Proceedings of the International Symposium on Engineering Lessons Learned from
the 2011 Great East Japan Earthquake, March 1-4, 2012, Tokyo, Japan

EXPERIMENTAL STUDY ON SEISMIC RETROFIT OF RC COLUMN WITH WING WALL IN TAIWAN AND JAPAN

Shih-Hsun YIN[1], Shuenn-Yih CHANG[2], Wen-I LIAO[3] and Yu-Chi SUNG[4]

[1,3]Associate Professor, Department of Civil Engineering, National Taipei University of Technology
Taipei, Taiwan, shihhsun@ntut.edu.tw, wiliao@ntut.edu.tw
[2,4]Professor, Department of Civil Engineering, National Taipei University of Technology
Taipei, Taiwan, changsy@ntut.edu.tw, sungyc@ntut.edu.tw

ABSTRACT: In this study, a series of cyclic loading tests were conducted for three full-scale specimens including an existing column and two columns strengthened with wing walls respectively fabricated using Taiwan's and Japan's structural details. The experimental results show that the existing columns retrofitted with wing wall can effectively improve seismic strength and that there is no rupture of concrete cover in the base of the column with wing walls if using Japan's structural details while the rupture does occur if using Taiwan's structural details.

Key Words: Seismic retrofit, column with wing walls.

INTRODUCTION

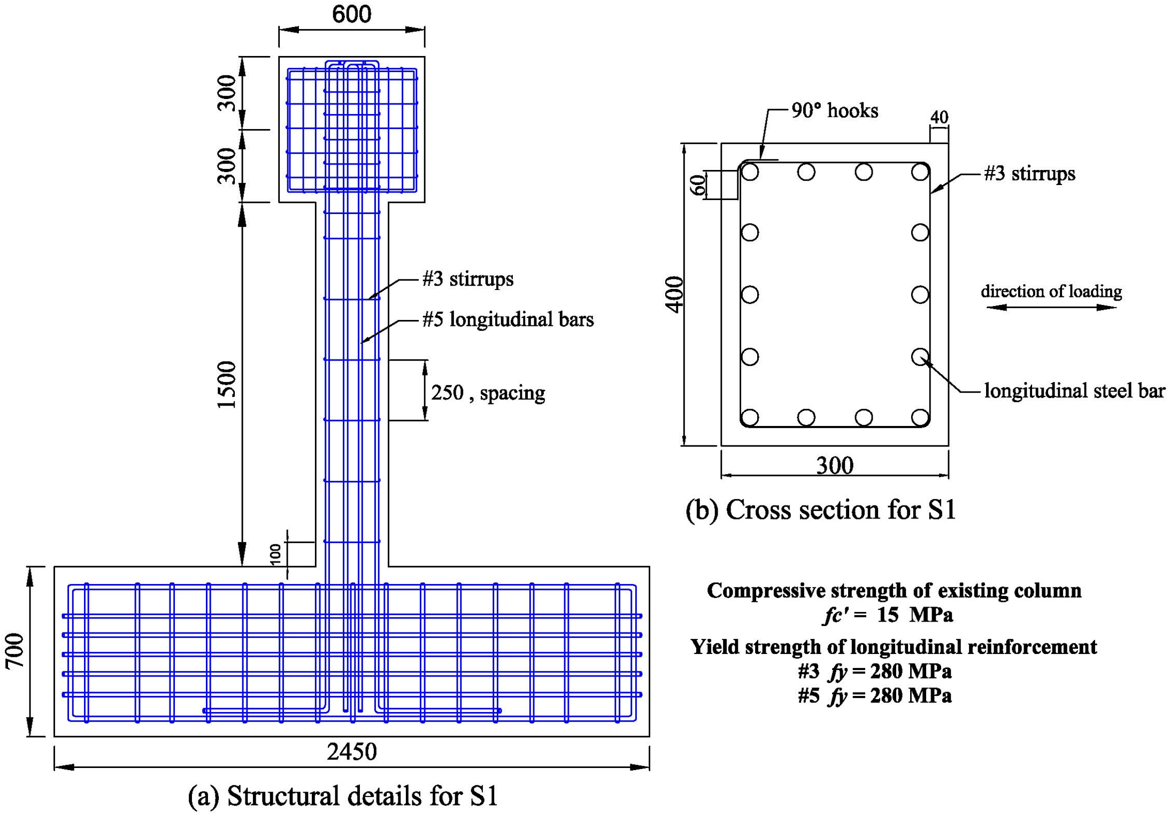
Many structures which do not meet current seismic code requirements were damaged or even totally collapse as a result of Taiwan Chi-Chi earthquake. Therefore, seismic evaluation and retrofitting of existing vulnerable buildings become urgent matters in Taiwan. It also accelerated the studies aimed to establish technology for strengthening existing buildings with different strategies including steel jacketing, RC jacketing, CFRP/GFRP jacketing, and addition of braces, walls, passive energy dissipating devices, and base isolation. In general, repair and retrofit techniques (ATC-40 1996, FEMA 2000, JBDPA2001) can be used for enhancing the stiffness, the strength, and/or ductility of buildings. Many studies indicated that reinforced concrete columns with wing-walls had relatively good earthquake-resistant performance such as increasing column stiffness and strength in reinforced concrete buildings and were simple, convenient, economic, and effective (Kabeyasawa 2007 & 2008, Md Nafiur 2007, Tetsuo 2006, Tojo 2008).

The reliable connection between original columns and added wing walls plays a key role on the seismic performance of the retrofitted columns (Moehle 2000). Also, we found that there are significant differences on reinforcement structural details between Taiwan and Japan in which column with wing walls are made. In this study, a series of cyclic loading tests were conducted for three full-scale specimens including an existing column and two columns strengthened with wing walls. The structural details commonly used in Taiwan and Japan were respectively adopted for fabricating the column with wing walls. Thus, the seismic performance of these specimens can be studied and compared due to different structural details. In addition, seismic evaluations of these specimens were performed, and the results obtained were compared to the test results for the confirmation of the feasibility of the evaluation techniques.

TEST ON COLUMNS WITH WING WALLS

Test specimens

To simulate the column of existing older school buildings which do not meet current seismic code requirements, the cross section size was chosen as 300mm×400mm, the D10 ties were spaced at a distance of 250 mm with unreliable 90° end hooks, and the nominal strength of concrete was 15 MPa. The configuration and details of the specimen denoted by S1 to simulate the substandard column are presented in Fig. 1. To enhance column stiffness, strength, and ductility, the original column is strengthen with wing walls on its both sides. To ensure that the wing walls connected with the column can work together, rebar doweling is needed. In Taiwan, the rebar doweling to footing, columns, and beams is used with double layers in practice. In contrast, the rebar doweling with a single layer is used in Japan. In addition, spiral rebar is placed along the boundaries between the new wing walls and the old footing, columns, and beams to prevent from the split of concrete. Also, the outmost rebars in wing walls from the surface of the original column should be connected to the rebar in the top beam and bottom footing by weld and hook in Japan. It is interesting to investigate the difference in seismic performance due to different reinforcement details. Therefore, two specimens of the substandard column retrofitted by wing walls respectively using Taiwan and Japan structural details are designed, and respectively denoted by S4 and S5. Their configuration and details are presented in Fig. 2 and 3.

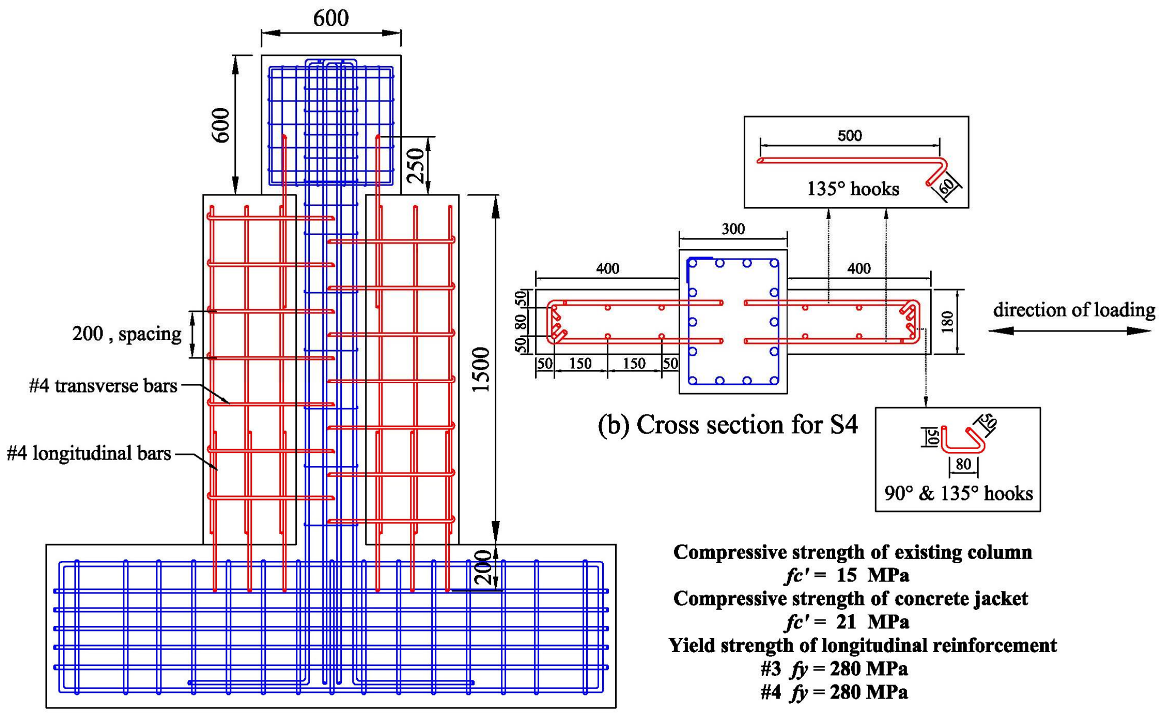


(a) Structural details for S1

(b) Cross section for S1

Compressive strength of existing column
$f_c' =$ 15 MPa
Yield strength of longitudinal reinforcement
#3 $f_y = 280$ MPa
#5 $f_y = 280$ MPa

Fig. 1 The specimen configuration and details of the substandard column (unit: mm)

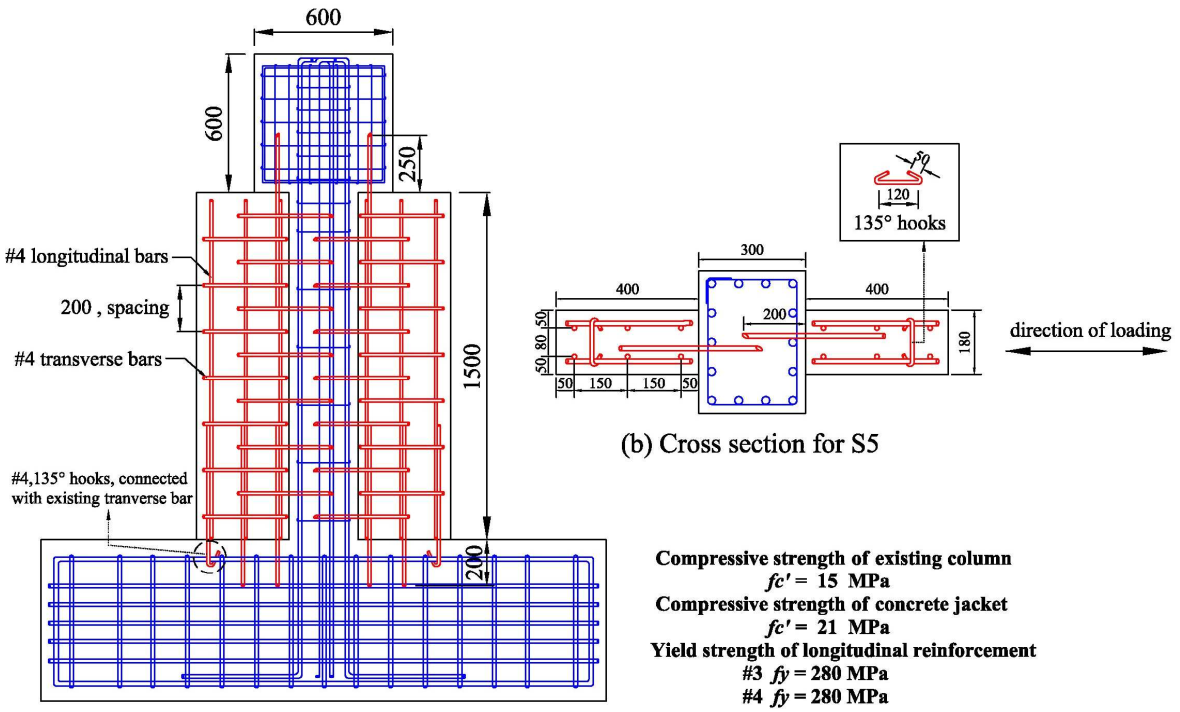


(b) Cross section for S4

Compressive strength of existing column
$f_c' = 15$ MPa
Compressive strength of concrete jacket
$f_c' = 21$ MPa
Yield strength of longitudinal reinforcement
#3 $f_y = 280$ MPa
#4 $f_y = 280$ MPa

(a) Structural details for S4

Fig. 2 The specimen configuration and details of the substandard column retrofitted by wing walls using Taiwan structural details (unit: mm)



(b) Cross section for S5

Compressive strength of existing column
$f_c' = 15$ MPa
Compressive strength of concrete jacket
$f_c' = 21$ MPa
Yield strength of longitudinal reinforcement
#3 $f_y = 280$ MPa
#4 $f_y = 280$ MPa

(a) Structural details for S5

Fig. 3 The specimen configuration and details of the substandard column retrofitted by wing walls using Japan structural details (unit: mm)

Cyclic loading test

Fig. 4 shows the experimental apparatus installed at the Architecture and Building Research Institute, the Ministry of the Interior, Taiwan, which consists of reaction wall, strong floor, and one horizontal jack with maximum loading capacity of 2000kN. The rigid beam is placed on the top of the column and two high-strength bars are tensioned to connect to the rigid beam and strong floor such that the axial load can be applied at the column. The constant axial load applied in the cyclic loading test is 247 kN corresponding to $0.15f_c^{'}A_g$, where A_g is column section area and $f_c^{'}$ is compressive concrete strength. In addition, the lateral load is applied to the specimen through the horizontal jack and controlled based on displacement. The displacement time history of the actuator for cyclic loading as shown in Fig. 5 is specified in the control unit.

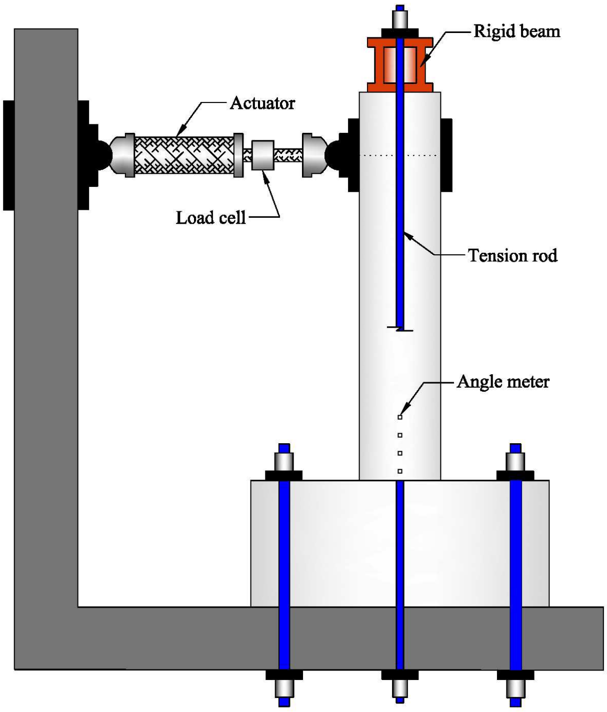


Fig. 4 Test setup

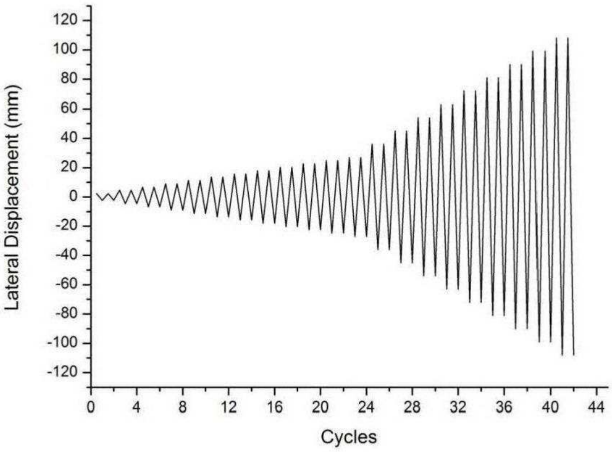


Fig. 5 The displacement time history of the actuator for cyclic loading

EXPERIMENTAL RESULTS AND DISCUSSIONS

Fig. 6, 7, and 8 respectively present the hysteretic responses for the substandard column (*i.e.* S1), the substandard column retrofitted by wing walls using Taiwan structural details (*i.e.* S4), and the substandard column retrofitted by wing walls using Japan structural details (*i.e.* S5). Table 1, 2, and 3 summarize the important phenomenon observed during the test of each specimen. In addition, the ultimate shear strength for each column is calculated by the evaluation method found in Seismic Evaluation Standard for RC buildings by The Japan Building Disaster Prevention Association [JBDPA, 2001]. The calculated shear strength and the observed shear strength and ductility ratio for each specimen are listed in Table 4.

Based on the above results, we found that the substandard column retrofitted by wing walls using either Taiwan or Japan structural details showed excellent response with an increase in both shear strength and stiffness. However, the ductility ratio was decreased, which means that the retrofit columns cannot provide a ductile failure mechanism. Also, hysteretic loops in Fig 7 and 8 are very similar, which means that the seismic performance of the columns with wing wall is not highly affected by different structural details. The very important finding about the difference on structural behavior between S4 and S5 is that there is no rupture of concrete cover in the base of the column with wing wall if using Japan's structural details while the rupture does occur if using Taiwan's structural details. This is because that both ends of vertical reinforcing bars near the outmost section of the wing wall were securely connected to existing stirrups if Japan's structural details are adopted.

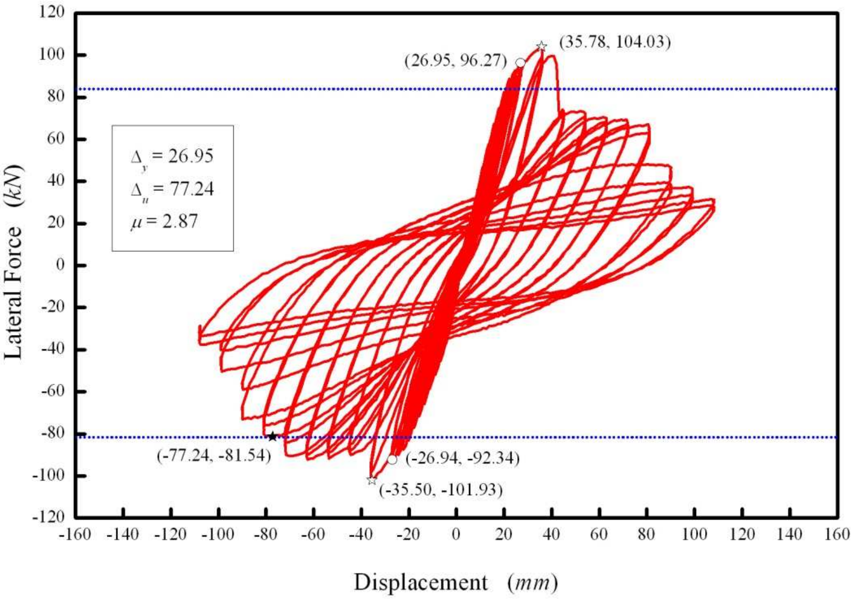


Fig. 6 Load displacement response of the specimen S1

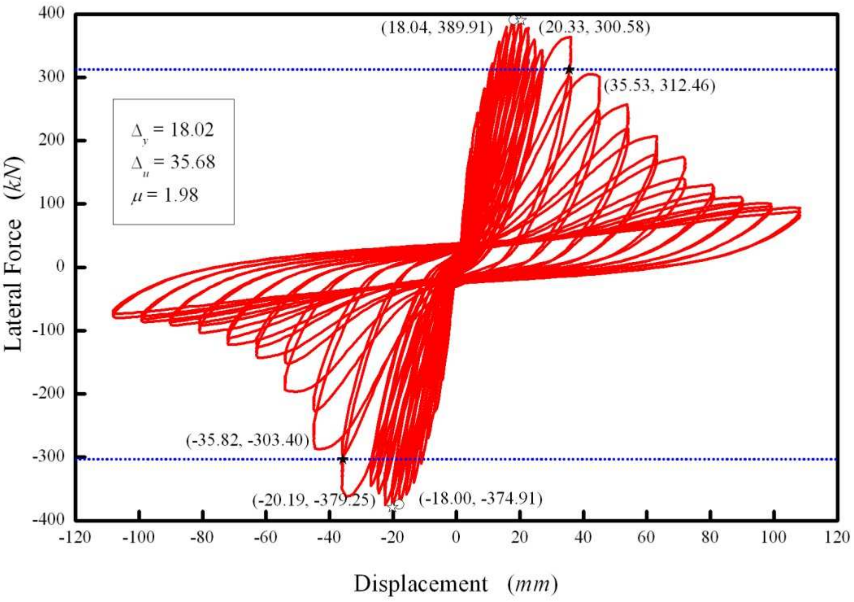


Fig. 7 Load displacement response of the specimen S4

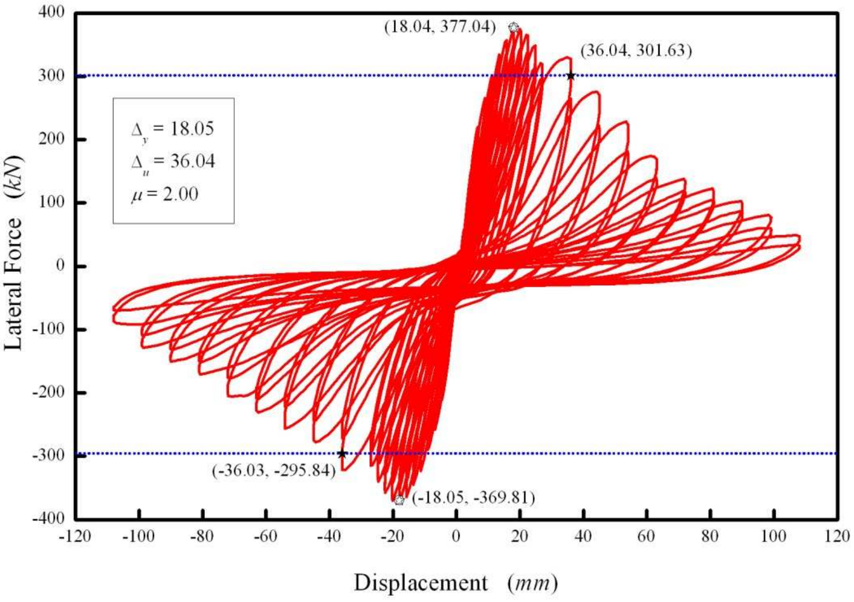


Fig. 8 Load displacement response of the specimen S5

Table 1 The descriptions of observation during the test of specimen S1

Lateral displacement (mm)	Drift ratio (%)	Observation
25	1.375	Flexural cracks were initially developed at the bottom of column.
36	2	Spalling of cover concrete near the bottom of column occurred.
72	4	Massive Spalling of cover concrete and extensive exposure of reinforcing bars were observed.
90	5	Crush of core concrete and buckling of reinforcing bars were observed at the bottom of column as shown in Fig. 9.

Table 2 The descriptions of observation during the test of specimen S4

Lateral displacement (mm)	Drift ratio (%)	Observation
20	1.125	Shear cracks were initially developed at the outmost corner of wing wall.
22.5	1.25	Narrow cracks occurred on the surface of cover concrete in the footing.
36	2	Spalling of cover concrete and exposure of reinforcing bars were observed in the outmost edge of wing wall.
45	2.5	Severe damages were observed in the bottom of wing wall and cover concrete of the footing as shown in Fig. 10.
54	3	Rebar dowels in the bottom of wing wall were pulled out, and damage in the cover concrete of the footing occurred extensively.
72	4	Wing walls lost their shear resistance
108	6	Reinforcing bars of the original column buckled.

Table 3 The descriptions of observation during the test of specimen S5

Lateral displacement (mm)	Drift ratio (%)	Observation
20	1.125	Shear cracks were initially developed at the outmost corner of wing wall.
22.5	1.25	No cracks occurred on the surface of cover concrete in the footing.
36	2	Spalling of cover concrete and exposure of reinforcing bars were observed in the outmost edge of wing wall.
45	2.5	Severe damages were observed in the bottom of wing wall, but minor damage occurred in the cover concrete of the footing.
54	3	Rebar dowels in the bottom of wing wall buckled, and shear cracks at the bottom of column were developed very quickly.
72	4	Wing walls lost their shear resistance
108	6	Reinforcing bars of the original column buckled, and crush of core concrete at the bottom was observed as shown in Fig. 11.

Table 4 Comparison of calculated and observed shear strengths and ductility ratio

	The original column S1	The original column with wing walls using Taiwan structural details S4	The original column with wing walls using Japan structural details S5
Ultimate shear strength $Q_{\text{experiment}}$	104.03 (kN)	389.91 (kN)	377.04 (kN)
Ultimate shear strength Q_{su} (JBDPA, 2001)	135.28 (kN)	317.65 (kN)	317.65 (kN)
Ultimate displacement Δu	77.24 (mm)	35.68 (mm)	36.04 (mm)
Yield displacement Δy	26.9 (mm)	18.02 (mm)	18.05 (mm)
Ductility ratio $\mu_{\Delta} = \Delta u / \Delta y$	2.87	1.98	2.00

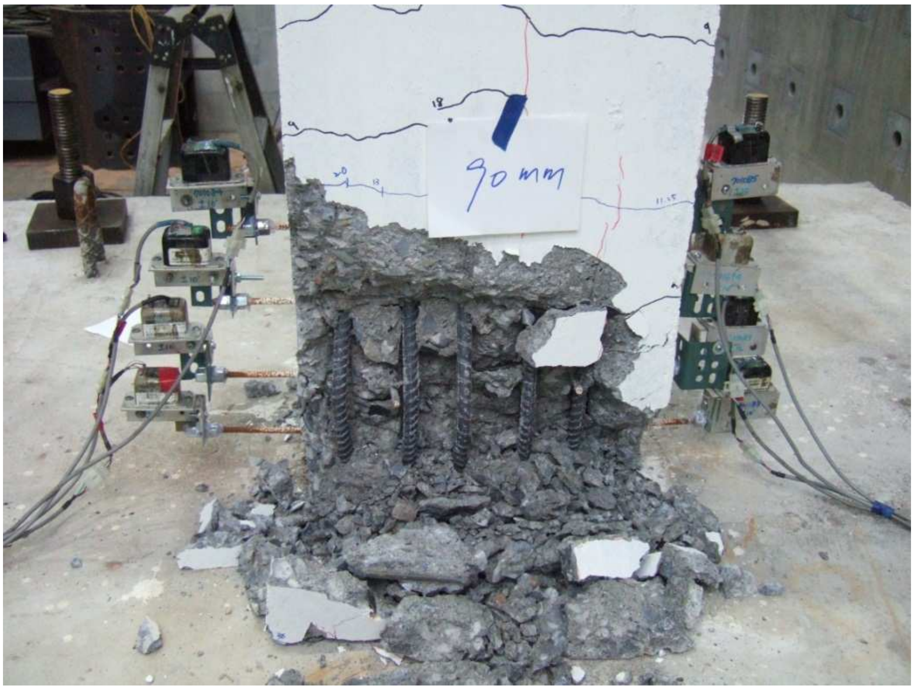


Fig. 9 Final failure state of the specimen S1 when the drift ratio reaches to 5%

Fig. 10 Damage state of the footing of the specimen S4 when the drift ratio reaches to 2.5%

Fig. 11 Final failure state of the specimen S5 when the drift ratio reaches to 6%

CONCLUSIONS

This study focused on experimental testing for seismic retrofit of RC column with wing walls respectively fabricated using Taiwan's and Japan's structural details. The experimental results show that the existing columns retrofitted with wing walls can effectively improve seismic strength for either using Taiwan’s structural details or Japan’s structural details. It seems that the seismic performance of the columns with wing walls is not highly affected by different structural details since very similar hysteretic loops were obtained from the cyclic loading tests. It is interesting to find that there is no rupture of concrete cover in the base of the column with wing walls if using Japan’s structural details while the rupture does occur if using Taiwan’s structural details. This is because that both ends of vertical reinforcing bars near the outmost section of the wing wall were securely connected to existing stirrups if Japan’s structural details are adopted.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Architecture and Building Research Institute, the Ministry of the Interior, Taiwan and the National Science Council, Taiwan for the generous support of this work.

REFERENCES

Applied Technology Council (ATC-40). (1996). “Seismic Evaluation and Retrofit of Concrete Buildings,” California Seismic Safety Commission, CA, USA.

Federal Emergency Management Agency (FEMA). (2000). “Prestandard and Commentary for the Seismic Rehabilitation of Buildings”, FEMA-356

Japan Building Disaster Prevention Association (2001). *Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings*. (in Japanese), JBDPA.

Kabeyasawa, T., and Kabeyasawa, T. (2007). “Shear Design Equation in Practice for Columns with Wing-Walls.” *Proceedings of the 5th Annual Meeting, JAEE*, 248-249.

Kabeyasawa, T., Kabeyasawa, T., Tojo, Y. and Kabeyasawa, T. (2008). “Experimental Study on Columns with Wing Walls failing in Shear.” *Proceedings of the Japan Concrete Institute*, Vol.30, No.3, 115-120.

Md Nafiur, R. and Tetsuo, Y. (2007). “Investigation of a hybrid technique for seismic retrofitting of bare frames.” Journal of Advanced Concrete Technology, Vol. 5, No. 2, 209-222

Moehle, J. P., Sezen, H. and Elwood, K. J. (2000). "Response of reinforced concrete buildings lacking details for ductile responses," *Proceedings of international workshop on annual commemoration of Chi-Chi earthquake*, Vol. 2,26-40, Taipei.

Tojo, Y., Kabeyasawa, T., Kabeyasawa, T. and Kim, Y.S. (2008). “Experimental Study on Column with Wing Walls Yielding in Flexure.” *Proceedings of the Japan Concrete Institute*, Vol.30, No.3, 109-114.

Tetsuo, Y., Md Nafiur, R., and Yoichi, M. (2006). “Experimental Investigation and Analytical Approach for Seismic Retrofit of RC Column with Wing-wall.” *Journal of Structural and Construction Engineering*, No. 608, 109-117