Study on Steel Plate Reinforced Concrete Bearing Wall for Nuclear Power Plants Part 1; Shear and Bending Loading Tests of SC Walls

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ABSTRACT

Shear and bending loading tests of steel plate reinforced concrete walls (it is called SC walls) were conducted. The series A was to observe typical shear ultimate state, the series B was for the bending yield and the series C to observe influence of an opening. The results were investigated about fundamental structure characteristic of every SC wall which assumed practical use. In the test of series A and B, a shear span ratio and a steel plate ratio were test parameters, the influence of these parameters on load-deformation relationship and on the bending shear strength of SC wall was investigated.

1. INTRODUCTION

A steel plate reinforced concrete wall (SC wall) has good resistance characteristic against earthquake. Beside the SC achieves high quality in a building construction, because steel plate panels were fabricated as like in a factory at the site (Fig.1)[1]. So it is effective for an important structure such as a nuclear power plant to apply it.It is important to study bending and shear strength and the deformation characteristics of SC walls.

A few studies on SC structure were performed by the authors, and some test results on the shear destruction property that is a typical characteristic of a SC wall are presented. It is regarded as need to study regarding structural characteristics of case that the shear span ratio is big and case to include an opening in order to apply SC walls to real buildings. From the viewpoint of above, tests of following three series of SC wall were conducted to investigate those characteristics.

Series A: five specimens reaching a shear ultimate strength before bending yielding

Series B: four test specimens of cases to become a shear ultimate after bending yielding and case to destroy after bending ultimate.

Series C: An examination specimen which has an opening

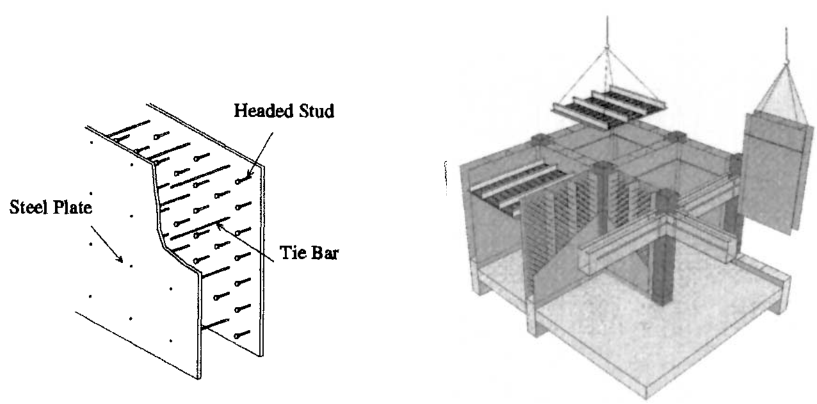


Fig.1 SC Structure

2. TEST PLAN

2.1 Outline of Specimen

(1) Series A

A list of specimens of series A is shown in Table 1, and the shape of specimen is shown in a Fig.2. All the cross-sections of test specimens are the same. As the major factor which gives influence to bending shear property of a SC wall, the shear span ratio (M/QD) and the steel plate ratio (T/t) are chosen as test parameters. M/QD value is decided by the heightof a specimen, and 0.5, 0.7 and 0.85 were tested. T/t value is controled by the thickness of a steel plate of each specimen with the range of paractical 50-150. Studs are welded inside of a steel plate as anchors with concrete. The stud pitch B was decided in accordance with the plate thickness t which was to be B/t ≒ 30. A thick steel plate was used for flange in order to flucture a web wall by shear stress before bending yielding. Material properties of specimen are shown in Table 2.

Table 1. Summary of Specimen (Series A)

Shear - Span Ratio (M/QD)	Steel Ratio (T/t)		
	51 (t = 4.5)	100 (t = 2.3)	144 (t = 1.6)
0.5 (H=945)	—	BS50T10	—
0.7 (H=1323)	BS70T05	BS70T10	BS70T14
0.85 (H=16065)	—	BS85T10	—

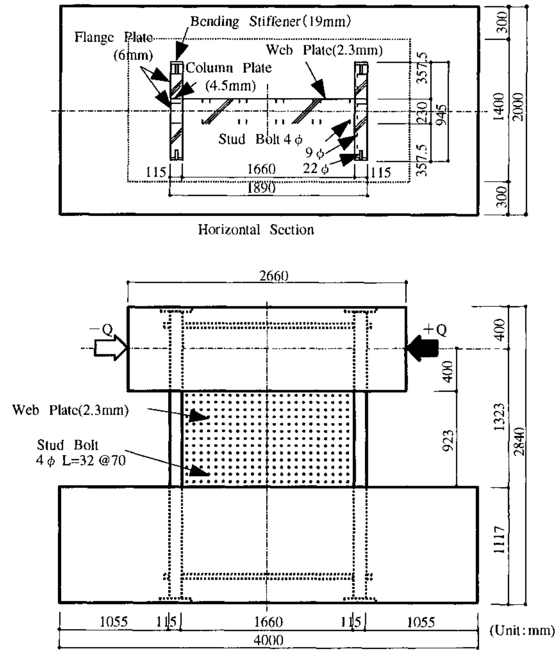


Fig.2 Test Specimen (BS70T10)

Table 2 Material Properties (Series A)

Material		Size	Max. Stress			
			Yield Stress (kgf/cm^2)	Max. Stress (kgf/cm^2)	Young' s Modulus (kgf/cm^2)	Poisson' s Ratio
Steel Plate	Web	1.6mm	4484	5695	2090000	0.263
	Web	2.3mm	3892	5134	1990000	0.267
	Web	4.5mm	3525	5285	1910000	0.264
Concrete	I *1	—	—	339	246000	0.207
	II *2	—	—	362	248000	0.222

*1: BS85T10, BS70T10, BS70T05 *2: BS70T14, BS50T10

(2) Series B

A list of specimens of series B is shown in Table 3, and shape of specimen is shown in Fig.3. The test parameter is shear span ratio (M/QD), the bending reinforced quantity and presence of an axial force. The cross-section of specimens is same as series A. The thickness of a wall of all specimens was 230mm, and thickness of steel plate was 2.3mm (T/t=100). Cross-section area to be effective for shear stress was fixed. No.1 specimen was especially designed to reach shear ultimate state after the bending ultimate. Specimens except NO.1 were designed to be fractured by shear stress finally after having yielded by bending stress. In No.3 specimen, an axial force equivalent to weight of a real building was given. About No.4 specimen, the quantity of anchor rebar under a bottom of specimen was reduced, and influence of up-lift and influence of a slip were examined. Anchor reinforcing rod was designed to be equivalent about 80% of yielding strength of a steel plate. Material properties of specimen are shown in Table 4.

Table 3 Summary of Spesimen (Series B)

Shear-Span Ratio	Flange Plate		
	2.3mm	3.2mm	Note
0.85 (H=1606.5)	No.1	BS50T10	
0.7 (H=1323)		No.2	
		No.3	Axial Stress of 30kgf/cm^2 Applied
		No.4	An Anchor is a small quantity than other Specimen

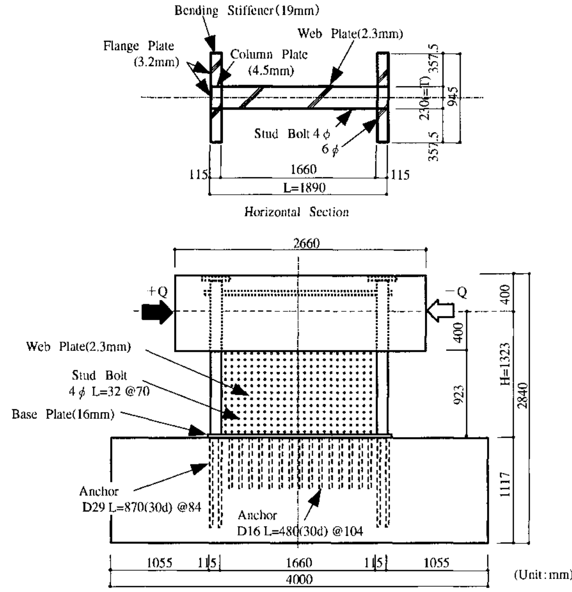


Fig.3 Test Specimen(No.2)

Table 4 Material Properties (Series B,C)

Material		Size	Max. Stress			
			Yield Stress (kgf/cm^2)	Max. Stress (kgf/cm^2)	Young' s Modulus (kgf/cm^2)	Poisson' s Ratio
Steel Plate	Web	2.3mm	4003	5206	2076000	0.274
	Flange	2.3mm	4023	5204	2069000	0.271
	Flange	3.2mm	4768	5861	2249000	0.255
Concrete	I *1	−	−	344	225100	0.196
	II *2	−	−	406	266000	0.219

*1: No.1～3 *2: No.4

(3) Series C

The shape of specimen is shown in Fig.4. The specimen arranged an opening in the center of BS7010T which was typical specimen of series A. The side of opening was reinforced with a steel plate of thickness of 2 times of the surface steel plate so that concrete did not slide.

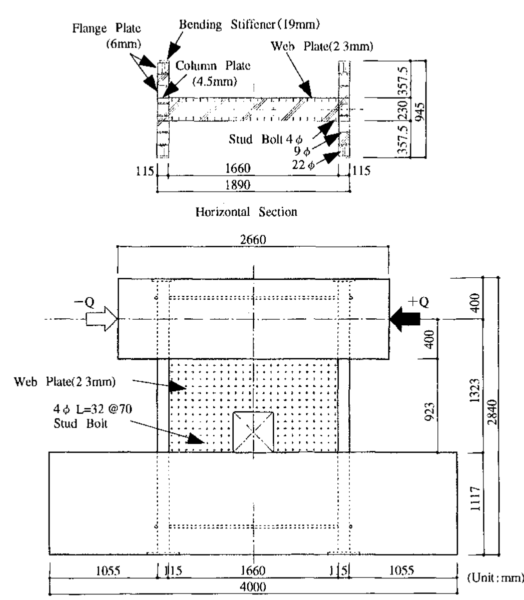


Fig.4 TestSpecimen (Series C)

2.2 Test Method

Using the oil pressure jack that push and pull was possible, a static force of plus and minus of maximum 1000 tonf was applied to the specimens in a horizontal direction shown in photograph 1. The deformation and strain of steel plate were measured. The deformations of flange wall were measured in detail to evaluate bending deformation in the others which measured a typical deformation of horizontal direction of top of specimen. The quantity that subtracted bending deformation from a deformation of top was considered to be a shear deformation. And strains of a steel plate were measured, and cracking point, strain distribution property, shear resistance ratio of a steel plate / concrete were evaluated.

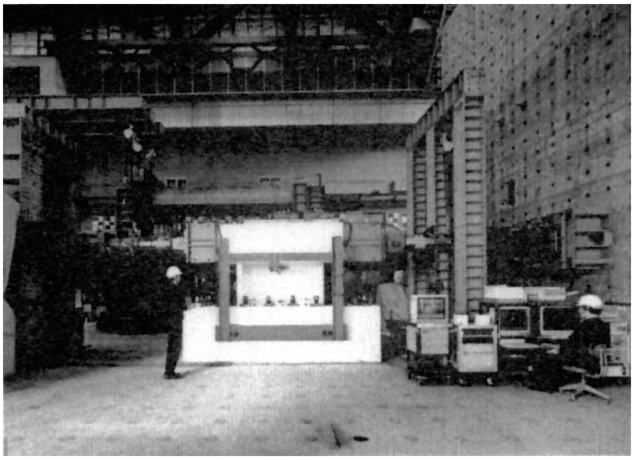


Photo.1 Testing Appratus

3. TEST RESULTS

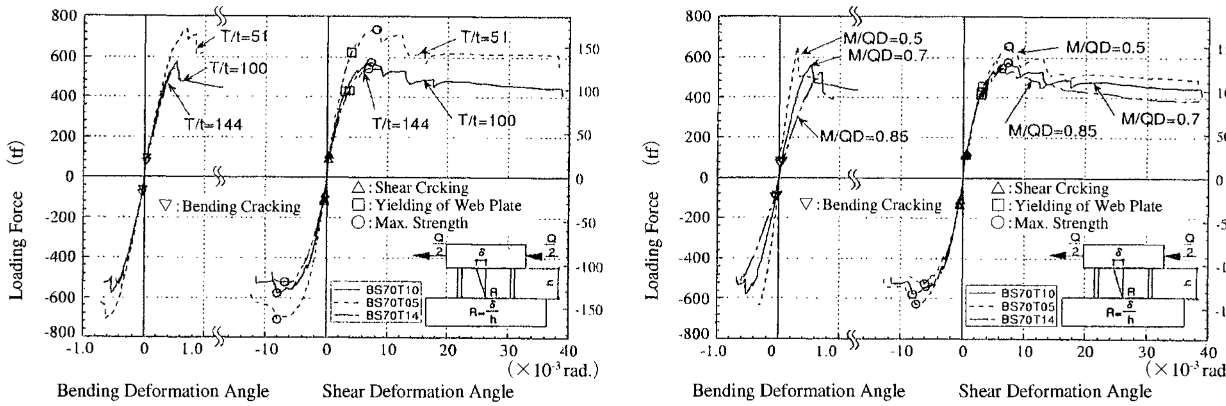
3.1 Series A

The test results of series A are shown in Table 5. The relationships between experimental load and bending deformation / shear deformation are shown in Fig.5 according to experimental parameters. From the Fig...., the following things are understood. As a value of steel plate ratio(T/t) decreases, the initial stiffness and the cracking strength increase inconsiderably. The yield strength and the maximum shear strength increase by a value of T / t conspicuously. Deformation angles at the yielding point and the maximum point do not change remarkably even if a value of T/t changes. Value of shear span ratio (M/Qd) gives only a little influence to shear yielding strength. M/Qd is a smaller value, and maximum shear strength increases. The relationship of experimental cracking strength and the square root of concrete strength is shown in Fig.6 and Fig.7. ${}_c\sigma_t = 1.2\sqrt{{}_c\sigma_B}$ and ${}_c\tau_{cr} = \sqrt{{}_c\sigma_B}$ which are common use on a RC wall show the average of experimental values. The relationship of shear yield strength / the maximum shear strength and steel plate ratio is shown in Fig.8 and Fig.9. The shear yield strength and the maximum shear strength are in proportion to the strength of the steel plate.

Table 5 Results of Test

Specimen	Direction	Cracking by Bending		Cracking by Shear		Yielding of Web Plate		Maximum Strength	
		eQfc	eRfc	eQsc	eRsc	eQy	eRy	eQu	eRu
BS70T10	+ –	90 -90	0.04 -0.04	110 -110	0.39 -0.44	428 –	2.93 –	573 -577	7.17 -7.99
BS70T05	+ –	70 -70	0.03 -0.03	110 -120	0.35 -0.37	621 –	3.99 –	737 -710	8.01 -8.06
BS70T14	+ –	– –	– –	90 -85	0.33 -0.32	434 –	3.71 –	541 -521	686 -6.83
BS85T10	+ –	90 -89	0.06 -0.06	120 -129	0.46 -0.55	415 –	2.84 –	545 -526	6.27 -6.03
BS50T10	+ –	75 -80	0.02 -0.02	128 -140	0.53 -0.59	459 –	3.09 –	657 -627	7.30 -7.49

Q : Loading Force(tf) , R : Rotation Angle($\times 10^{-3}$rad.)



(1) Influence of T/t (2)Influence of M/QD

Fig.5 Comparison of Load-Deformation Relationships

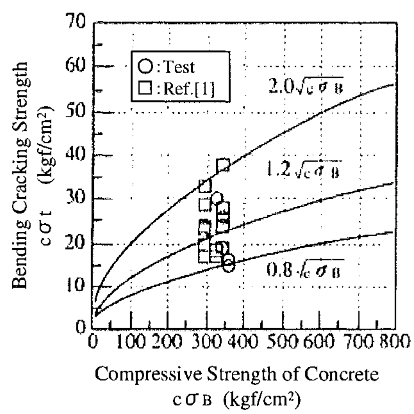


Fig.6 Relationship between c σ B and c σ t

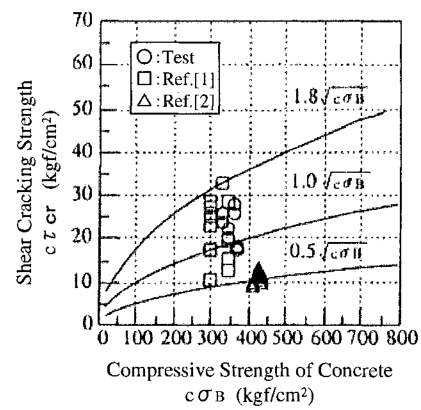


Fig.7 Relationship between c σ B and c τ cr

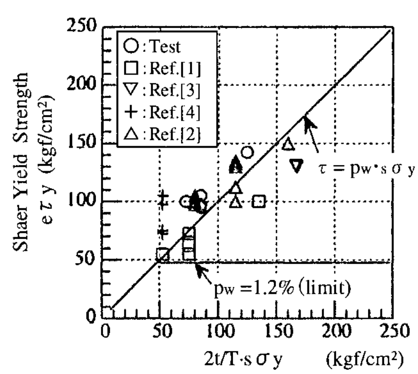


Fig.8 Relationship between Shear Yield Strength and Strength of Steel Plate

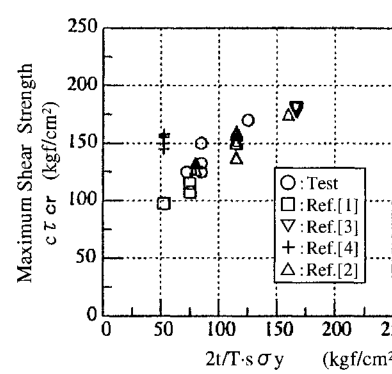


Fig.9 Relationship between Maximum Shear Strength and Strength of Steel Plate

3.2 Series B

The test results are shown in Table 6, and the relationships of load and deformation are shown in Fig.10. About No.1 specimen, flange wall yielded by bending stress. After the yielding, the stiffness of specimen reduced by degrees, and the maximum strength was observed after having exceeded deformation angle 10/1000rad. Partial compressive destruction was observed in flange wall of specimen, and this specimen was fractured by bending stress. The reduction of strength of specimen is small after maximum strength. As for No. 2 specimen, web steel plate yielded by shear stress after bending yielding. A shear deformation progressed, and the maximum shear strength of shear was observed. BS70T10 of series A which did not yield by bending stress is compared with this result, the yield strength and the maximum strength are smaller than BS70T10 about 10%. The yield strength of steel plate materials used with series B was smaller than about 10% than steel plates of series A. It can be considered that there is no effect of bending yield to shear yield strength. No.3 specimen showed failure mode same as No.2. As for No.3 specimen. The strength of cracking and bending yielding increased by effect of an axial force remarkably, and shear strength increased to some extent, too. As for the result of No.4 with a few quantities of anchor, there is no significant difference to No.2.

Comparison of calculated bending yield strength / shear yield strength based on straight-line theory[5] and experimental values is shown in Fig.11 and 12. The calculated values agree approximately with experimental values.

On maximum strength, comparison of calculated values of bending strength based on full-plastic cross-section assumption[7] and experimental values of series A/B is shown in Fig.13. The calculated values of shear strength in the Fig.13 are based on evaluation method described in detail this report Part2 to show next. The calculated values agree well with experimental values.

Table 6 Results of Test

	Cracking Strength (tf)		Yield Strength (tf)		Max. Strength (tf)
	bending	shear	bending	shear	
No.1	+30.43 -29.48	+75.44 -84.33	+321.12 -319.10	— —	+424.00 -412.00
No.2	+55.78 -54.83	+111.09 -106.57	+441.15 -460.07	+497.03 -500.97	+516.26 -500.97
No.3	+71.44 -89.80	+160.48 -140.03	+546.96 —	+546.96 -448.03	+551.00 -510.20
No.4	+55.70 -64.80	+116.00 -108.40	+413.40 -409.40	+544.80 -498.50	+558.70 -527.00

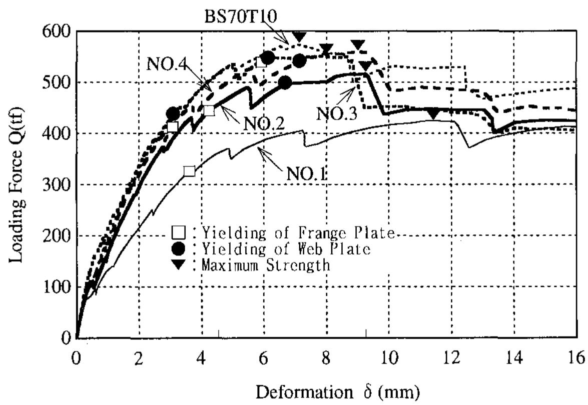


Fig.10 Load-Deformation Relationship

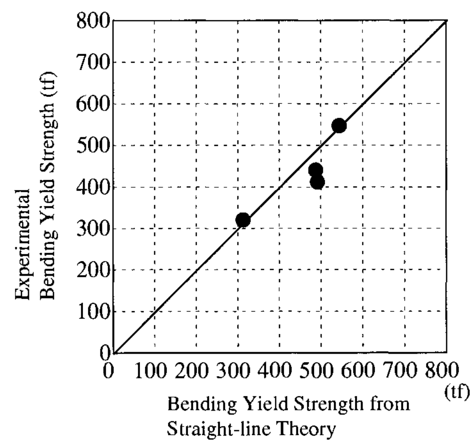


Fig.11 Comparison of Bending Yield Strength between Calculated and Test

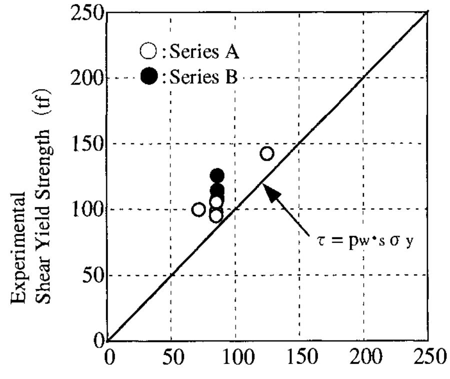


Fig.12 Relationship between Shear Yield Strength and Strength of Steel Plate

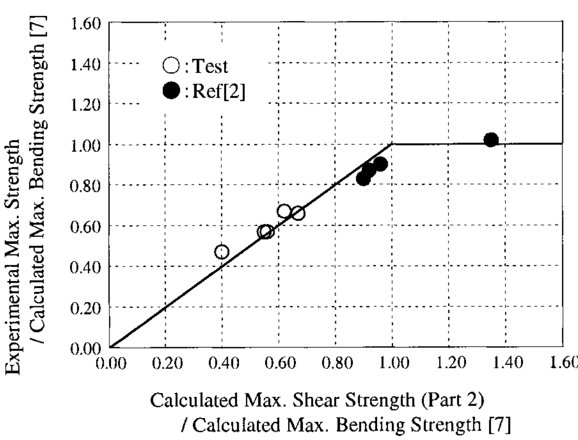


Fig.13 Comparison of Max.Strength between Calculated and Test

3.3 Series C

The load-deformation relationship is shown in Fig.14. A steel plate of a corner of opening yielded early, and buckling of a steel plate was observed in the corner of opening by load of minus direction. The maximum strength was observed at the deformation angle was 10/1000rad in the same of specimen BS70T10. But the maximum strength was about 80% of BS70T10. A crack of steel plate occurred at the corner of opening. Progressing of the crack was slow, and resistance ability of specimen did not suddenly deteriorate.

Methods to calculate the reduction coefficient of strength by an opening used for a design of reinforced concrete (RC) structure are shown in Fig.15. The reduction coefficient given by equation (1)[5] or (2)[6] is used for RC structures. Comparison of the calculated value that reduced the load values of BS70T10 which has no opening, using those coefficients and test result of No.5 specimen is shown in Fig.16. The calculated values are corrected by equation (3) to decrease the effect of the difference of concrete strength. The calculated value by equation (2) agrees well with the experimental values. The calculated values by equation (1) gives evaluation of security side same as a wall of RC wall.

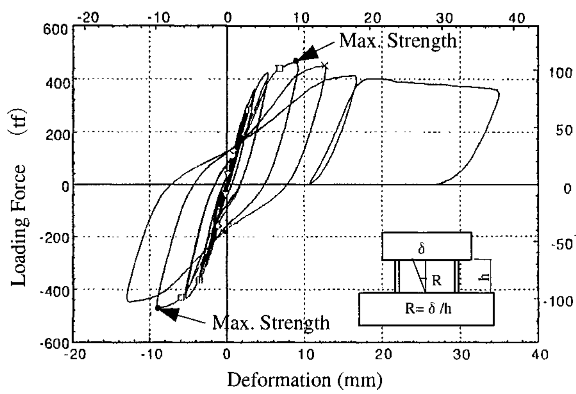


Fig.14 Load-Deformation Relationship

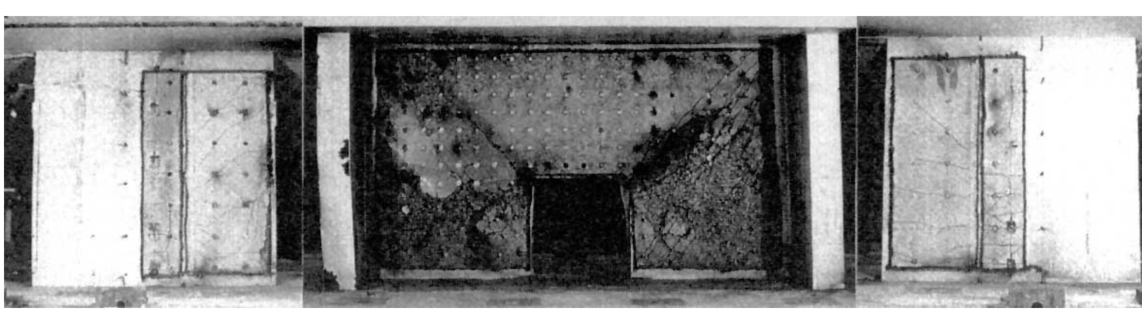
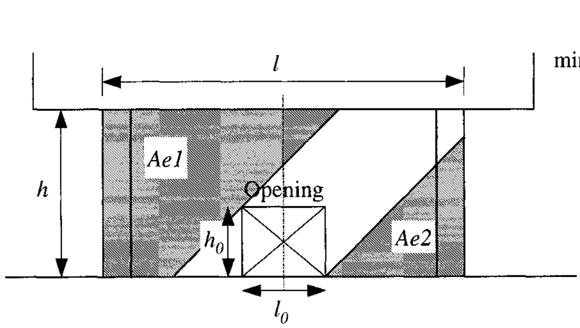


Photo.2 Crack Pattern after testing



$$\min\left(r_1 = l - \frac{l_0}{l},\ r_2 = l - \sqrt{\frac{h_0 \cdot l_0}{h \cdot l}}\right) \quad \cdots(1)$$

$$r_3 = \sqrt{\frac{\sum Ae}{h \cdot l}} \quad \cdots(2)$$

$$r_{ip} = r_i \sqrt{\frac{Fc(Series\ C)}{Fc(BS70T10)}} \quad \cdots(3)$$

$(i=1,2,3)$

Fig.15 Effective Strut Area of SC wall [6][5]

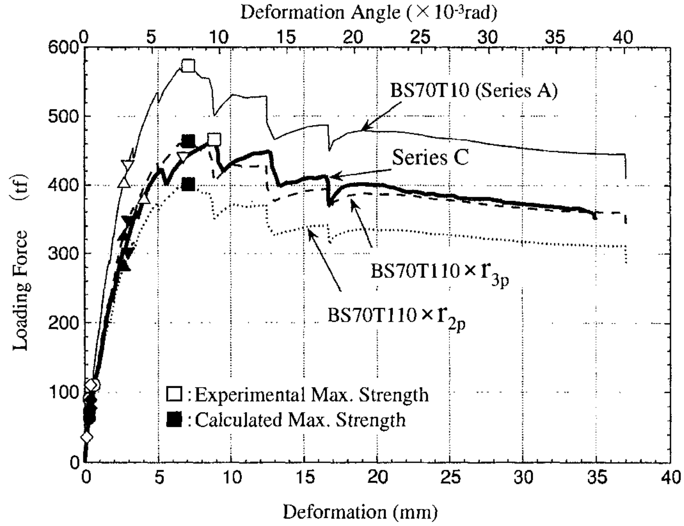


Fig.16 Comparison of Load-Deformation Relationships

4. SUMMARY

Shear and bending loading tests of SC walls were conducted, and the following knowledge were confirmed.

(1) The shear cracking strength and the bending cracking strength are estimated by square root of concrete strength same as RC walls.

(2) The shear yield strength and the maximun yield strength are in direct proportion to the steel plate quantity of web wall. It can be considered that there is no effect of bending yield strength to a shear yiled strength.

(3) Bending yield strength can be calculated by the method on the basis of straight-line theory in common use. Bending ultimate strength can be calcuated by the method on the basis of full-plastic cross-section assumption same as the RC wall.

(4) The influence of an opening to the strength can be evaluated using method same as RC wall.

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