General Conclusions of the Studies on Sophisticated Model for Nuclear Building Structures

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ABSTRACT

The outline of the results obtained by the experimental and analytical studies are introduced first. A set of thirteen specimens of the box wall model, the conical shell wall model and the coupled sophisticated models is employed in this experimental study.

The load-deflection characteristics of the coupled sophisticated models could be substituted by the sum of that for the box wall and the conical shell wall model. A formula to estimate the load-deflection characteristics of the coupled sophisticated model is proposed, which yields the strength and deflection with a good agreement with that obtained from experimental results. And the load-deflection characteristics of each model could be evaluated by analysis using the flexural beam theory.

INTRODUCTION

A nuclear reactor building consisted of the complicated structural elements such as the box walls, the conical shell walls, etc. It was very difficult to perform the lateral loading experiment to evaluate safety margins of seismic strength of the building with such complicated structure. Therefore, the reasonable load-deflection characteristics model for dynamic analysis of that structure has not been sufficiently revealed.

Presented in this study are the results of both experimental and analytical studies upon the effect of individually constituent walls on the load-deflection characteristics of the coupled sophisticated models. The difference of load-deflection characteristics between the coupled sophisticated model and the individual model is discussed in detail. And the authors wish to introduce the quantitative estimation of the load-deflection characteristics obtained by the experimental studies on the box wall model and the conical shell wall model.

OUTLINE OF EXPERIMENT

Specimens

A typical BWR type reactor building in Japan is shown in Fig.1. Three types of the box wall model, the conical shell wall model and the coupled sophisticated model, modeling an earthquake resistant component of reactor
Loading Procedure

As the lateral loading, the alternatively cyclic loading schedule, which is a similar sequence of loading program, previously prepared as files in computer are applied. The axial stress is kept as the constant value of 20 kgf/cm² by the actuator with servomechanism, which is uniformly distributed over the cross section of box wall and conical shell wall. The test set-up is illustrated in Fig. 3. The feature of the experimental plan for the sophisticated model is that the loading device is applied at each wall directly as illustrated in Fig. 4. The deflections and deformations of specimens, the strains of reinforcing bars and the strains of concrete are obtained.

Fig. 3 Test Set-Up

Fig. 4 The Loading Method

Test Results

The test results of the sophisticated model is compared with those obtained for the box wall models and the conical shell wall models. The results from the individual models are coupled at corresponding deformation stage. Crack pattern and strain distribution of reinforcing bars are identical to each other from the results for the sophisticated model and those for the individual wall model. The crack distribution patterns for the specimen of box wall model and sophisticated model at the end of loading are shown in Fig. 5. The crack load of the box wall within the sophisticated wall model is assumed as the lateral load applied by the actuator which is 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.

The failures of the individual box wall models is located at the bottom of the web wall. The conical shell walls take a failure near the top of the web portion in a circular cross-section. The sum of initial stiffness from individual models and that of the sophisticated model coincide closely with each other.

The sum of maximum strength from individual wall models is nearly equal from the sophisticated model as shown in Fig. 6. Therefore, the maximum strength of the sophisticated model can be estimated well as the sum of the strength of the individual model.
building are prepared. A set of thirteen specimens is employed in this study. Contents of the specimens are listed in Table 1. The shape of the specimens, i.e., (the box wall model and the conical shell wall model) is identical to the corresponding element of the coupled sophisticated model. All the specimens are the half symmetrical model. Every specimen is scaled one twenty-fifth of a prototype building and one or two story model. The horizontal length of the box wall is 2000 mm and the top of the loading point is 1200 mm in height. The diameter of conical shell walls is 540 mm at the top of the wall, and 1200 mm at the bottom of the wall. Thickness of all walls is 8cm. The reinforcement ratio for the walls is 1.2%. The shapes of typical specimens are shown in Fig. 2.

Table - 1 Contents of Specimens

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<th>Thickness(mm)</th>
<th>Reinforcement ratio(%)</th>
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</table>

* Height by Length
#2 of 2nd or 1st story
#3 at the bottom of 2nd or 1st floor
#4 Reinforcement ratio of the sophisticated mode is the same value of the individual model

Fig. 1 A Typical BWR Type Reactor Building in Japan

Fig. 2 The Shape of Typical Specimens
**FIG. 5 Crack Distribution Patterns**

**OUTLINE OF ANALYSIS**

**Analytical Method**

For an analytical study, the flexural beam theory is employed. In the analysis, the box wall and the conical shell wall are represented by a set of the sub-beam elements as shown in Fig. 7. The deflection is considered the sum of shear deflection and flexural one. The equations for the models of the load-deflection characteristics, which are used for the sub-beam elements, are proposed by Chiba et al. (Ref.1) from the test results of reinforced concrete shear wall. Those numerical models are given by the results of the experiments of reinforced concrete shear walls. The validity of those equation for the box wall model is confirmed by the comparison with 28 test specimens of box wall model and conical shell model. The equations of shear stress-shear strain relation, which are idealized for Tri-Linear model as shown in Fig. 8, are written as

- For box wall model, \( \tau_1 = 0.3 \tau_{\text{max}} \),
- For conical shell wall model, \( \tau_1 = 0.4 \tau_{\text{max}} \),

\[
\tau_{\text{max}} = a \tau_0 + \tau_s + \tau_o, \\
\gamma_1 = \frac{\tau_1}{G_0}, \\
\tau_s = 0.8 \tau_{\text{max}} \text{ and } \\
\gamma_2 = 0.5 \gamma_{\text{max}}.
\]

Where

- \( a \) : coefficient for the effect of column or flange,
- \( \tau_0 \) : shear stress strength of concrete,
- \( \tau_s \) : shear stress strength of reinforcement,
- \( \tau_o \) : shear stress strength of axial stress,
- \( r_w \) : reinforcement ratio for the walls,
Fc: compressive strength of the concrete,
\(\sigma_y\): yield stress of the reinforcing bar,
\(\sigma_o\): constant axial stress, and
\(M, Q, D\): bending moment, shear force and span length.

The flexural deflection is obtained from assuming idealized bending moment-curvature relation for sub element of beam theory. The moment-curvature relation is calculated by fiber model and is idealized for Tri-Linear model as shown in Fig. 9. The rotation at the base is calculated by following equation proposed by Inada(Ref. 7).

Analytical Results

All the results of the experiments are compared with the analysis using the flexural beam theory. Shear stress–shear strain relation and flexural moment-curvature is shown in Fig. 9. The analytical results of the individual model and the sophisticated model are shown in Fig. 10 and Fig. 12. The computed value exceeded a little the test results in the range of deflection angle 1/1000 and 6/1000 rad. But, the computed value almost agrees with experimental results in all range of deflection angle.
CONCLUSION

Employing fifteen specimens of the box wall model, the conical shell wall model and the sophisticated model in this study, the authors obtained the many effective results to the load-deflection characteristics for those models. In this paper, we introduce the equations to estimate the maximum shear strength, the shear deflection at the maximum shear strength and the skeleton curve.

The summarize of the conclusion in this study are as follows;

The validity of the half-symmetrical model for the experiments is confirmed by the previous experiments in which the experimental result of the half-symmetrical-shape model approximately agrees in behavior with that of full-shaped model. Therefore, the half-symmetrical model is employed for the experimental studies instead of full-shape model.

The load-deflection characteristics of the coupled sophisticated models can be substituted by the sum of that for the box wall model and the conical shell wall model. A formula to estimate the load-deflection characteristics of the coupled sophisticated model is proposed which yields the strength and deflection with a good agreement with that obtained from experimental results.

The skeleton curve from load-deflection characteristic of the box wall could be modeled by Tri-Linear model which is proposed by Chiba et al. In the conical shell wall model, the cracking load on the skeleton curve is improved by that is given by $0.4x\tau_{\text{max}}$.

The load-deflection characteristics of the each model could be evaluated by analysis using the flexural beam method.

ACKNOWLEDGMENTS

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