Load-deflection characteristics of shear walls with openings

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1 INTRODUCTION

Major aseismic components of a nuclear reactor building are shear walls which are heavily reinforced. Within these walls, openings for hatches and pipes are placed. Recently experimental studies have been carried out concerning the effect of heavy reinforcement on the load-deflection characteristics of shear walls such as box and cylindrical walls. The effect of the opening within a wall panel, however, on the load-deflection characteristics in its elasto-plastic region has not been sufficiently revealed.

Presented are in this study the results of both experimental and analytical studies upon the effect of openings placed within a wall on the load-deflection characteristics of heavily reinforced concrete shear walls. The influence of the location and shape of a opening, and the number of openings is discussed in detail.

2 EXPERIMENTAL PROGRAM

2.1 Test specimen

A set of eighteen specimens of a single-story and single-bay heavily reinforced concrete shear wall are prepared in this study (Higashiura, et al. 1983-1985). The thickness of the walls is 8cm. Columns of 30 by 30cm are placed on both sides of the wall, and girders with same dimensions on the top of the wall. Length and height of the wall are 200cm and 120cm, respectively. The resultant shear-span ratio is 0.6. The reinforcement ratio for the walls is 1.2%. The amount of reinforcing bars around the perimeter of a opening is determined by rules in the calculation standard proposed by the Archi. Insti. of Japan.

The yield stress of the reinforcing bar is in the range between values 4066 and 4152kgf/cm^2. The compressive strength of the concrete is 248 to 374kgf/cm^2.

2.2 Experimental parameters

The following four parameters are taken into consideration in this study. Figure 1 describes the correlation among these parameters. These parameters are taken to be close correlated with the maximum shear

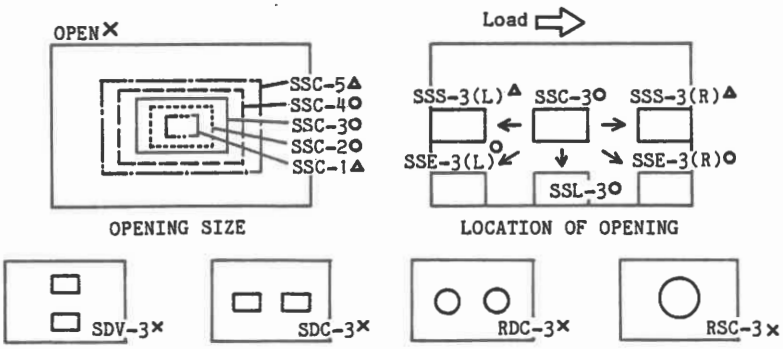

Fig. 1 Parameter of experiment

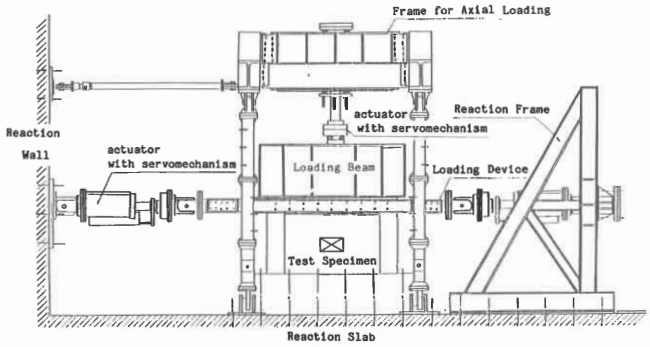

Fig. 2 Test set up

strength and the corresponding ductility of a shear wall.

1. Size of a opening : large, intermediate or small
2. Number of openings : one or two
3. Location of a opening : center, center-lower or left-lower
4. Reinforcing method in the perimeter of a opening : by bars or plate

2.3 Loading procedure

The test set-up is illustrated in Fig. 2. Computer-controlled actuators with servo-mechanisms are utilized to apply lateral loads automatically prescribed at every controlled displacement stage. Three times of cyclic loading are repeated. A constant axial stress of 20kgf/cm^2 is applied uniformly over the cross-section area of wall and columns.

Deflection and deformation of the shear wall, the strain of the reinforcing bars, and the strain of the concrete on the surface are obtained.

3 ANALYTICAL PROGRAM

For an analytical study, the F.E.M. analysis is employed. In the analysis, the panel of the shear wall is represented by a set of four node plane elements. The constitutive law for the concrete proposed by

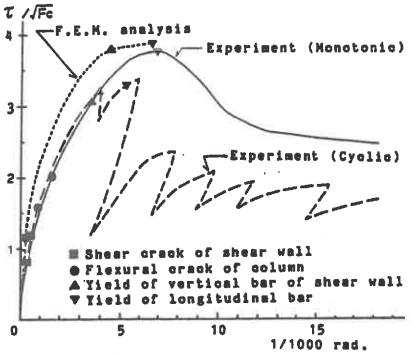

Fig. 3 Comparison of envelope curves by experiment and F.E.M.

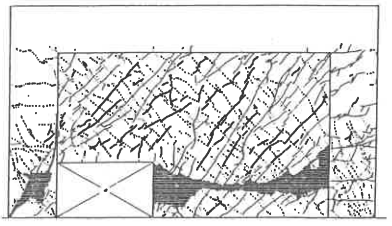

Fig. 5 Crack distribution

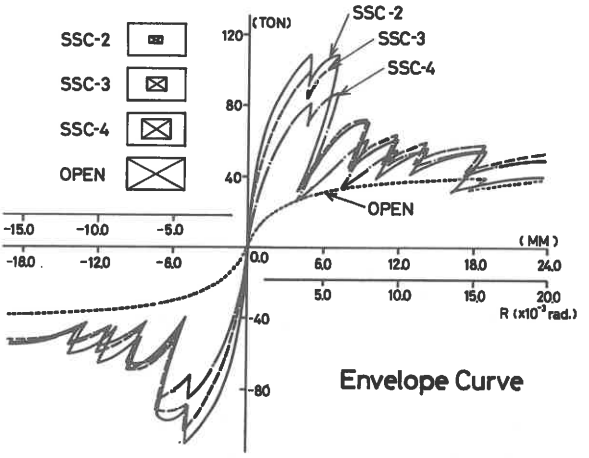

Fig. 4 Envelope curves by experiment

Dawin and Pecknold was used. A small modification is made so that the compressive strength parallel to the cracks is taken smaller value as proposed by Collins. The stress-strain relationship of the reinforcing bar is determined by the perfect elasto-plastic rule. The parameters used in the F.E.M. analysis is included in Fig. 1.

The envelope curves obtained both from the F.E.M. analysis and from the experimental results are shown in Fig. 3. The results of the F.E.M. analysis fall in close with those obtained from the experiment.

4 RESULTS AND DISCUSSION

The envelope curves for the load-deflection relation and the crack distribution pattern for the specimen SSE-3 at the end of loading are shown in Figs. 4 and 5, respectively. A tendency that the smaller is a opening in a wall panel, the larger maximum shear strength of a specimen is yielded as shown in Fig. 4. An initial diagonal shear crack is observed for each specimen at the deflection of around 0.25×10^{-3}rad. In the final stage, it is extended to the entire length of the wall panel.

Sliding shear failures occur for the specimens with a opening in the lower position of the wall panel (SSE-3 and SSL-3) as described in Fig. 5. Failure modes for other specimens are diagonal shear compression. The maximum shear strength of the specimen in which the opening is located in the lower position is larger than that for the specimen with an opening at the center. When an opening is placed at the center, the maximum shear strength is yielded at a deflection angle around 6.0×10^{-3}rad. for the specimen with a single opening, while that is yielded at 4.0×10^{-3}rad. for the specimen with a couple openings. The failure mode of a wall with a opening depends upon its location, When the opening is located in the center-lower or left-lower, less ductility

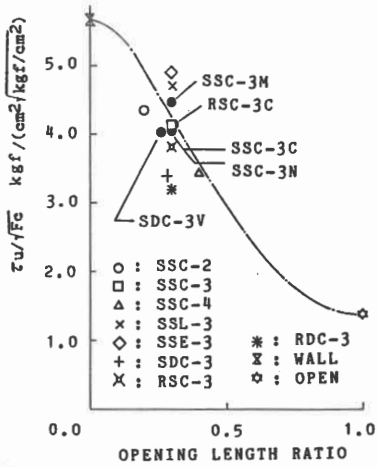

Fig. 6 Relationship between $\tau u/\sqrt{Fc}$ and opening length ratio

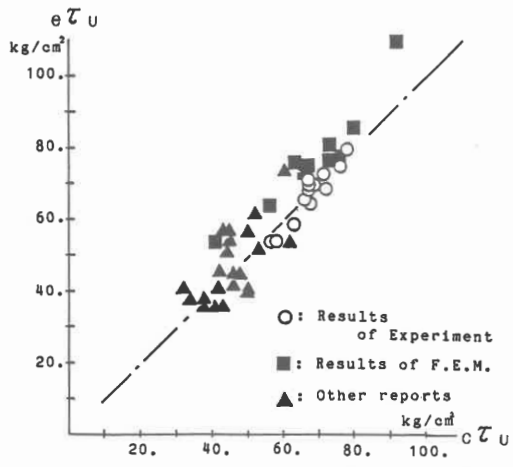

Fig. 7 Comparison of $e\tau u$ and $c\tau u$

is found than that when it is located at the center.

When the perimeter of the opening is strengthened by a steel plate, a larger ductility is observed than that strengthened by reinforcing bars.

4.1 Maximum shear strength

The correlation between maximum shear strength and size of an opening is described in Fig. 6. The value along the x-axis denotes the opening length ratio which generally represents the ratio of the size of openings to that of a wall panel.

The formulas introduced up to the present such as that proposed in the Japanese calculation standard for reinforced concrete structures to evaluate the maximum shear strength of a wall with openings do take the size of openings into consideration. They, however, do not take the location of openings into account in evaluation of the maximum shear strength of a wall with openings. A new formula taking the influence by the location of openings into evaluation of the maximum shear strength is proposed in this study as follows:

$$ {}_cQ_u = (\tau_c+\tau_s+\tau_o)\, t\, D \qquad (1) $$

$$ \tau_c = \sqrt{F_c}\,(4.87 - 3.18\, M/QL') \qquad (2) $$

where, ${}_cQ_u$: the maximum shear strength of a wall
τ_c : shear stress strength of concrete
τ_s', τ_o : shear stresses in the reference (Chiba, et al. 1985)
t, D : thickness and span length of a wall
F_c : compressive strength of concrete
M, Q : flexural moment and shear force applied to a wall
L' : effective span length (Chiba, et al. 1985)

The value L' in Eq. (2) reflects an influence of the location of openings within a wall panel.

In this study a set of Eqs. (1) and (2) are applied to evaluate the maximum shear strength of the shear wall specimens. The results are

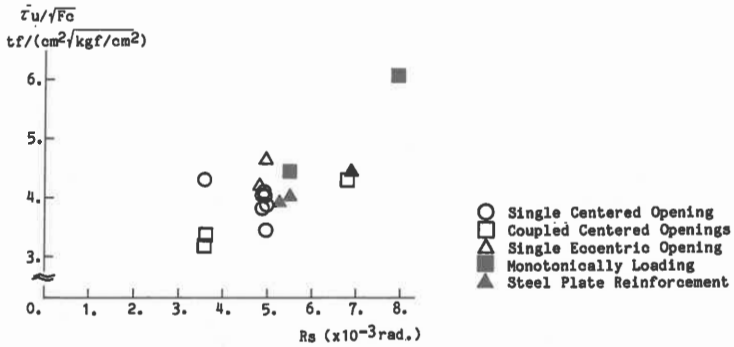

Fig. 8 Relationship between $\tau u/\sqrt{Fc}$ and shear deflection

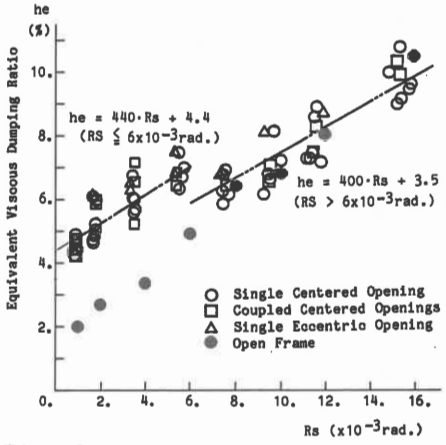

Fig. 9 Relationship between he and shear deflection

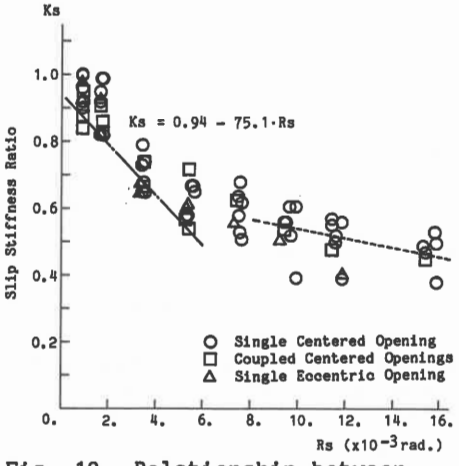

Fig. 10 Relationship between Ks and shear deflection

shown in Fig. 7. The x-axis denotes the analytical values obtained from Eqs. (1) and (2), and the y-axis designates the values obtained from experimental results. A close correlation between the results from an analysis and from the experiment is found. It leads to the evidence that the analytical results from the Eqs. (1) and (2) yield the maximum shear strength of a shear wall with openings with an good agreement. All the experimental results except one fall in the range between the analytical results plus and minus 20% of those.

The correlation between the values of ultimate shear strength obtained from Eqs. (1) and (2) and those obtained from the F.E.M. is plotted in Fig. 7. In the plot, the x-axis designates the strength obtained from Eqs. (1) and (2), while the y-axis denotes that obtained from the F.E.M. analysis. They are found to be close correlated with each other. The fact above mentioned proves the effectiveness that properties of shear walls especially such as the maximum shear strength are evaluated by use of the F.E.M. analysis. Since the number of the specimens is limited, the influence of various openings within a wall panel associated with variety such as the size of an opening, the number of openings, the location of an opening is examined through the F.E.M. analysis in this study. The analytical results obtained from the F.E.M. study for shear walls with various types of openings are compared with those obtained from the experimental study.

4.2 Load-deflection characteristics

Shear deformation of the specimens at the maximum shear strength are shown in Fig. 8. The shear deformation depends significantly upon both the number of openings and the reinforcing method around the perimeter of the opening. Smaller shear deformation is found for the specimens with a couple of openings than the specimen with a single opening.

The normalized characteristic loop model is utilized in an analytical study presented herein. Two important factors among those to determine the shape of the normalized loop is an equivalent viscous damping coefficient and the slip-stiffness (Tani, et al. 1970) are shown in Figs. 10 and 11, respectively. A tendency that the larger the shear deformation is, the larger the equivalent viscous damping coefficient is. When the shear deformation exceeds 6.0×10^{-3}rad., the coefficient takes a similar value to that for the specimen without an opening. A tendency that the larger the shear deformation is, the smaller the slip-stiffness is in the range of deflection less than 6.0×10^{-3}rad.

5 CONCLUSION

A pile of significant data for the load-deflection characteristics are obtained in this study. The results obtained from this study are summarized in the following:

1. The failure mode depends upon the location of openings with in a wall panel. A sliding shear failure is observed when the opening is placed in the lower position within a wall panel. In the other specimens diagonal compression shear failures are observed.
2. When the opening is located in the center-lower or left-lower positions, the ductility is decreased when compared with that for the specimens with opening in the center.
3. A formula to estimate the maximum shear strength of a shear wall with openings is proposed which yields the strength with a good agreement with that obtained from an experimental result.

Reflecting the results obtained in this study, a formula is proposed to evaluate the maximum shear strength of a shear wall with various types of openings. Utilization of the formula, one can take the influence of the location of an opening within a wall panel into account.

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