Experimental study on lapped splices in a shear wall

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1.INTRODUCTION

Reactor buildings are the large reinforced concrete structures, and make use of many large-diameter reinforcing bars. Mechanical splices, gas pressure-welded splices, or lapped splices are used as the splices of the reinforcing bars. Lapped splices are the easiest construction method and are most economical in them.

In Japan lapped splices for large-diameter bars (nominal diameter>29mm) are forbidden, but for the large reinforced concrete structures, concrete cover and spacing of bars are large enough, we think that the application of lapped splices for large-diameter bars in wall panels of large structures is possible. In many previous investigations on lapped splices, the structural characteristics of columns or beams with lapped splices have been examined, those of wall panel with lapped splices have not been examined.

In this study concerning wall panels subjected to in-plane shear stress the structural characteristics of wall panels with lapped splices are examined, and the application of lapped splices for large-diameter bars is ascertained.

2.EXPERIMENTAL PROGRAM

The experiments consist of basic tests with small-diameter bars and confirmation tests with large-diameter bars. The former comprise diagonal loading tests with the wall panels subjected to pure shear stresses and horizontal loading tests with the wall panels subjected to flexural and shear stresses. Concerning the structural characteristics of the wall panels with lapped splices, the influences of various parameters in those tests are examined. The latter comprise horizontal loading tests. Concerning the wall panels with large-diameter bars, the structural characteristics of the wall panels with lapped splices in those tests are examined.

Table 1 shows the parameters in diagonal loading tests, and Fig.1 shows one of the specimens. Tension and compression cyclic loads were applied to the loading beams diagonally at the same time.

Table 2 shows the parameters in horizontal loading tests, and Fig.2 shows one of the specimens. The horizontal cyclic loads were applied to the loading slab of the specimen.

3.TEST RESULTS

3.1 Diagonal loading test

The test results are shown in table 1, Fig.3 shows one of the load-shear deformation curves, and Fig.4 shows one of the crack patterns.

The failure modes of all specimens were sliding shear failures.

3.2 Horizontal loading test

The test results are shown in table 2, Fig.5 shows one of the load-shear deformation curves, and Fig.6 shows one of the crack patterns.

The failure modes of specimens HS-02 and HS-03 were flexural failures, while those of other specimens were sliding shear failures.

4.DISCUSSION OF TEST RESULTS

4.1 Arrangement of lapped splices

In this study of the arrangement method of splices in the wall panels, the structural characteristics of the specimens with straight splices and those of the specimens with staggering splices are examined. The straight splice is the arrangement method of splices in which the center of splices are located in the same cross section of a reinforcement layer, and the staggering splice is that of splices in which the axial distance of adjacent splices is the same as the splice length.

Figure 7 shows the results of the diagonal loading tests, and Fig.8 shows the results of the horizontal loading tests. It was found that there were no differences in the structural characteristics as regards the arrangement of the splices, though the ultimate strength of the specimen with splices was relatively small in comparison to that of the specimen without splices in the diagonal loading tests.

4.2 Influence of transverse bars

To discuss the influence of transverse bars, the differences in the structural characteristics of the specimens with transverse reinforcing bars outside splices and those of specimens without bars outside splices were examined.

Figure 7 and 8 show the envelope of load-shear rotation curves. It was found that there were no differences in structural characteristics of the specimens with or without transverse bars.

4.3 Steel ratio

In reactor buildings, the steel ratio of shear walls has been from 0.6% to 1.6% of the cross section area. In this study the structural characteristics of the wall panels with lapped splices were examined for low and high steel ratios.

Figure 8 shows the test results for the low steel ratio (Pw=0.8%) ,and Fig.9 shows the test results for the high steel ratio (Pw=1.6%). For both steel ratios it was found that the structural characteristics of the specimens with splices is the same as those of the specimens without splices.

4.4 Size of reinforcing bars

We used the specimens with small-diameter bars (D10:nominal diameter=10 mm) in the parameter tests, and the specimens with large-diameter bars (D38:nominal diameter=38mm) in the confirmation tests. To examine the structural characteristics of the wall panels with lapped splices as regards the size of reinforcing bars, the structural charcteristics of wall panel with small(D10),medium(D19:nominal diameter=19mm),and large(D32: nominal diameter=32mm)-diameter bars were examined in the horizontal loading tests.

Figure 10 shows the comparison of the load-rotation curves as regards the size of bars,and Fig.11 shows the comparison of the load-rotation curves with and without splices. From these results it was found that there were no differences in the structural characteristics of the wall panels whether there were splices or not, though the strength of the spec imens with large-diameter bars was relatively small in comparison to that of the specimens with small-diameter bars.

4.5 Lapped splices of large-diameter bars

In the confirmation tests of the wall panels subjected to in-plane shear stress, the structural characteristics of the wall panels with lapped splices of large-diameter bars (D38:nominal diameter=38mm) was examined in comparison to the wall panels without splices in the horizontal loading tests.

Figure 12 shows the load-shear rotation curves, and Fig.13 shows the crack patterns. From these results it was found that there were no differ ences in the structural characteristics of the wall panels regardless of whether there were splices. As a result,if the lap length is not less than 40d, and the concrete cover is not less than 1.5d, the structural characteristics of the wall panels with the lapped splices of large-diam- eter bars were approximately the same as those of the wall panels without splices regardless of the arrangement method of the splices.

5.CONCLUSIONS

Conclusions derived from diagonal and horizontal loading tests are summa rized as follows.

1.As regards the arrangement of splices, the structural characteristics of the wall panels with straight splices are approximately the same as those of wall panel with staggering splices.

2.As regards the influence of transverse bars, the structural character istics of specimens with transverse reinforcing bars outside splices are approximately the same as those of specimens without transverse bars.

3.As regards the steel ratio in the wall panels, the structural charac- teristics of the wall panels with splices are the same as those of the wall panels without splices regardless of steel ratio.

4.As regards the size of bars, there are no differences in the struc- tural characteristics whether there are splices or not, though the strength of the specimens with large-diameter bars is relatively small in comparison to that of the specimens with small-diameter bars.

From the above conclusions it is ascertained that for the wall panels with large-diameter bars, if the lap length is not less than 40d, and the concrete cover is not less than 1.5d, it is possible to use lapped splices in wall panels subjected to in-plane shear stresses.

This paper is a part of joint research study "Experimental Study on lapped splices of Large-Diameter Bars", and has been carried out by ten electric power companies(the Tokyo,the Hokkaido,Tohoku, the Chubu,the Hokuriku,the Kansai,Chugoku,Shikoku,Kyusyu,the Japan Atomic Power), and five construction companies(Shimizu,Ohbayashi,Kajima,Taisei,Takenaka Komuten).

REFERENCES

(1) Japanese Architectural Standard Specification,JASS 5,Reinforced Concrete Work,Architectural Institute of Japan.1986

Table 1 Specimens of Diagonal loading tests

specimen	splices		strength		failure mode	specifications
	inner bar	outer bar	τ_c (kg/cm^2)	τ_u (kg/cm^2)		
DS-01	OUT	OUT	16.4	75.9	SL	reinforcing bars :D10
DS-02	OUT	STR	19.0	70.0	SL	steel ratio: 0.8%
DS-03	OUT	STR	18.7	69.5	SL	concrete strength :Fc=2409
DS-04	STR	OUT	18.0	71.1	SL	
DS-05	STA	OUT	19.7	70.3	SL	lap length: 40d

τ_c : shear stress at shear cracking
τ_u : shear stress at ultimate state

NOTATION OF EACH COLUMN in Table 1 and 2
OUT: without splices
STR: straight splices
STA: staggering splices
SL: sliding shear failure
FC: flexural failure

NOTATION in Fig. 3, 5, 12
SC: Shear Cracks in web wall
FC: Flexural Cracks in frange wall
YI: Yield of Inner bars
YO: Yield of Outer bars
YF: Yield of bars in Frange wall
YW: Yield of bars in Web wall
CF: Compression Failure of web wall
SF: Sliding Failure of web wall

Table 2 Specimens of Horizontal loading tests

specimen	*1 bar	Fc	splices *2			steel ratio %		strength		failure mode
			fla*3	web wall				τ_c	τ_u	
			inner bar	inner bar	outer bar	fla	web	(kg/cm^2)	(kg/cm^2)	
HS-01	D10	250	OUT	OUT	OUT	2.9	0.8	6.0	71.1	SL
HS-02			STR	STR	STR	0.8	0.8	5.0	52.3	FC
HS-03			OUT	OUT	OUT			5.0	51.6	FC
HS-04			OUT	OUT	STR			8.4	73.0	SL
HS-05		233	OUT	STA	OUT	2.9	0.8	10.3	64.7	SL
HS-06			OUT	STR	OUT			11.3	64.0	SL
HS-07			OUT	OUT	OUT	3.7	1.6	9.8	84.9	SL
HS-08			OUT	STR	OUT			13.2	85.6	SL
HM-01	D19	263	OUT	OUT	OUT	3.0	0.8	8.7	66.6	SL
HM-02		262	OUT	OUT	STR			14.0	66.7	SL
HE-01	D32	229	OUT	OUT	OUT	4.0	1.6	10.9	73.2	SL
HE-02		213	OUT	OUT	STR			12.8	63.0	SL
HL-01	D38	272	OUT	OUT	OUT	2.3	1.0	10.5	60.1	SL
HL-02		302	OUT	OUT	STR			9.5	65.2	SL

*1 steel stregth (σ_y) : D10 (3528 kg/cm^2), D19(3981kg/cm^2) D32 (3898kg/cm^2), D38 (3971kg/cm^2)

*2 lap length : 40d

*3 fla :flange wall

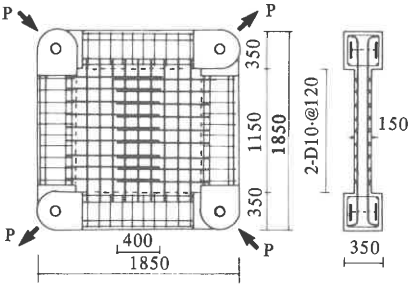


Fig. 1 Specimen (DS-02) and load

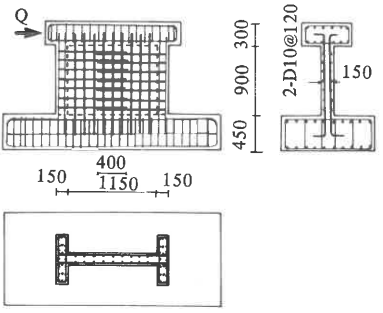
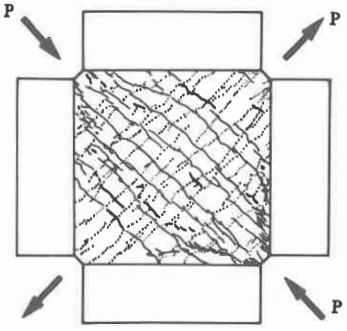
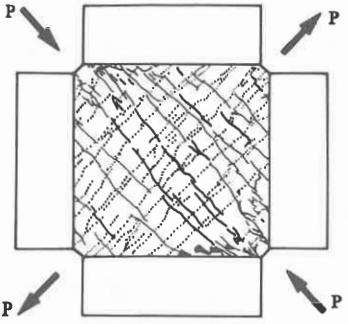


Fig. 2 Specimen (HS-04) and load



(a) DS-01



(b) DS-02

Fig. 4 Crack patterns at the final state

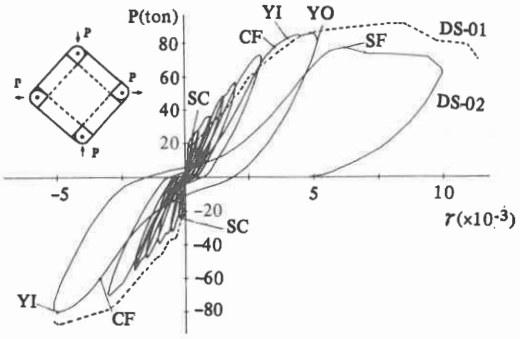


Fig. 3 Load-shear rotation curves

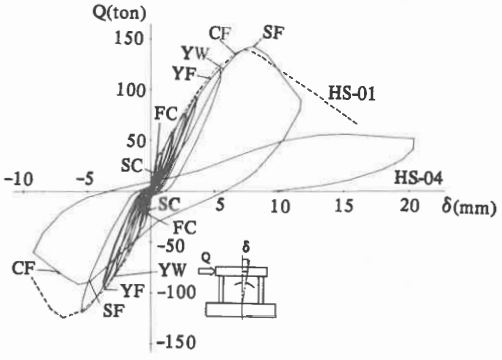
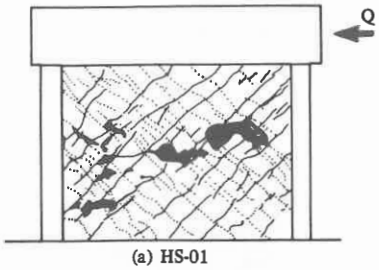
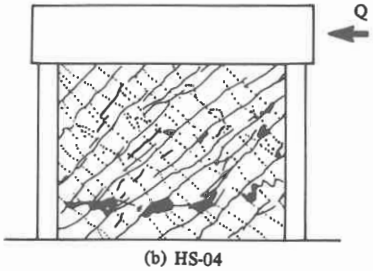


Fig. 5 Load-shear deformation curves



(a) HS-01



(b) HS-04

Fig. 6 Crack patterns at the final state

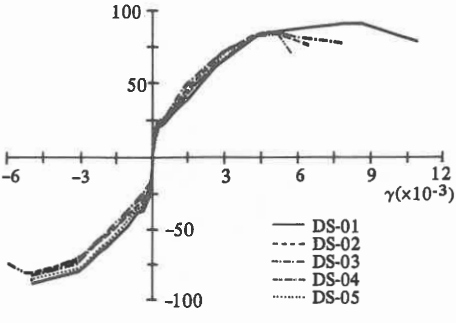


Fig. 7 Envelope of load-rotation curves

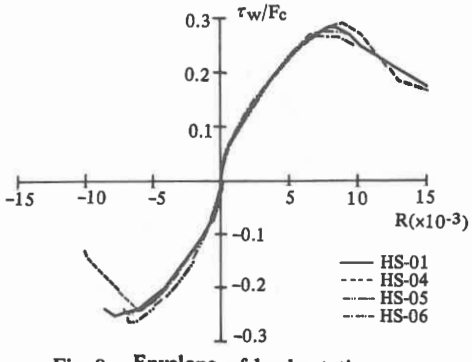


Fig. 8 Envelope of load-rotation curves (Pw=0.8%)

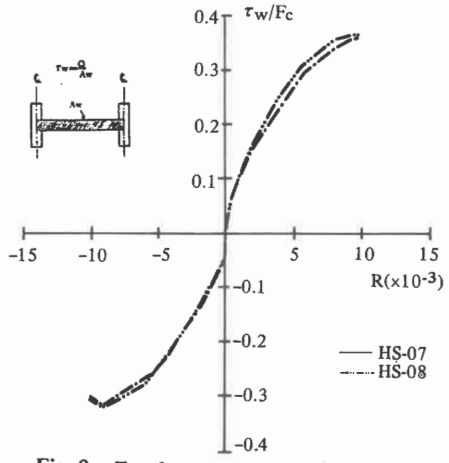


Fig. 9 Envelope of load-rotation curves (Pw=1.6%)

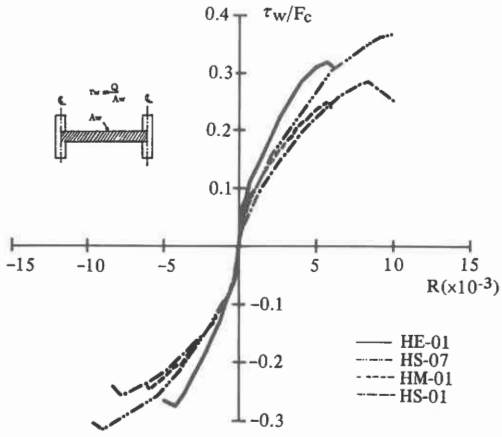


Fig. 10 Envelope of load-rotation curves (without splices)

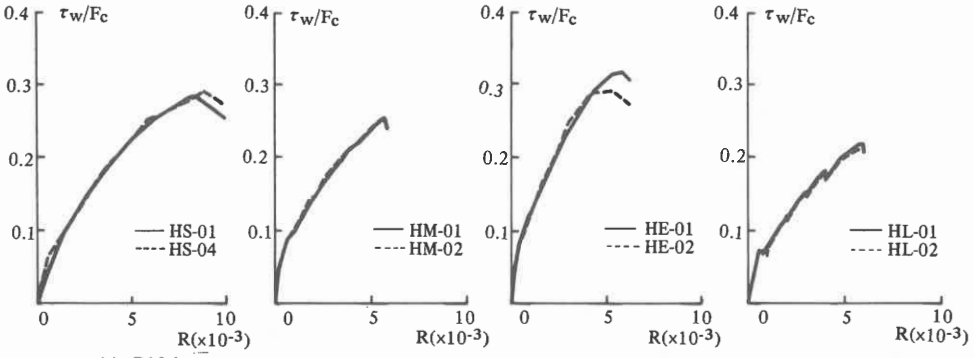


Fig. 11 Envelope of load-rotation curves (for various size of bars)

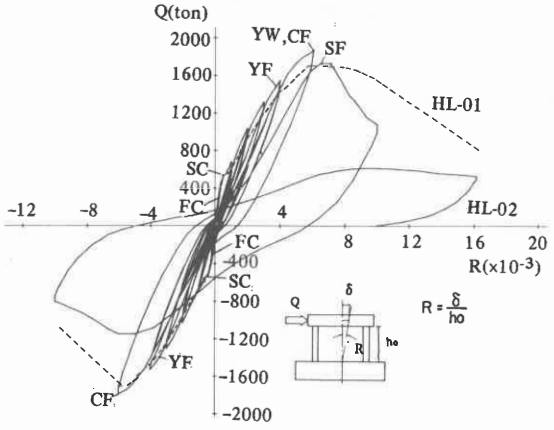


Fig. 12 Load-rotation curves

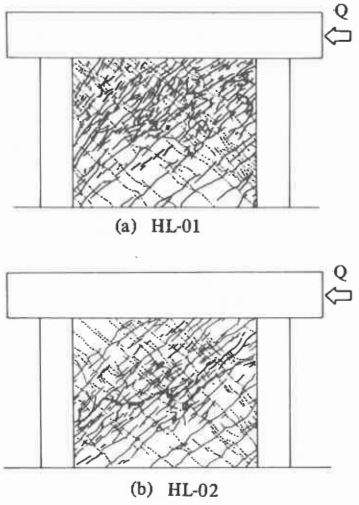


Fig. 13 Crack patterns