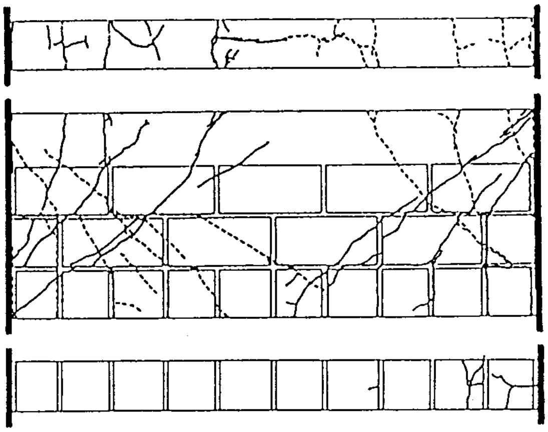
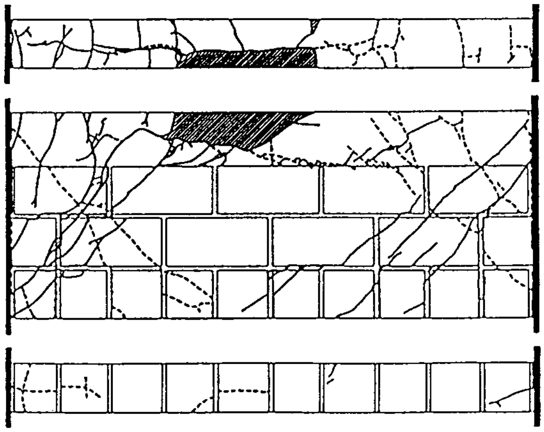


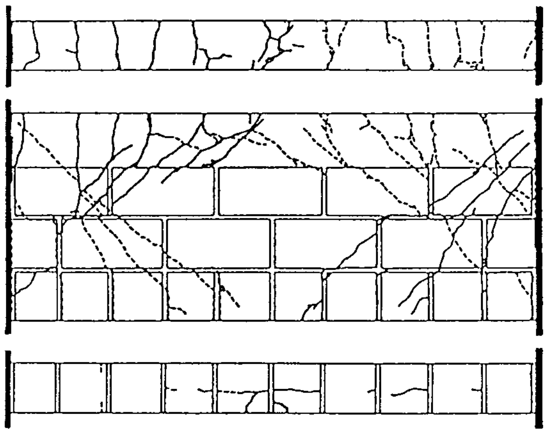
Fig. 3 Locations of Displacement Transducers



(a) GF7 R=1/63 rad.

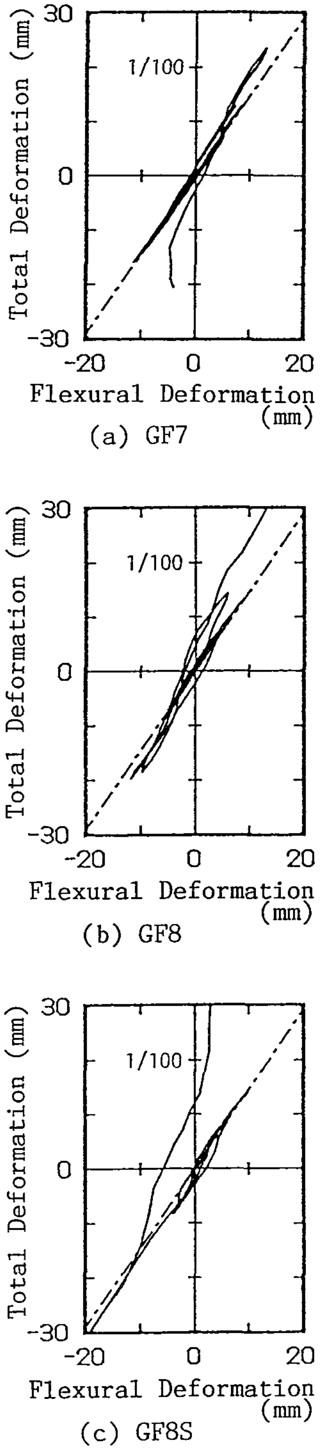


(b) GF8 R=1/56 rad.



(c) GF8S R=1/50 rad.

Fig. 4 Crack Patterns



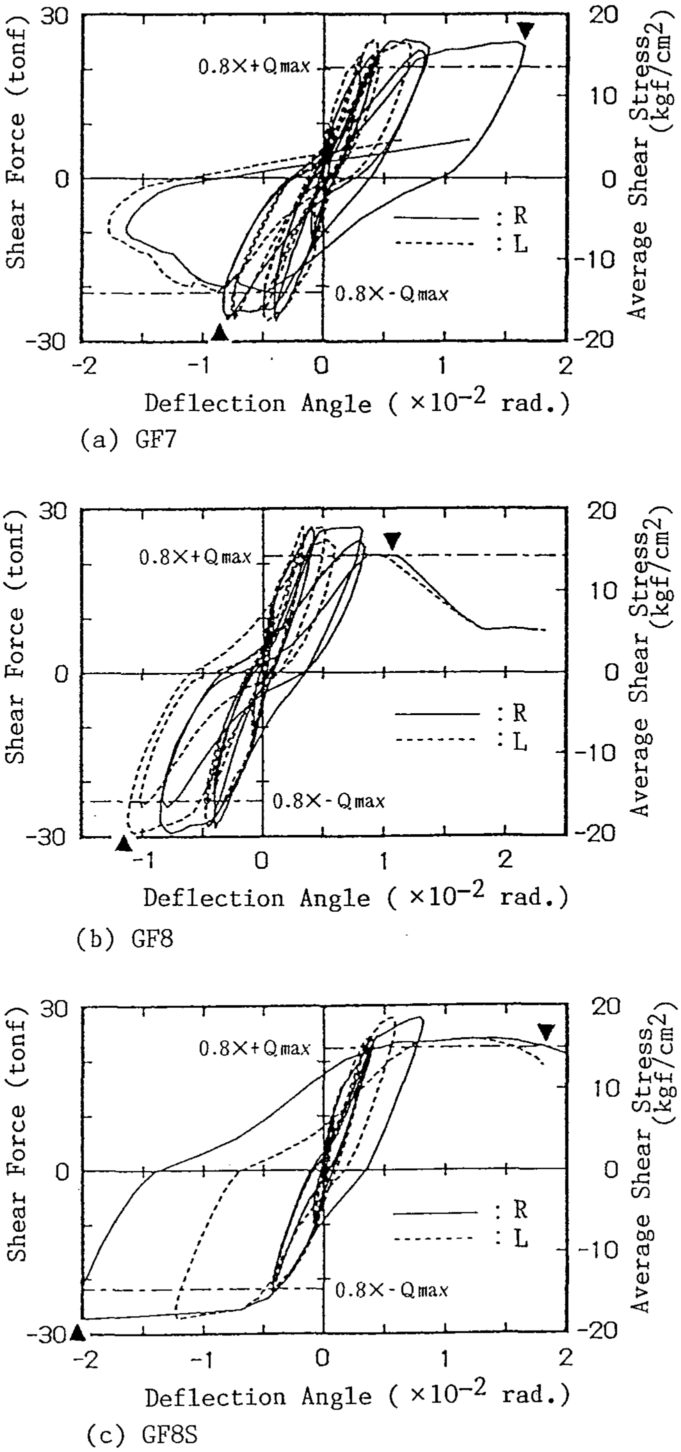


Fig. 5 Flexural Deformation-Total Deformation Relationships

Fig. 6 Shear Force-Deflection Angle Relationships