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

6-5-9

EXPERIMENTAL STUDY TO INCREASE DUCTILITY OF R/C FRAMED SHEAR WALLS BY PREVENTING SLIP FAILURE OF MONOLITHIC INFILLED WALL PANEL (CONFINING TOP AND BOTTOM PORTIONS OF EDGE COLUMNS IN SQUARE STEEL TUBE)

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SUMMARY

In order to develop the reinforcing method to increase ductility of framed shear walls for which the predominant action is shear, the shear walls whose potential shear failure regions at the top and bottom ends of edge columns are confined in steel tubes are tested. This paper describes that the shear walls whose edge columns are confined in steel tubes behave in more ductile manner than the shear walls whose edge columns are reinforced transversally by hoops do.

INTRODUCTION

The shear failure of columns in the moment resisting frame of R/C structures is undesirable since the failure results in the collapse of the R/C structures. However, the shear failure of framed shear walls is tolerable if the edge columns can carry the vertical load after the infilled wall panels failed.

Authors have proposed the design method of the shear wall to promote slip failure in the wall panel while preventing failure in the edge columns (Ref. 1). This design concept considers the wall panel as element to absorb energy during an earthquake. The wall panel can also be easily repaired afterward. However, the shear cracks are apt to occur in the wall panel by small or moderate earthquakes which occur more frequently than severe earthquakes do since this method demands to make the wall panel thin. Moreover, when the shear distortion, R, of the shear wall designed by this method reaches over 0.008, the lateral load carrying capacity and the energy dissipation capacity of the shear wall deteriorate remarkably due to the crushing of its thin wall panel. In order to improve this weak point, it is necessary to prevent the slip failure of the wall panel by making it thick. However, the edge columns are apt to fail in shear if the wall panel is thick. It is very difficult to prevent the shear failure of the edge columns of shear walls with thick wall panel by conventional reinforcing method such as hoops.

The objective of this investigation is to develop the reinforcing method to prevent perfectly the shear failure of potential shear failure regions at the top and bottom ends of edge columns even if making the wall panel fairly thick in order to increase the ductility of shear walls for which the predominant action is shear. This new method is to confine the potential shear failure regions at the top and bottom ends of edge columns in square steel tube. This new method can change the shear failure mode into the flexural failure mode. This paper describes the shear walls transversally reinforced by this new method behave in excellent ductile manner in the lateral shear tests.

EXPERIMENTAL PROGRAM

Test Specimens The five 1/3 scale model specimens and seven 1/10 scale model specimens transversally reinforced by steel tubes or by the conventional method such as hoops were tested. Variables included in the test series are shear reinforcement ratio in edge columns, magnitude of axial stress and thickness of wall panel.

Nominal dimensions of 1/3 scale model test specimens are shown in Fig. 1(See

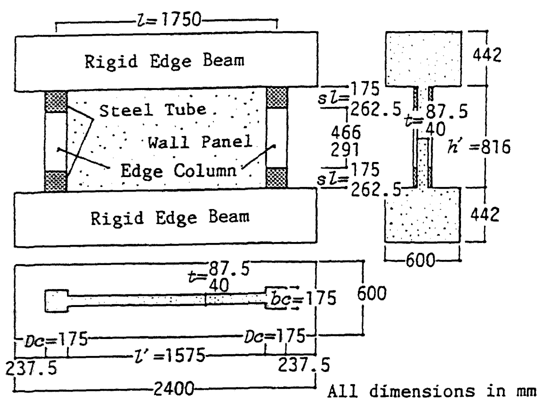


Fig. 1 Nominal dimensions of 1/3 scale model test specimen

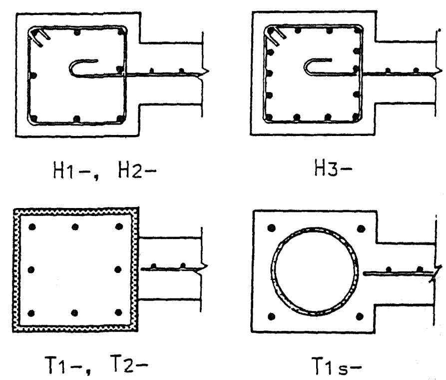


Fig. 2 Detail of edge column reinforcement

Table 1 Properties of test specimen

Specimen		Edge column reinforcement: Transverse ρ_w	σ_{yw} (kgf/cm²)	Longitudinal ρ_g	σ_{yg} (kgf/cm²)	Wall reinforcement, Vertical and Horizontal ρ_s	σ_{ys} (kgf/cm²)	Wall thickness t (mm)	$_c\sigma_B$ (kgf/cm²)	σ_0 (kgf/cm²)
1/10 scale model	H1-W30-N50	0.002	2840	0.0084	3040	0.0031	2840	30	293	50
	H2-W30-N50	0.011	2650	0.0084	2970	0.0031	2650	30	290	50
	T1-W30-N50	□-60×60×2.3*1)	3390	0.0084	2970	0.0031	2650	30	291	50
	T2-W30-N50	□-60×60×2.3*2)	3390	0.0084	2970	0.0031	2650	30	282	50
	T1s-W30-N50	42.7φ×2.3*1)	–	0.0084	3040	0.0031	2840	30	299	50
	T1-W37.5-N50	□-60×60×2.3*1)	3390	0.0084	3040	0.0025	2840	37.5	278	50
	T1-W30-N100	□-60×60×2.3*1)	3390	0.0084	2970	0.0031	2650	30	299	100
1/3 scale model	H2-W87.5-N50	0.011	2910	0.0084	3440	0.0031	2910	87.5	277	50
	H3-W87.5-N50	0.011	2910	0.0084	3440	0.0031	2910	87.5	266	50
	H3-W40-N65	0.011	2910	0.0146	3440	0.0069	2910	40	350	65
	T1-W87.5-N50	□-175×175×5.6*1)	3590	0.0084	3440	0.0031	2910	87.5	357	50
	T2-W87.5-N50	□-175×175×5.6*2)	3590	0.0084	3440	0.0031	2910	87.5	331	50

$_c\sigma_B$ = compressive strength of concrete.
σ_0 = $N/(2b_cD_c)$, where N is axial load applied to shear wall, and b_c and D_c are width and depth of edge column respectively.
σ_{yg} = yield stress of longitudinal reinforcing bars in edge column.
σ_{ys} = yield stress of wall reinforcement.
σ_{yw} = yield stress of confinement reinforcement in edge column.
ρ_g = ratio of total sectional area of longitudinal reinforcing bars to gross sectional area of edge column.
ρ_s = ratio of vertical (or horizontal) shear reinforcement area to gross area of a vertical (or horizontal) section of wall panel.
ρ_w = confinement reinforcement ratio of hoop (= $a_w/(b_c x)$, where a_w is vertical sectional area of hoop and x is spacing).
*1) Length of reinforcing steel tube equals depth of edge column.
*2) Length of reinforcing steel tube equals 1.5 times depth of edge column.

Ref. 2 on these of 1/10 scale model specimens). Table 1 summarizes properties of test specimens. Details of edge column reinforcement are shown in Fig. 2.

Experimental Apparatus The test setup for the 1/3 scale model specimens is shown in Fig. 3. The test setup for the 1/10 scale model specimens is described in Ref. 2. The reason why the setup with the parallel supporting mechanism is used is due to the fact that the flexural deformation of shear walls arranged in a three-dimentional frame is restrained by surrounding structural element and consequently the predominant action for the shear walls is shear.

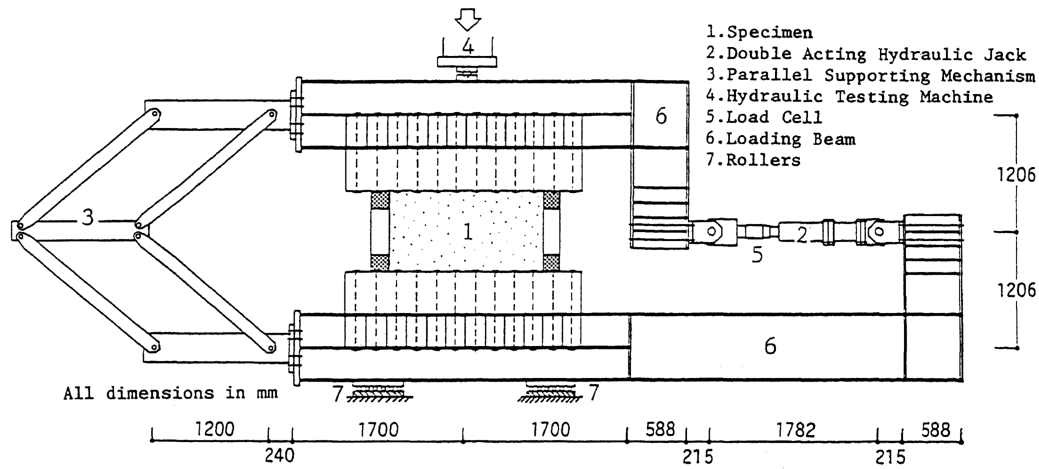


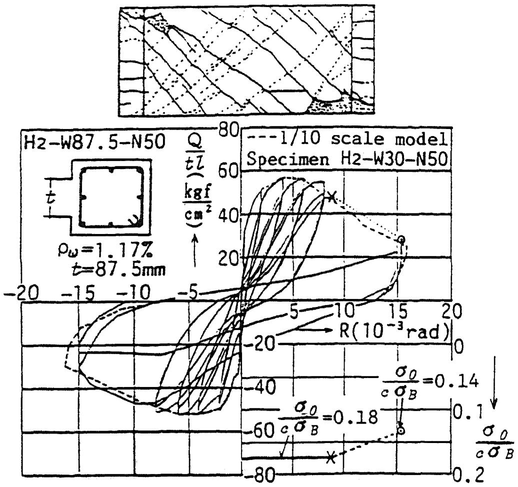
Fig. 3 Test setup for 1/3 scale model specimen

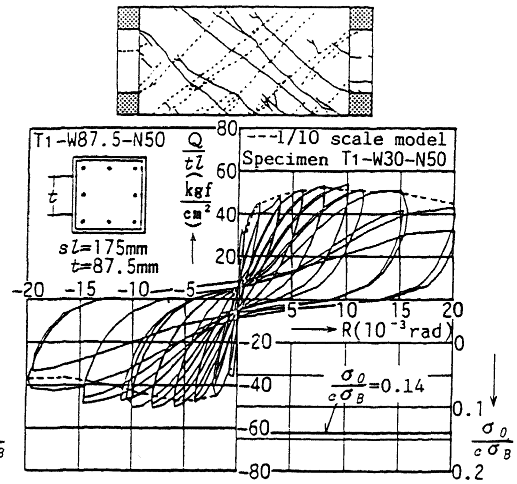
Experimental Procedure The axial load which was maintained constant throughout the experiment was applied to the specimen by means of the hydraulic testing machine. The loading pattern was a cyclic type with alternating drift reversals. The peak drifts were increased stepwise from $0.002h'$, where h' is clear height of wall panel, until $0.01h'$ with incremental drift of $0.002h'$ after two successive cycles at each displacement level.

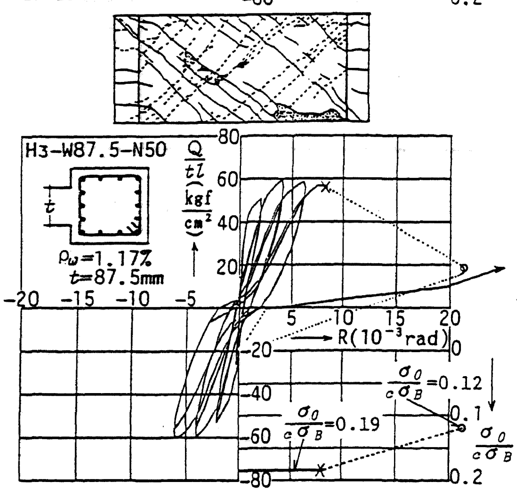
EXPERIMENTAL RESULT

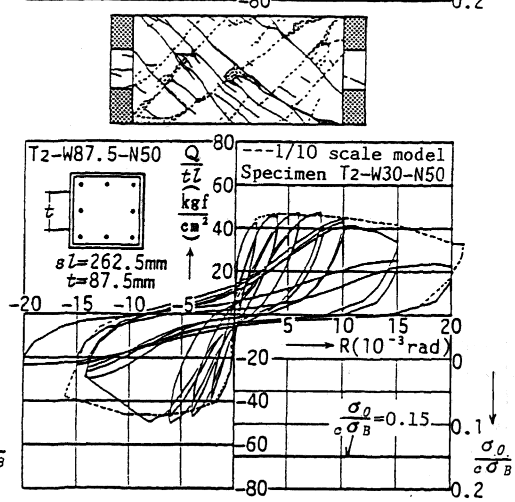
Crack patterns at $R(=\delta_h/h'$, where δ_h is relative lateral displacement between the inside face of upper and bottom rigid edge beams$)= 0.015$ and hysteresis curves of the 1/3 scale model specimens are shown in Fig. 4 (See Ref. 2 on these of the 1/10 scale model specimens). The broken line denotes the envelop of the hysteresis curve of the 1/10 scale model which is the scale down model of the 1/3 scale model. In this experiment the scale effects on the lateral shear capacity and the deformation capacity aren't observed since the agreement between the hysteresis curve of the 1/3 scale model and that of the 1/10 scale model is extremely good.

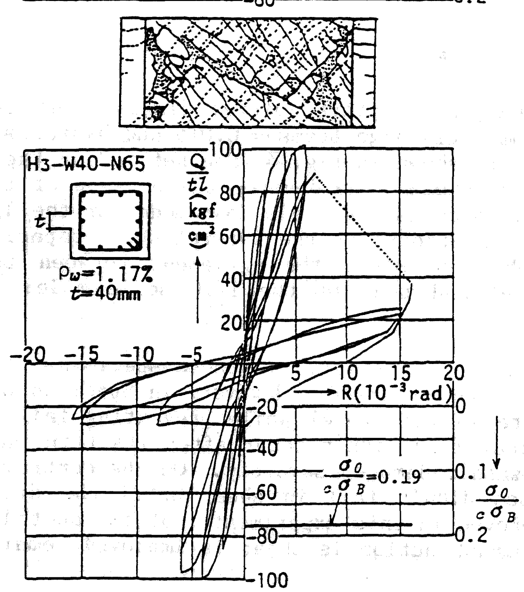
The specimens reinforced by hoops failed in shear. In these specimens, the sudden loss of the lateral and vertical loads occurred. However, in Specimen H3-W40-N65 designed to promote slip failure in wall panel while preventing failure in edge columns, the loss of the vertical load didn't occur after its thin wall panel crushed because the edge columns wasn't damaged severely. On the contrary, the specimens reinforced by steel tubes didn't fail in shear until the drift reached approximately $0.015h'$. It is proved in this experiment that the ductility of shear walls for which the predominant action is shear is improved remarkably by this new reinforcing method.











Q = lateral force
t = thickness of wall panel
l = distance from center to center of edge column
$_sl$ = length of reinforcing steel tube
R = δ_h/h', where δ_h is relative lateral displacement between the inside face of upper and bottom rigid edge beam and h' is clear height of wall panel
$_c\sigma_B$ = compressive strength of concrete
σ_0 = $N/(2b_cD_c)$, where N is axial load applied to shear wall, and b_c and D_c are width and depth of edge column respectively

Fig. 4 Crack pattern at R=0.015 and hysteresis curve of 1/3 scale model specimens

Fig. 5 shows the mean strain of the concrete struts in the wall panel between cracks inclined at 45 degree acting in compression. In the specimens reinforced by tubes, the strain is considerably smaller due to the vertical elongation of cracked wall panel than the calculated one by assuming that the area of the wall panel doesn't change. This means that since the cracked wall panel expands due to the elongation of the edge columns caused by yielding of longitudinal reinforcing bars without the shear failure, the dilation of the panel delays the occurrence of the crushing of compressed struts and consequently the deformation capacity is fairly improved.

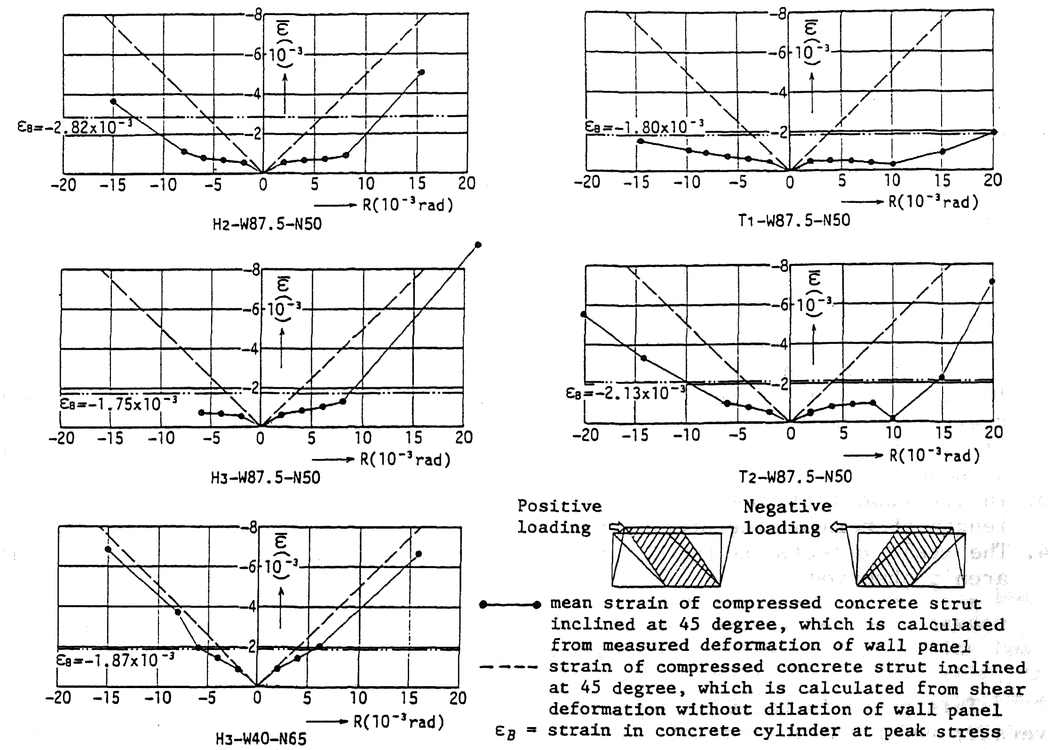


Fig. 5 Mean strain of compressed concrete strut inclined at 45 degree in cracked wall panel

Tabel 2 Lateral load carrying capacity and failure mode

1/10 scale model						1/3 scale model					
Specimen	Failure mode	Measured (tonf)	Calculated (tonf)			Specimen	Failure mode	Measured (tonf)	Calculated (tonf)		
			$Q_{u(ws)}$	$Q_{u(cs)}$	$Q_{u(y)}$				$Q_{u(ws)}$	$Q_{u(cs)}$	$Q_{u(y)}$
H1-W30-N50	cs	10.13	12.02	8.14	9.94	H2-W87.5-N50	cs	86.8	100.4	71.1	85.0
H2-W30-N50	cs	10.15	11.98	8.01	9.77	H3-W87.5-N50	cs	91.6	99.0	80.2	93.7
T1-W30-N50	y	9.39	11.99	–	8.42	H3-W40-N65	ws	71.1	67.2	83.9	77.2
T2-W30-N50	y	8.46	11.86	–	8.32	T1-W87.5-N50	y	83.3	109.5	–	79.8
T1s-W30-N50	y	9.37	12.10	–	8.62	T2-W87.5-N50	y	73.0	106.6	–	77.9
T1-W37.5-N50	y	9.85	13.92	–	9.06						
T1-W30-N100	y	12.15	13.93	–	11.02						

1) In the column of failure mode, cs, ws and y denote shear failure of edge column, slip failure of wall panel and tensile yielding of longitudinal reinforcing bars in edge column, respectively.
2) The underlined value denotes the minimum value among $Q_{u(cs)}$, $Q_{u(ws)}$ and $Q_{u(y)}$.
3) $Q_{u(cs)}$ = lateral shear capacity dominated by shear failure of edge column (See Ref. 3).
$Q_{u(ws)}$ = lateral shear capacity dominated by slip failure of wall panel (See Ref. 3).
$Q_{u(y)}$ = lateral shear capacity dominated by tensile yielding of longitudinal reinforcing bars in edge column (See Ref. 4).

Table 2 summarizes the experimental ultimate lateral loads and calculated ones. The failure mode coincides with one predicted by the calculation of the lateral shear capacity for each failure mode. The agreement between the experimental values of the capacity and the calculated ones is fairly good. The shear wall reinforced by tubes may behave in excellent ductile manner by preventing the slip failure of its wall panel if the wall thickness and amount of longitudinal bars are selected so that the lateral shear capacity, $Q_{u(ws)}$, dominated by slip failure is larger than the capacity, $Q_{u(y)}$, dominated by tensile yielding of longitudinal bars as these of the specimens in this experiment.

CONCLUSIONS

The following conclusions may be drawn from the investigation based on tests of shear walls described in this paper.

1. It is difficult to prevent the shear failure of edge columns of shear walls with fairly thick wall panel and edge columns reinforced by small amount of longitudinal reinforcing bars even if reinforcing edge columns with large amount of hoops. But, if confining edge columns in steel tube, it is possible to prevent perfectly the shear failure of edge columns.
2. By selecting wall thickness and amount of longitudinal reinforcing bars in edge columns so that the lateral shear capacity, $Q_{u(ws)}$, dominated by slip failure is larger than the capacity, $Q_{u(y)}$, dominated by tensile yielding of longitudinal bars in edge columns and by confining the potential shear failure regions at the top and bottom ends of edge columns in steel tube, it is possible to improve drastically the deformation capacity of shear walls reinforced by hoops.
3. In the case that the predominant action for shear walls is shear, the enough length of reinforcing steel tubes is 1.5 times depth of edge columns.
4. The scale effects on the lateral shear capacity and the deformation capacity aren't observed

ACKNOWLEDGMENTS

This paper is based on experimental investigation carried out at Kyushu University under the support of the Grant-in-Aid for Scientific Research from Japanese Ministry of Education in 1987.

The authors wish to thank Messrs. F. Fujiwara and A. Kawaguchi, engineers of Kyushu University who contributed in this experiment.

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