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EXPERIMENTAL STUDY ON THE LOAD-DEFLECTION CHARACTERISTICS OF A SHEAR WALL COMPOSED OF BOX AND CONICAL SHAPED ELEMENTS

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SUMMARY

Examined are in this paper the following two properties for both experimental and analytical studies upon the composite shear wall which is composed of the box and conical shaped shear walls connected by floor slabs. One is the interaction of responses between them, the other is the restraint effect of a floor slab of the composite shear wall. The results yield the conclusion that mechanical properties including the load-deflection characteristics of the composite shear wall are well represented from those obtained for box-shaped and conical elements, and that the restraint effect of slab is of no significance.

INTRODUCTION

A Boiling-Water-Reactor (BWR) building is a composite structure which consists of three major shear walls, outer box, inner box and shield walls connected together with by floor slabs as shown in Fig. 1. The seismic behaviour of the building is complicated because of various factors such as the geometrical complexity, a large number of penetrations, heavy reinforcement, high axial load and so on. As mentioned previously, the major shear walls of the composite shear wall are connected by floor slabs. Therefore, some kinds of forces between these shear walls are interacting through the floor slabs. However, there are few studies which treat interactive effects between shear walls through the floor slabs. And as for the restraining effects of floor slabs affecting the strength and deformation characteristics of the structures, almost no research has been made. Considering this circumstance, experimental studies are carried out upon the composite shear wall and its component walls, i.e. box shaped and truncated conical shear walls (Ref. 1 and 2). Four specimens are prepared, two of which are composite shear wall models scaled on the basis of BWR type reactor building, and other two are the box-shaped shear wall and the truncated conical shear wall, which correspond to the inner box wall and the shield wall respectively.

In this study, in order to know well the interactive effect through floor slabs on the composed shear walls, first, experimental results are investigated and load-deflection characteristics of the composite shear wall are compared with the superposition of results of constitutive wall elements. Secondly, we examined the restraining effect due to the difference in thickness of the slabs which may influence the strength and deformation characteristics of the structures. We also added some discussions on the relationship between the base shear and displacement obtained through FEM analysis.

EXPERIMENTAL IMPLEMENTATION

Specimens The correlation among these specimens is shown in Fig. 2. The model Bp and the model CP correspond to the inner box wall and the shield wall respectively. The composite shear wall connects these specimens with floor slabs. Two composite shear walls are prepared. The model Ap-1 has 50 mm thick slabs and the model Ap-2 100 mm thick slabs. Every specimen is a two storied shear wall which is scaled at about one twenty-fifth the full scale. In our previous experiment, we have already done mechanical property tests for two types of specimen, full-shaped specimens and half-symmetrical specimens. Through these tests, it is demonstrated that the half-symmetrical model approximately agrees in behavior with the full-shaped model (Ref. 3). Therefore employed are half-symmetrical-shaped specimens for these studies instead of full-shaped specimens.

Mechanical properties of each concrete and reinforcing steel bar are listed in Table 1. The maximum diameter of concrete aggregate is 10 mm. Concrete strength for design is 240 kgf/cm^2. Deformed steel bars of 6 mm in diameter are used for the specimens.

Loading Procedure We apply lateral reversed cyclic loads to the roof floor slab and the second floor slab in the models Ap-1 and Ap-2. To the second floor of these models, a lateral load is applied which corresponds to 90 percent of the reaction-load at the roof floor slab. Lateral load is applied to the models Bp and Cp individually so that displacement of each specimen may be identical to that of the model Ap-1 obtained from the experiment. An axial load is applied so that the compressive stress remains 20 kgf/cm^2 at the bottom of the specimen.

Failure Process In Table 2 are indicated not only base shears at the moments of the first flexural crack, the first shear crack and of yielding of the reinforcing steel bar, but also the maximum base shears and the observed failure modes. As shown there, it occurs a shear slip at each of the specimens due to compressive concrete crush at the bottom of the web zone.

In comparing the cracking patterns of the box-shaped shear wall between the models AP-1 and Bp, the damage on the latter is not so significant as that of the former. From this, we can assume that the model Bp has a smaller rigidity than the model Ap-1, because of a lower Young's modulus of concrete on the model Bp. There is no appreciable difference in the conical shear wall. But, it is observed a slightly larger damage in the box-shaped shear wall in the model Ap-2 than the model Ap-1.

Envelope curve for the load-deflection characteristics Figure 3 represents the envelope curves obtained from the load-deflection hysteresis curves of the model Ap-1, the model Ap-2 and the model Bp+Cp. Hereafter the notation Bp+Cp designates the sum of the base shears obtained from the model Bp and the model Cp. In this figure, base shears are normalized by square root of the corresponding compressive concrete strength (Fc) and deflections are indicated as displacement at the top of the specimen. Comparison of Ap-1 and Bp+Cp demonstrated that their maximum strengths agree well. But, it is observed that the slope of the envelope curve on the model Bp+Cp is slightly smaller than that of the model Ap-1, and that the deterioration after the maximum strength of the model Ap-1 is larger than that of the model Bp+Cp. Considering that Young's modulus of concrete on the model Bp is 0.8 times that of the model Ap-1, we can say that the model Bp+Cp and the model Ap-1 correspond well with each other in the envelope curves. Comparing the models Ap-1 and Ap-2, the maximum strength of the former is larger by 3.3 percent than the latter. We understand that this is due to displacement on the 2nd floor under a negative direction loading of the model Ap-2, this displacement being larger than that of the model Ap-1, with a result that the model Ap-2 is damaged in the first story, further than the model Ap-1. As a general tendency, the envelope curve of the model Ap-1 coincides in shape with that of the model Ap-2.

Mode Shape Figure 4 illustrates, for the models Ap-1 and Ap-2, the relationship between load-cycles and lateral displacement ratios (X2/Xr). X2 represents lateral displacement at the 2nd floor and Xr that at the roof floor. The ratios in the ranges of 1.0×10^{-3} and 2.0×10^{-3} radians remain around 0.6 for the both specimens. The ratio curves, however, show a gentle upward slope with increase in deformation cycle. We suppose that, as the deformation increases, the damage in the 1st story becomes serious. Comparing, for the model Ap-2, the ratios for the positive and negative direction loadings, it is confirmed that the lateral negative displacement at the 2nd floor is always around 10 percent larger than that in the positive direction. This suggests that the damage in the 1st story on the model Ap-2 is more serious than that on the model Ap-1 under negative direction loading.

Out-of-plane moment Figures 5 (a) and (b) show bending moments over the slabs and over the flanges of box shaped wall of the model Ap-1, the model Ap-2 and the model Bp. The moments are calculated based on the stresses of the reinforcing bars in the experiments. In Fig. 5 (a), it is observed that the out-of-plane bending moment for the model Ap-2 slab is about 10 times as large as that for the model Ap-1, and that almost no moment is produced in the model Bp. This suggests that the out-of-plane bending moment is mainly due to rotation of the conical shear wall and that the bending rigidity of the model Ap-2 slab is 8 times as large as that of the model Ap-1.
In Fig. 5 (b), we can also observe bending moments occurring at the compressive side flange of box-shaped shear wall; from this, it is found that the compressive side flange supports out-of-plane shear force. The shear force becomes smaller in the order: models Ap-2, Ap-1, Bp. But its difference is not so significant as observed in the slab.

ANALYTICAL IMPLEMENTATION

For furthering our study, we examine the experimental results by using Finite Element Method analysis. This analysis is intended to demonstrate the possibility to obtain the load-deflection characteristics of the composite shear wall through those of its composing shear walls, and to evaluate the effect of the difference in slab thickness upon the load-deflection characteristics of the composite shear wall. In this analysis procedure, material properties and deformation mode shape are equal to the experimental results of the model Ap-1. Monotonic loads are applied for this analysis. As for details of the method and the assumption for this analysis, see Reference 3.

Figure 6 shows envelope curves of load-deflection from FEM analysis for the model Ap-1, the model Ap-2 and the model Bp+Cp with that from experimental result of the model Ap-1. The percentages plotted in Fig. 7 are the ratios to the total base shear of the base shear on individual elements, that is, on the box shaped and conical shear walls. As indicated by the envelope curves constructed by the experiment and the analysis for the model Ap-1, the analytical strengths are slightly larger than the experimental strengths. Considering that the loading for experiment is cyclic reversed type, it can be said that the envelope curves of both agree well with each other. Consequently, the analysis model and the conditions for analysis, we consider, correspond well to the experiment. A good correspondence between the envelope curves of the model Ap-1 and the model Bp+Cp demonstrates that the load-deflection characteristics of the composite shear wall can be evaluated by superposition of those of the composite shear walls. As for the model Ap-1 and the model Ap-2, the maximum strength of the model Ap-2 is larger by 4 tons than that of the model Ap-1. No significant differences in the tendency of envelope curves indicate that the restraint effects on the load deflection characteristics of slab is negligible.

In view of comparison between the base shear carried by the box-shaped and conical shear walls, the portion by the latter tends to increase gradually along with increase in deformation. However, since the increase ratio is so small, it can be said that the box shaped shear wall supports around 65 percent of the total base shear. Such a tendency is observed with no appreciable difference in every model and we can assume that there is no significant interactive effects between shear walls nor restraint effects of floor slabs.

CONCLUDING REMARKS

The results obtained in these studies, the interactive effects between shear walls through the floor slabs and the restraint effects affecting the strength and deformation characteristics of the composite shear wall yield the following conclusions.

(1) Observed is no significant difference between the general properties of the model Ap-1 and the model Bp+Cp. Thus, the load-deflection characteristics of this composite shear wall can be represented by summing up the characteristics obtained from the corresponding box-shaped and truncated conical shear walls.

(2) The restraint effect of the slab on the strength and deformation characteristics of these composite shear walls is of no significance.

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REFERENCES

1. Asega, H., S. Iizuka et al. "Loads experimental study on two-story RC box and truncated conical walls" Trans. the 9th Int. Conf. on Structural Mechanics in Reactor Technology, Vol. H, pp. 549-554 (1987).
2. Machida, N., T. Shibuya et al. "Experimental study on the strength and deformation characteristics of sophisticated wall" Trans. the 9th Int. Conf. on Structural Mechanics in Reactor Technology, Vol. H, pp. 555-560 (1987).
3. Watabe, M., T. Kubo et al. "Experimental Study on the Strength and Deformation Characteristics of Shield Wall for BWR Type Reactor Building "Trans. the 8th Int. Conf. on Structural Mechanics in Reactor Technology, Vol. H, pp. 297-304 (1985).
4. Kubo, T., M. Watabe et al. "Load deflection characteristics of nuclear reactor building structure, part 1: program of experimental research studies "Trans. Archi. Japan, Annual Convention, pp. 1495-1496 (1983). (in Japanese)

Table 1 Material Properties

Items	specimens	Ap-1	Ap-2	Bp	Cp
Concrete	Compressive strength (kg/cm^2)	231	266	264	191
	Cleavage strength (kg/cm^2)	24.4	25.5	25.8	22.7
	Young's modulus (10^5kg/cm^2)	2.09	2.14	1.76	2.14
	Poisson's ratio (ν)	0.12	0.14	0.16	0.16
Steel bar	Yielding strength (kg/cm^2)	4400	4400	4469	4373
	Tensile strength (kg/cm^2)	5520	5520	5577	5394
	Young's modulus (10^6kg/cm^2)	1.87	1.87	1.84	1.79
	Plastic extension (%)	18.2	18.2	16.3	23.9

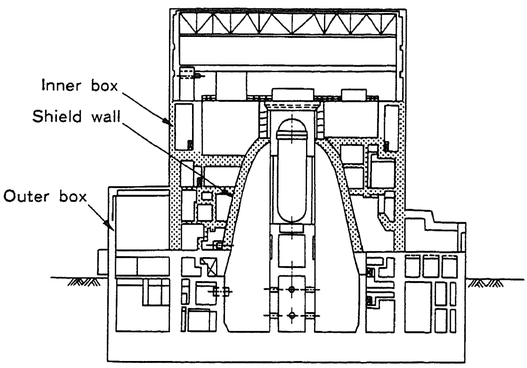
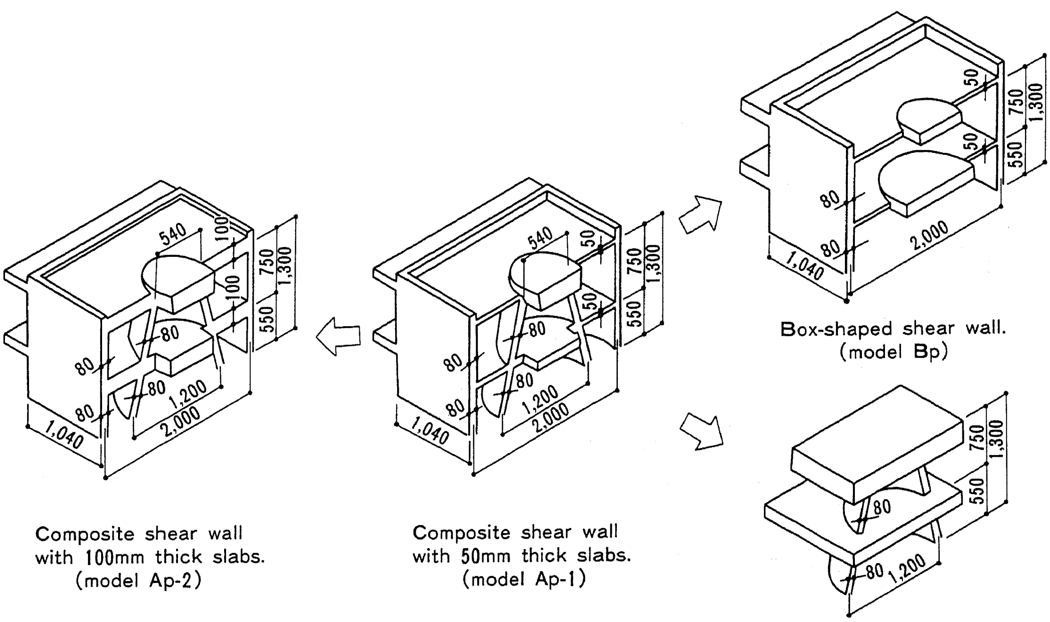


Fig. 1 A Typical BWR Type Reactor Building in Japan.

Table 2 Experimental Results

		Specimens	Base shear (ton)	Rotation angle (1/1000 rad.)
First flexual cracking		Bp	50.4	1.0
		Cp	28.2	0.51
		Ap-1(BW, CW)	67.3 84.5	0.31 0.50
		Ap-2(BW, CW)	48.7 88.8	0.25 0.60
First shear cracking		Bp	23.6	0.33
		Cp	28.2	0.51
		Ap-1(BW, CW)	67.3 59.7	0.31 0.25
		Ap-2(BW, CW)	64.5 48.7	0.24 0.25
First yielding of steel bars	Longi. direction at flange	Bp	82.2	6.20
		Cp	50.9	2.02
		Ap-1(BW, CW)	173.0 153.7	3.01 2.61
		Ap-2(BW, CW)	168.2 160.3	3.21 2.83
	Longi. direction at web	Bp	96.3	3.20
		Cp	61.8	3.64
		Ap-1(BW, CW)	168.2 168.2	3.42 3.42
		Ap-2(BW, CW)	164.2 173.7	3.01 3.83
	Trans. direction at web	Bp	77.2	6.61
		Cp	no yieiding	−
		Ap-1(BW, CW)	−162.4 169.7	−3.34 3.63
		Ap-2(BW, CW)	−145.4 −155.4	−2.62 −3.61
Ultimate state		Bp	112.2	4.01
		Cp	63.1	3.85
		Ap-1(BW, CW)	179.6	4.02
		Ap-2(BW, CW)	173.7	3.83
Failure mode		Shear-slip each		

BW : BOX-SHAPED WALL CW : TRUNCATED CONICAL-SHAPED WALL



Composite shear wall with 100mm thick slabs. (model Ap-2)

Composite shear wall with 50mm thick slabs. (model Ap-1)

Box-shaped shear wall. (model Bp)

Conical-shaped shear wall. (model Cp)

Fig. 2 Correlation among Specimens.

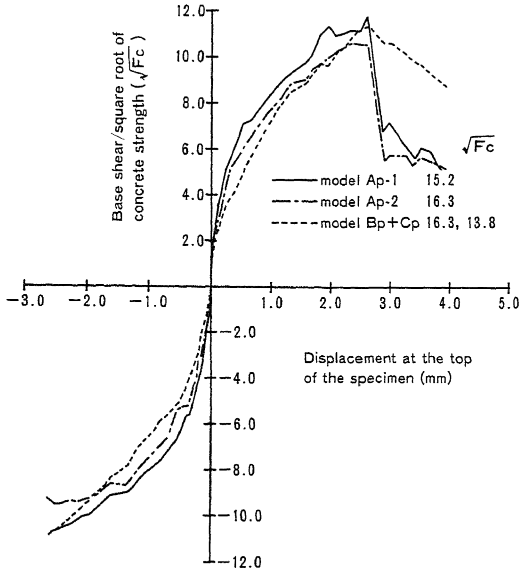


Fig. 3 Envelope Curves of Load-deflection Hysteresis Curves Obtained from Experiments on the Model Ap-1, Model Ap-2 and Model Bp+Cp.

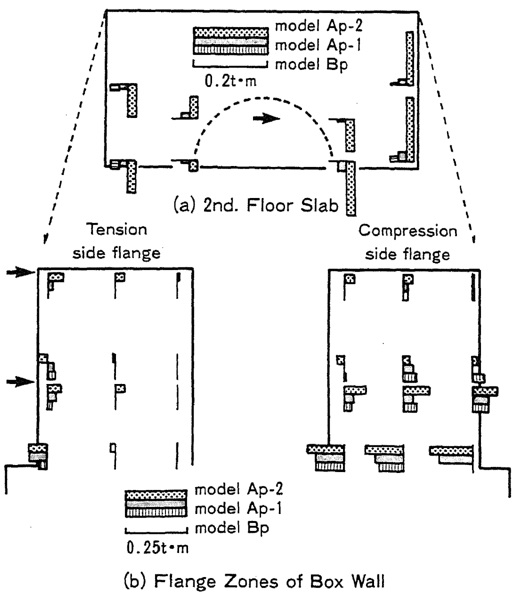


Fig. 5 Out-of-plane Bending Moment Distributions.

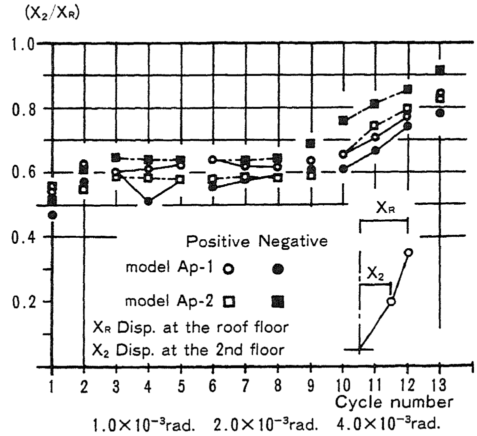


Fig. 4 Deformation of the Mode Shapes of the Composite Shear Walls.

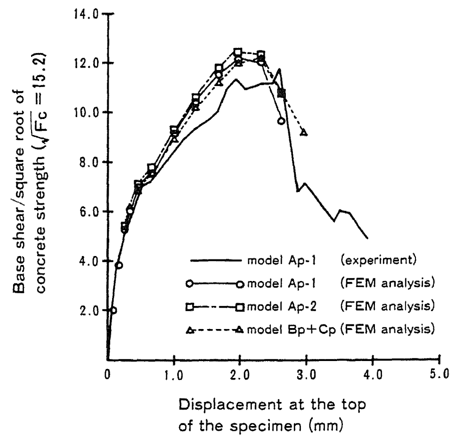


Fig. 6 Envelope Curves of Load-deflection Hysteresis Curves Obtained from a FEM Analysis on the Model Ap-1, Model Ap-2 and Model Bp+Cp.

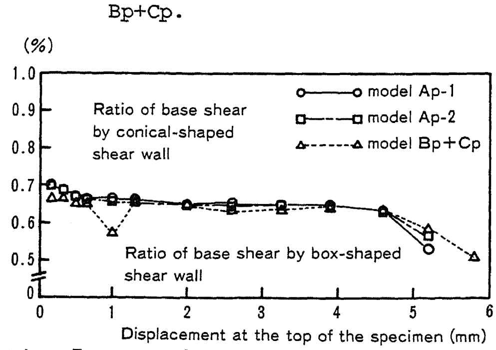


Fig. 7 Base Shears Carried by Box-shaped and Conical Shear Walls.