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

10-5-7

EXPERIMENTAL STUDY ON EARTHQUAKE RESISTANT COMPONENTS FOR BWR TYPE REACTOR BUILDING

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SUMMARY

To get fundamental materials which will be useful in obtaining load-deflection characteristics of reactor buildings, three types of specimens for modeling earthquake resistant components of a reactor building were tested.

It was founded that the various thickness of the slab slightly influenced the load-deflection characteristics of sophisticated wall models, and the load-deflection characteristics of sophisticated wall models can be substituted by the sum of that for the box wall model and conical shell wall models. And the load-deflection characteristics of the each model could be evaluated by analysis using the sub element beam model.

INTRODUCTION

In a BWR type reactor building, two reinforced concrete box walls and a conical shell wall resist the earthquake lateral force. Since the shape and the amount of reinforcement for these walls are different from shear walls used in an ordinary structures, it is essential to do experimental studies on these box and conical shell walls to determine the load-deflection characteristics for reactor buildings.

To evaluate general load-deflection characteristics of a reactor building, it is not sufficient to conduct experimental studies upon individual constituent members. For a complex system such as a reactor building, it is required to perform experimental researches upon a complex structure to evaluate its seismic capacities. Most experimental work done previously have been performed by using individual wall models.

The specimen in this study is a single story model to determine clearly the difference of load-deflection characteristics between the coupled sophisticated model and the superposed individual model. Also, all the test results were compared with the analytical ones using the sub element beam model.

OUTLINE OF EXPERIMENT

Test Specimen Three types of specimens, a box wall model (B), a conical shell wall model (C) and a coupled wall model (S), modeling an earthquake resistant component of a reactor building were prepared. Every specimen was scaled to one twenty-fifth of the prototype building. Specimens S1 and S2 were single storied sophisticated models representing the shield wall and the inner box wall of a reactor building. The thickness of the top slab of the specimen S1 and S2 were 5 and 25 centimeters, respectively. Specimens B was a box wall model representing the inner box wall of a building. Specimen C was conical shell wall model representing the shield wall. The shape of specimen B, C was identical to the corresponding elements of the specimens S1 and S2. All specimens were half symmetrical models. The details of specimens are shown in Fig. 1 and listed in Table 1. The yielding and ultimate stress of reinforcing bars were 4425 kg/cm^2 and 5651 kg/cm^2, respectively. The compressive strength of concrete was between 224 and 283 kg/cm^2.

Test procedure Fig. 2 shows the general setup of specimen S1. The lateral load was applied to the top slab by using electrically controlled actuators for which maximum capacities were 100 tons. The center of loading was determined to avoid the torsional deformation of specimens by taking both the experimental results and analytical ones from the finite element method. A similar sequence of loading program was applied to four specimens within this study.

The displacement in the direction perpendicular to that of the loading was constrained by using a device consisting of a universal joint and rollers specially prepared for this series of experiments. The axial load was applied upon a box wall and a conical shell wall, respectively. The axial stress was kept constant with the value of 20kg/cm^2. A steel block and rubber sheet were placed between the specimen and hydraulic jacks, so that axial stresses were distributed uniformly over the cross section of the walls.

TEST RESULTS

The test results of the two sophisticated models were compared to obtain the effect of the thickness of the top slab. And the test results of the sophisticated model was compared with those obtained for the box and conical shell wall models. The results from the individual models were coupled at corresponding deformation stages.

Stiffness and strength The experimental value for initial stiffness are listed in Table 2 with analytical values obtained from a beam theory. The sum of values of the individual wall models is larger than that for the sophisticated wall model. When initial stiffnesses are divided by Young's modulus of concrete for the corresponding specimen, the sum of values from individual models and that for the sophisticated model coincide closely with each other.

Cracking load and maximum load Shear and flexural cracking loads for each specimens are listed in Table 3. The crack load of the box wall within the sophisticated wall model is assumed as the lateral load applied by the actuator which was located on the center of the box wall. The crack load for the conical shell wall is determined in an identical manner as above by the load applied for the conical element. For the box wall, both shear and flexural crack loads were larger for the sophisticated wall model than those for the individual wall model. For the conical shell wall, on the other hand, both loads were smaller for the sophisticated model than for the individual model. Probably, some of lateral loads applied to the specimen were transmitted from the box wall element to the conical shell element through in-plane shear of the top slab. Maximum loads for each specimen is listed in Table 3. The sum of the maximum loads for the individual wall models is larger than the that for the sophisticated wall models. When the value were divided by $\sqrt{Fc}$, where Fc denotes the compressive strength of concrete, the sum from individual wall models is nearly equal to the load from the sophisticated wall model. The maximum load of sophisticated wall model could be estimated well as the sum of the loads of the individual wall model.

Load-deflection relation Fig. 3 shows the load-deflection relation of the specimen S1 and S2. There are little effect of the thickness of top slab on the load-deflection relation. The envelope curves of the load-deflection hysteresis for the specimens S1, S2, B, C are shown in Fig.4. The mark of O indicate the sum of B and C. The marks are located close to the envelope curves of S1 and S2. Note that the marks do not coincide exactly. To take the difference of concrete strength into account, the load quantites are normalized by $\sqrt{Fc}$. The resultant load-deflection relation is shown in Fig. 5. The marks ,which represent the sum of the loads obtained for individual wall models, fall in the envelope curves of the sophisticated wall model.

Crack pattern and Failure mode Final cracking pattern of each specimen is shown in Fig. 6. The failure mode were slip failures in all specimen. The conical shell walls failed near the top of the web zone in a circular cross-section. The failure of the individual box wall model was at the bottom of the web wall. The box walls in the sophisticated models failed at the top of the web wall. Crack pattern and the strain distribution of reinforcing bars were identical to each other from the results for the sophisticated wall model and those for the individual wall model.

ANALYTICAL RESULTS

Analytical model The analytical model of the sophisticated wall model is shown in Fig.7. The box wall and conical shell wall are modeled beams. The beam model consisted of sub elements. The deflection is considered the the sum of shear deflection and flexural deflection.

Load Shear deflection relation The shear stress-shear strain relation is given by following equation.

$$\tau_1 = 0.3\ \tau max \qquad \tau max = \alpha\ \tau c + \tau s + \tau o$$
$$\gamma_1 = \tau_1 / Gc \qquad \tau c = 2.7\ \sqrt{Fc}(1.9-1.5M/QD)$$
$$\tau s = Pw\,\sigma y/2 \qquad \tau o = \sigma o$$
$$\tau_2 = 0.8\ \tau max \qquad \alpha = \text{coefficient for the effect of column or flange}$$
$$\gamma_2 = 0.5\ \gamma max \qquad \gamma max = 4.8\times10^{-3}$$

The model was proposed by Chiba et al.(Ref.1) from the test results of reinforced concrete shear walls. The validity of the model for the box wall model was confirmed by the comparison 28 test results for box wall model. The comparison of maximum shear strength and shear stress - shear strain relation were shown in Fig.8 and 9. Also, the validity of the model for the conical shell wall was conformed (Ref.2).

Load - Flexural deflection relation The flexural deflection was calculated by assuming idealized bending moment - curvature relation at each element of beam model. The moment - curvature relation was calculated by fiber model and idealized for a tri-linear model. The rotation at the base was calculated by following equation proposed by Inada (Ref.3) and added to the flexural deflection.

$$\delta o = \theta \cdot H_B$$
$$\theta = M_B \,/\, (M_Y \cdot j_Y/(0.5 \cdot s\,\varepsilon y \cdot 40d)$$

Analytical results The analytical results of box wall model and the sophisticated wall model are shown in Fig.10 and 11. The computed value a little exceed the test results in the range of deflection angle 1/1000 and 6/1000 rad. But, the computed value almost agreed with experimental results in all range of deflection angle.

CONCLUSION

Seismic loading test were carried out for tree types of seismic shear wall components of BWR type reactor building. A set of fundamental data were obtained through the experimental studies. A maximum use of these data can be made in next stages to evaluate stiffnesses, strength, and so on of the complicated structural systems of a reactor building as well as its load-deflection characteristics.

The study presented herein is one of experimental works conducted in a series under advises of the technical research committee organized in Building Research Promotion Association, Tokyo, Japan. The authors are indebted to members of the Committee for their valuable discussion.

REFERENCES

1. R. Fukuzawa, O. Chiba, T. hatori, K. Yagishita, M. Watabe, H. Yamanouchi, "Study on load-deflection characteristics of heavily reinforced concrete shear walls" 9th SMiRT (1987)
2. Y. Tamamura et al., "Load-Deflection Characteristics Nuclear Reactor Building Structures part 88 and 89", SUMMARIES OF TECHNICAL PAPERS OF ANNUAL MEETING, AIJ (1988)
3. Y. Inada, "Restoring force characteristics of reactor building based on load tests and numerical analysis (Part 2)", JOURNAL OF STRUCTURAL AND CONSTRUCTION ENGINEERING (1987)

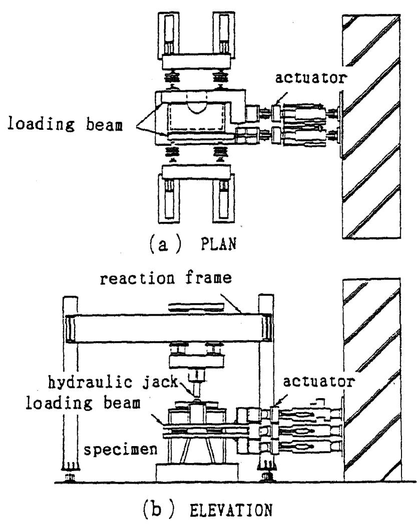

Fig. 2 Set up of specimen S1

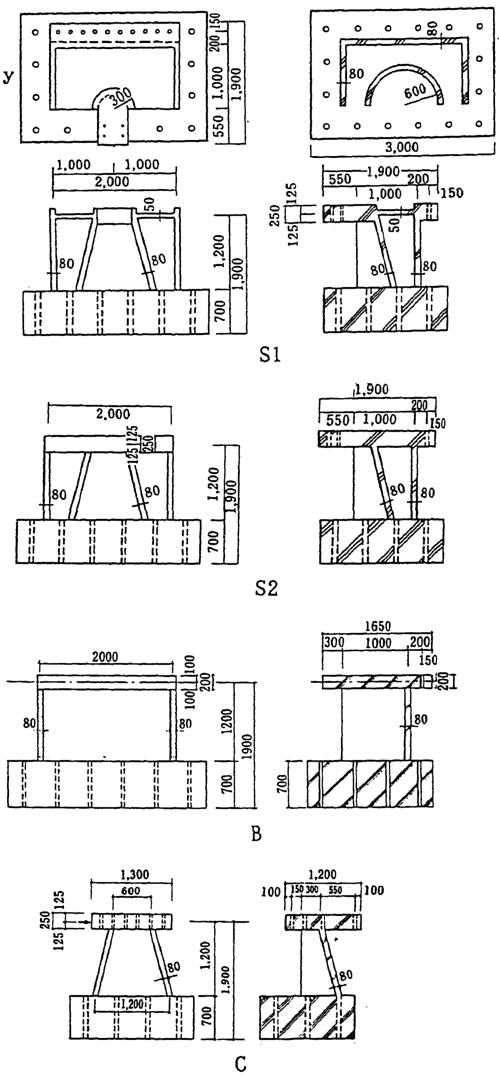

Fig. 1 Specimens

Table 1 Detail of Specimens

		Thickness of wall (mm)	Reinforcing bar	Reinforcement Ratio (%)	Heigh-to-length-ratio	Axial stress (kg/cm²)	strength of concrete (kg/cm²)
S1,S2	box wall	80	D6(double) @67 mm	1.2 %	0.6	20	224
	conical wall		D6(double) @53 mm	1.5 %	1.0		244
B			D6(double) @67 mm	1.2 %	0.6		283
C			D6(double) @53 mm	1.5 %	1.0		245

Table 3 Cracking load and Maximum load

		Shear crack load		Flexural crack load		Maximum load	
		P (t)	$P/\sqrt{Fc}$	P (t)	$P/\sqrt{Fc}$	P (t)	$P/\sqrt{Fc}$
S1	box wall	28	1.87	66	4.41	141	9.42
	conical wall	14	0.94	15	1.00		
S2	box wall	34	2.18	44	2.82	171	10.95
	conical wall	17	1.09	22	1.41		
B		30	1.78	66	3.92	125	7.43
C		18	1.15	18	1.15	45	2.87

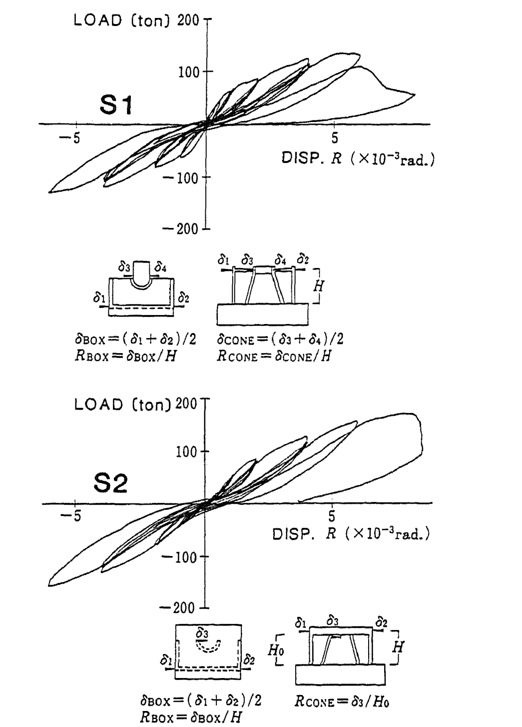

Fig. 3 Load-deflection relation of S1, S2

Table 2 Initial stiffness

Specimen	Experiment		Calculation
	Ke (t/cm)	Ke/Ec	Ke (t/cm)
Sophisticated wall model (S1)	1040	584	1206
Box wall model (B)	1086	4313	1410
Conical shell wall model (C)	241	121	235
B+C	1327	552	1645

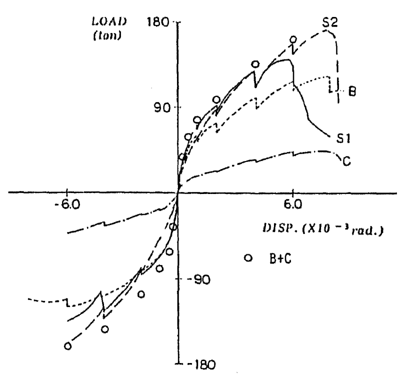

Fig. 4 Envelope curves

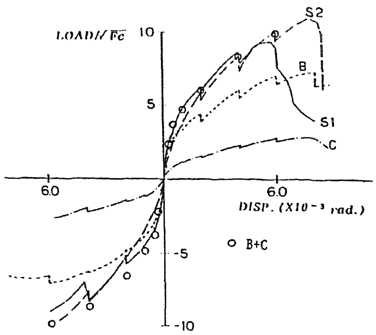

Fig. 5 Envelope curves (normalized by $\sqrt{Fc}$)

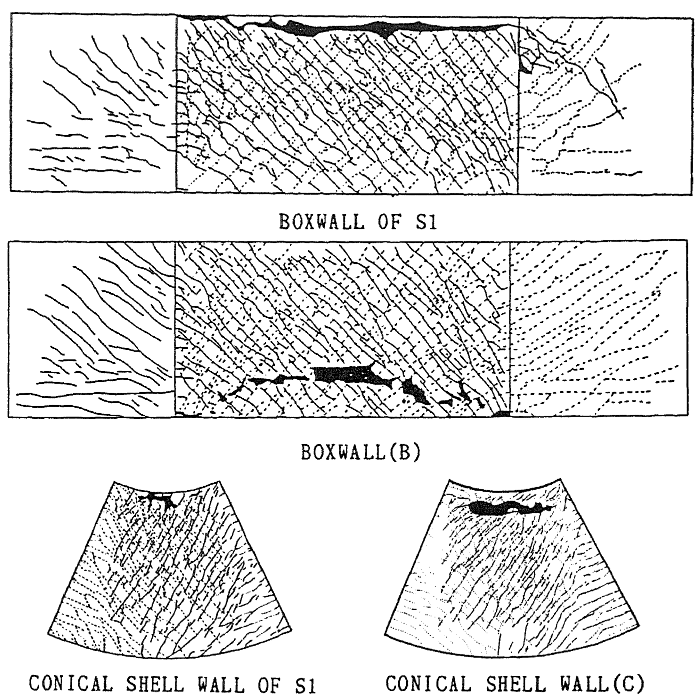

Fig. 6 Cracking pattern

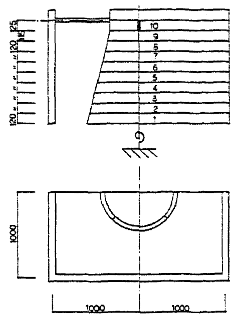

Fig. 7 Analytical model

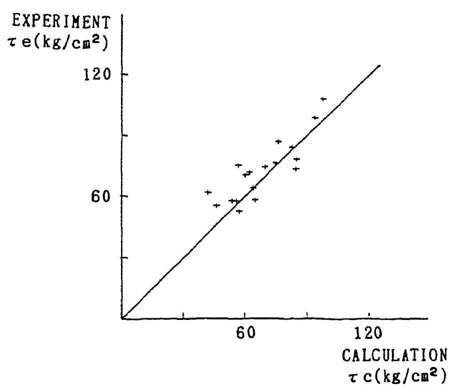

Fig. 8 Comparison of maximum shear strength

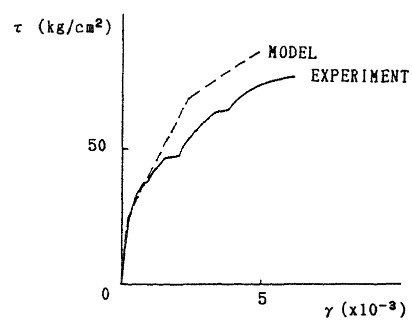

Fig. 9 Shear stress-shear strain relation

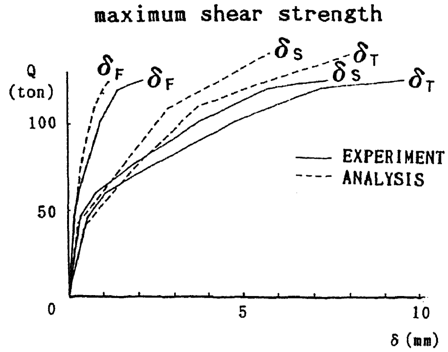

Fig. 10 Analytical results of B

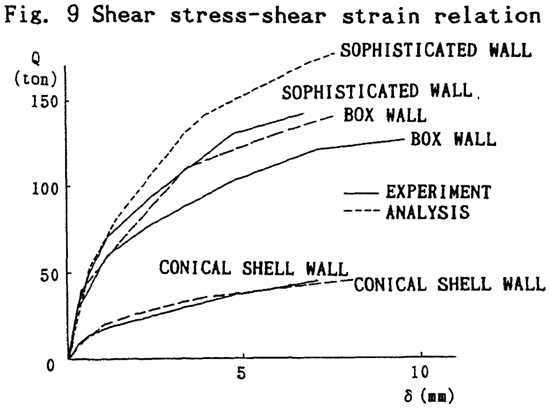

Fig. 11 Analytical results of S1, B, C