RECENT ADVANCES IN SEISMIC RETROFIT OF RC STRUCTURES IN TAIWAN

Shyh-Jiann Hwang and Wu-Wei Kuo
Department of Construction Engineering
National Taiwan University of Science and Technology, Taipei, Taiwan
sjhwang@mail.ntust.edu.tw, D9105301@mail.ntust.edu.tw

Abstract

The poor performance of the old RC structures with substandard reinforcing details had been widely observed during the Chi-Chi earthquake. Seismic retrofit of these numerous vulnerable buildings is an important societal issue to be resolved. Concerns about the seismic response of existing structures grew considerably and resulted in several programs to identify and mitigate seismic risk. This paper reviews existing research on RC structures in Taiwan to identify findings that may be immediately useful to the structural engineers in government and private practice who are working on seismic retrofitting.

INTRODUCTION

The majority of structures in Taiwan do not meet current seismic code requirements, and many of these structures are vulnerable to damage and even collapse in an earthquake. Concerns about the seismic response of existing structures grew considerably and resulted in several programs to identify and mitigate seismic risk. The 1999 Chi-Chi earthquake provided renewed impetus for seismic rehabilitation of structures in Taiwan.

At least two significant challenges are posed by the goal to manage the seismic risk in Taiwan. The first of these is to identify those structures that pose the greatest threat to life and property and for which seismic upgrades can be implemented successfully. The second is to establish retrofit guidelines that not only represent current knowledge on retrofit design and construction practice, but that will also serve to educate the practicing engineer or other professional who may not have significant experience in seismic rehabilitation.

This paper reviews existing research on RC structures in Taiwan to identify findings that may be immediately useful to the structural engineers in government and private practice who are working on seismic retrofitting.

SEISMIC STRENGTHENING OF RC BRIDGE COLUMN USING FRP LAMINATES

Objective and Scope

A retrofit scheme to strengthen a short column was designed and tested (Chang and Jong 2000). The original column exhibited a shear-dominated failure. The retrofit scheme was addition of FRP laminates. The performance is evaluated considering the failure mechanism and ductility capacity.

Summary and Significant Findings

Two reinforced concrete columns were tested: the column in its original form (BMRS) and the column retrofitted with FRP laminates (FRS). The configuration and details of the each specimen are presented in Fig. 1. Concrete strength was 16.7 MPa for BMRS and FRS.

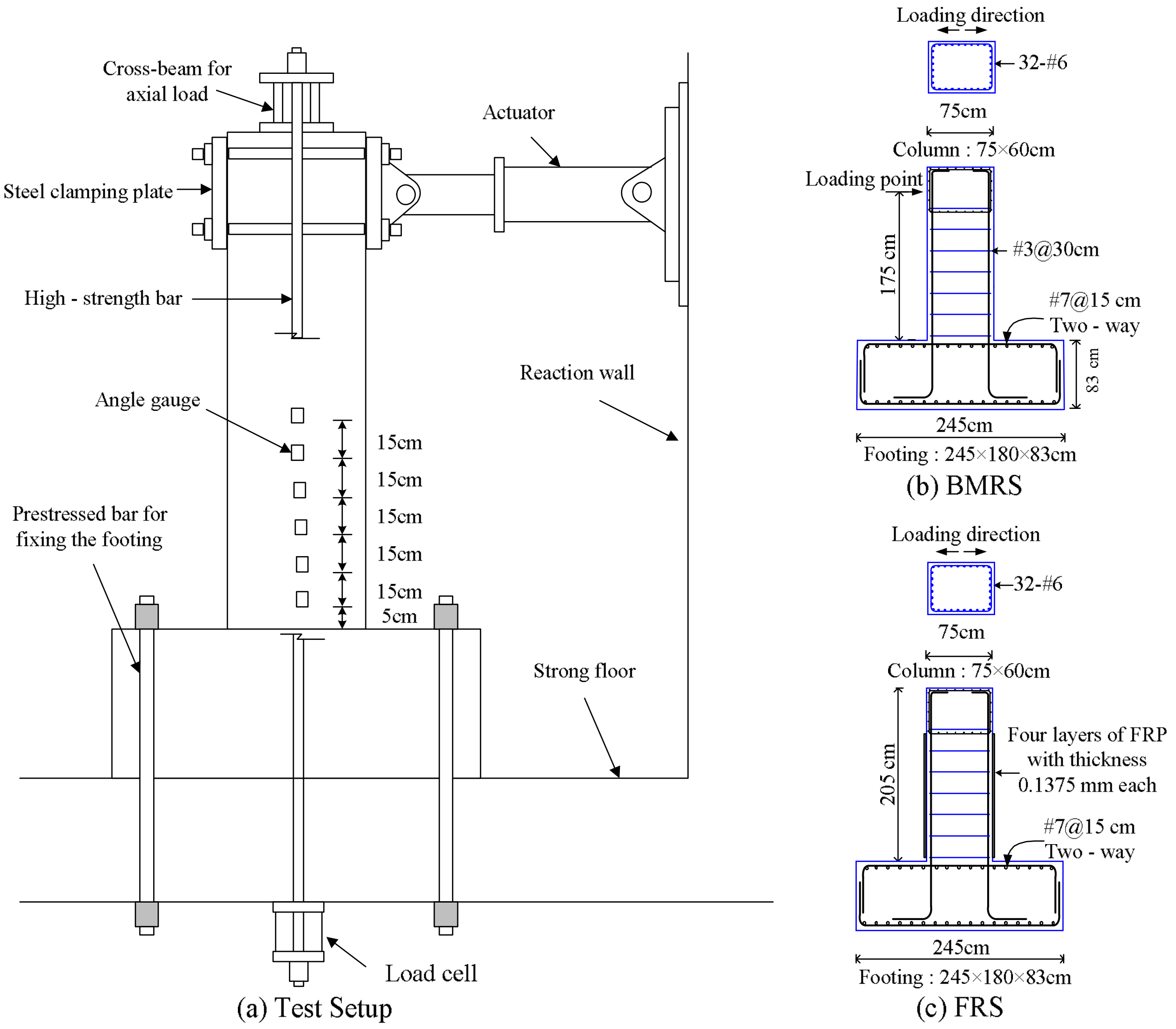
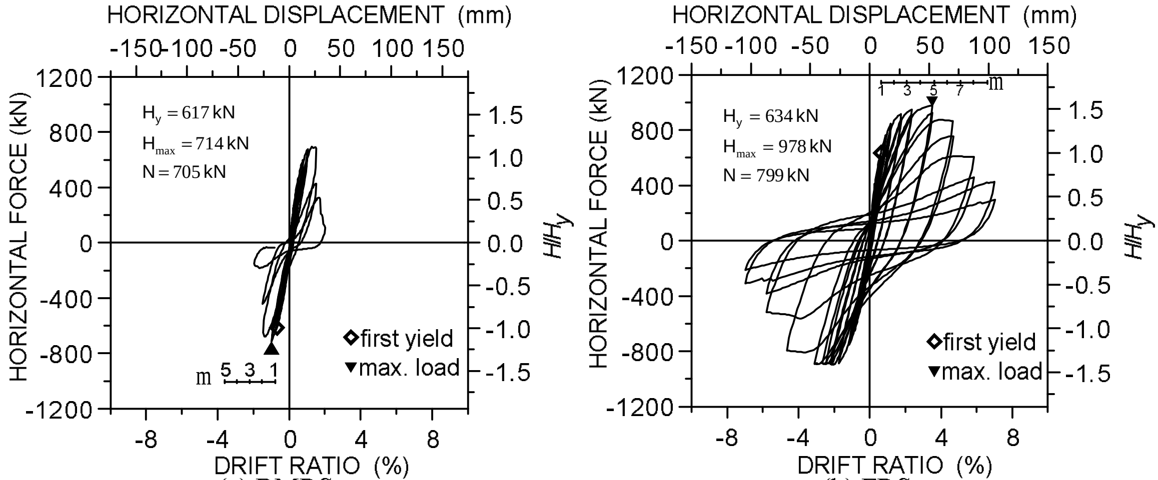


Fig. 1: Specimens configuration and details

Details of the original column BMRS include light transverse reinforcement without cross tie (Fig. 1). The response is elastic until a load of 714 kN (drift ratio of 1%), after which the strength degrades (Fig. 2).



(a) BMRS (b) FRS

Fig. 2: Load displacement response of test specimens

Column FRS was jacketed using four layers of FRP sheets with a thickness of 0.1375 mm for each (Fig. 1). The column showed excellent response with an increase in both lateral load carrying capacity and drift ratio. Strength degradation did not begin until a drift ratio of 3.5% was reached.

Overall, the response of the column retrofitted with FRP laminates increased the shear strength to provide a ductile failure mechanism.

SEISMIC RETROFIT OF RC CIRCULAR COLUMN WITH INADEQUATE LAP SPLICE

Objective and Scope

Spliced column bars found in older reinforced concrete buildings often have inadequate length for tensile loading, poor confinement and may be poorly located. Retrofit technique using steel jacket designed to improve the performance of such column was investigated experimentally (Hwang and Guo 2000).

Summary and Significant Findings

Two columns were tested. The specimen details are presented in Fig. 3. Figure 4 presents the hysteretic response for each specimen.

The test specimen was a cantilever with the longitudinal reinforcing bars spliced just above the footing. The lap splice length of the original circular column BMCL100 corresponding to 40 bar diameters (Fig. 3). The circular ties were spaced at a distance of 130 mm with two orthogonal cross ties for each layer (Fig. 3). One nominally identical column SCL100 was retrofitted with steel jacket of 3 mm thickness. The jacket was placed 30 mm above the column base and extended 2920 mm (almost entire column length; Fig. 3).

The original specimen BMCL100 exhibited a bond-dominated failure mechanism. The lap splice failed at a lateral load of 352 kN, after which the specimen lost strength and stiffness (Fig. 4). The retrofit column SCL100 showed excellent response with an increase in both lateral load carrying capacity and drift ratio. Strength degradation did not begin until a drift ratio of 5% was reached (Fig. 4).

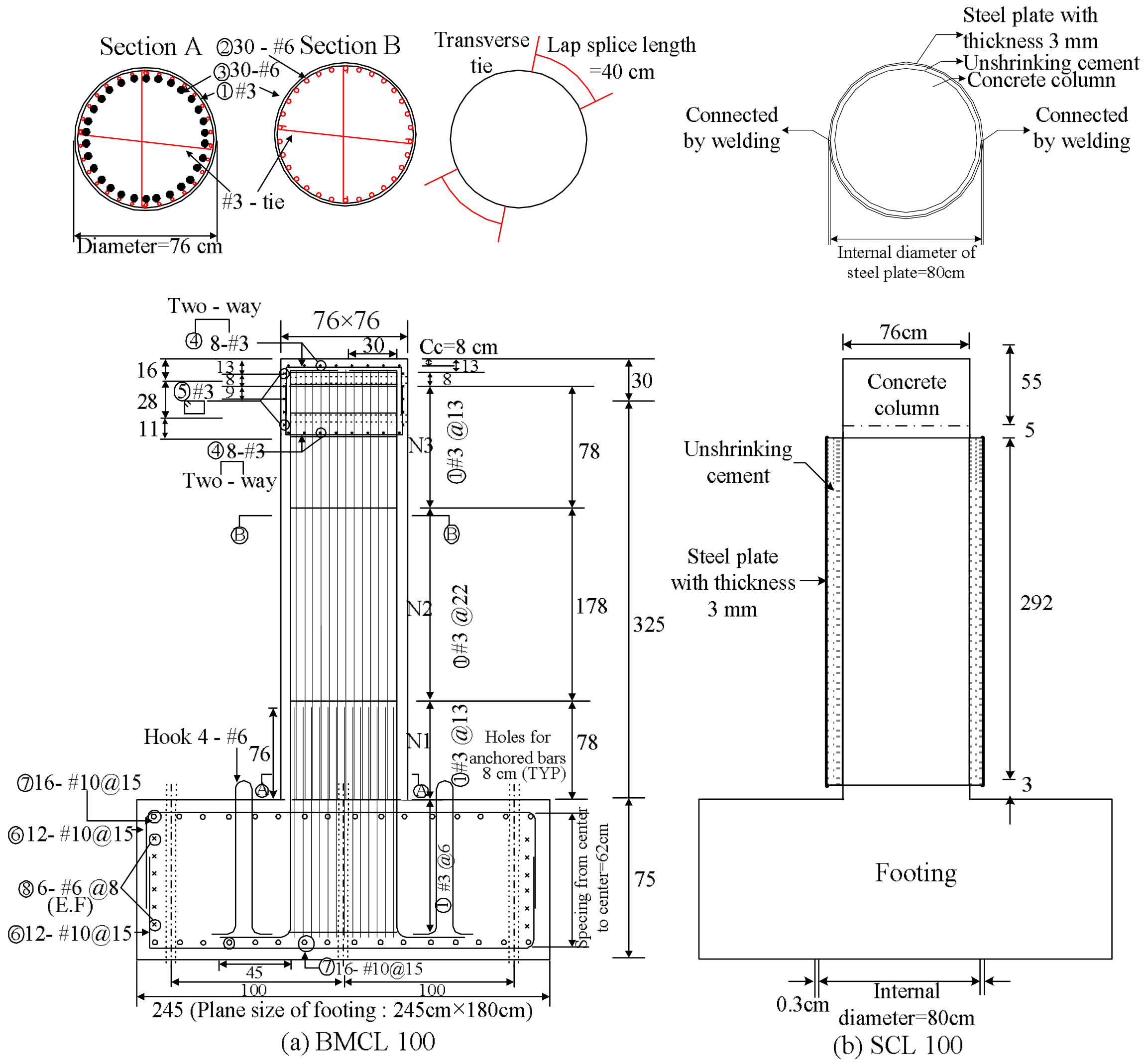


Fig. 3: Specimens configuration and details

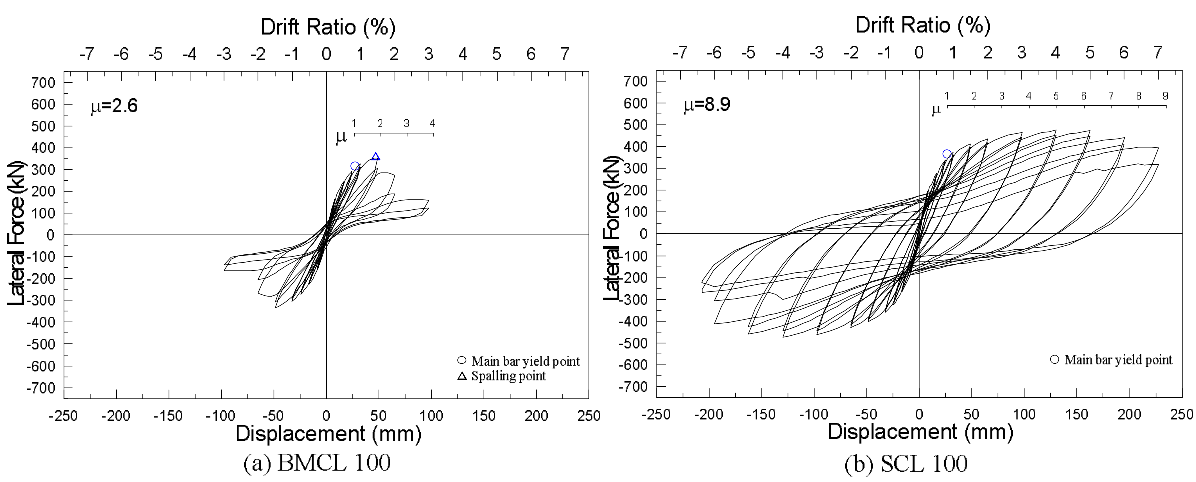


Fig. 4: Load displacement response of test specimens

It is concluded that steel jacketing is quite effective in enhancing the seismic performance of the column with its longitudinal reinforcement lapped at the plastic hinge zone.

SEISMIC RETROFIT OF BRIDGE COLUMN FOOTING BY ADDING RC OVERLAY

Objective and Scope

A retrofitting measure by adding the reinforced concrete overlay atop the existing footing to strengthen a bridge column footing was designed and tested (Hwang and Jian 2000). The original footing experienced a joint shear failure at the column footing connection. The retrofit scheme was addition of RC overlay. The performance is evaluated considering the failure mechanism and ductility capacity.

Summary and Significant Findings

Two reinforced concrete column footings were tested: the column in its as-built form (RF1) and the footing retrofitted with RC overlay (RF3). The test setup is shown in Fig. 5. The configuration and details of the each specimen are presented in Fig. 6. Concrete strength was 41.7 MPa for RF1 and RF3.

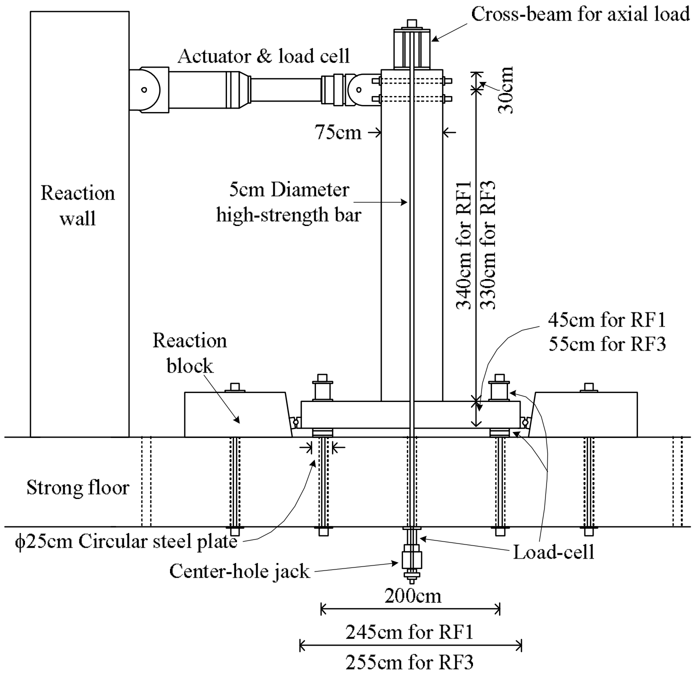


Fig. 5: Test setup

Details of the original footing RF1 include insufficient anchorage of column bars and none of joint hoop (Fig. 6). The maximum force-carrying capacity developed by RF1 was less than the nominal flexural strength of column, indicating insufficient footing strength of RF1 (Fig. 7).

Retrofit column footing RF3 was strengthened by adding reinforced concrete overlay with a thickness of 100 mm (Fig. 6). New concrete was connected with original footing by #4 dowels, as illustrated in Fig. 6. The thickness 100 mm of the reinforced concrete overlay was chosen to cover up the deficiency in joint strength and to provide enough development length of the column longitudinal reinforcement according to the ACI 318-95 Code (1995). As shown in Fig. 7, the retrofit column footing RF3 developed higher strength and more ductile hysteretic behavior than the as-built column footing RF1.

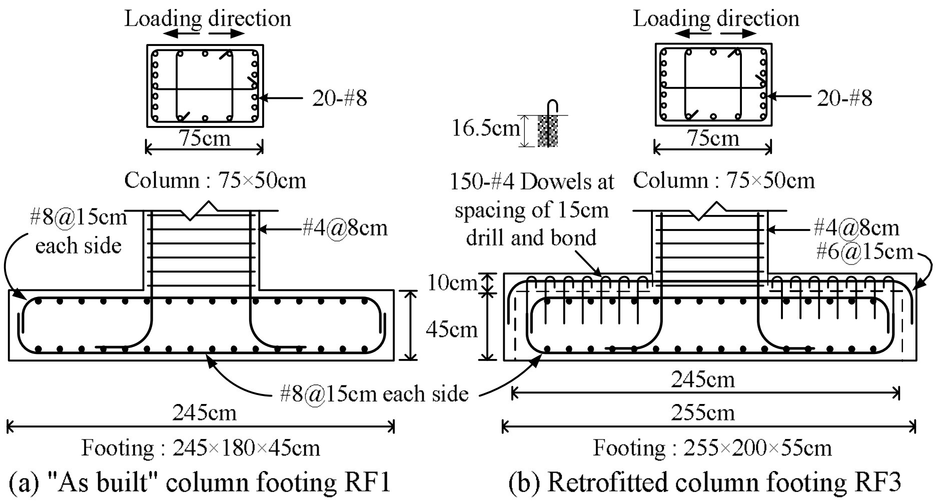


Fig. 6: Footing details

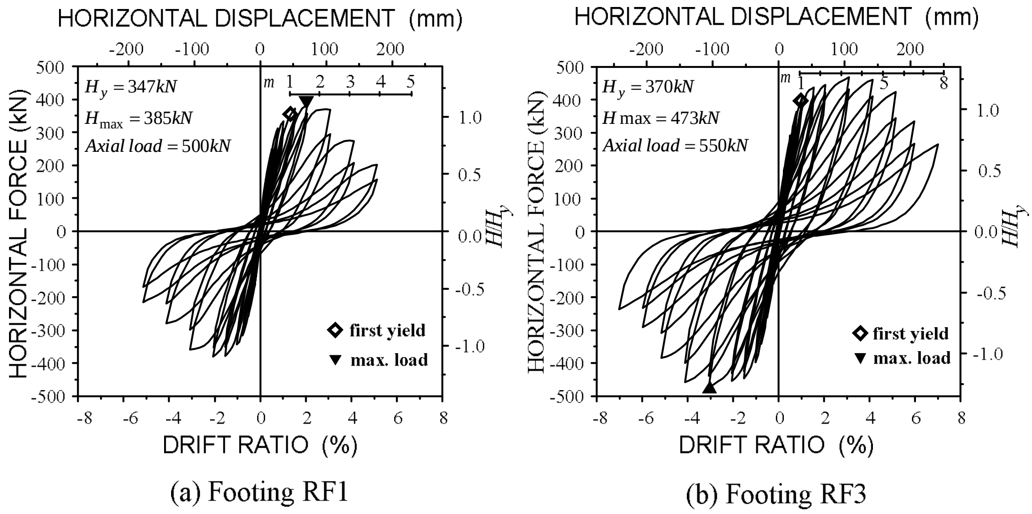


Fig. 7: Hysteretic response of column footings

The test result of the retrofitted model column footing indicated that the reinforced concrete overlay atop the existing footing is an effective retrofitting measure.

SHEAR ENHANCEMENT OF BEAM-COLUMN JOINT RETROFITTED WITH RC JACKETING

Objective and Scope

Strengthening of seismically insufficient beam-column-joint subassemblages were studied experimentally (Wang et al. 2003). Strengthening technique uses concrete jacketing. The retrofit aims to improve inadequate details such as lack of transverse joint reinforcement and insufficient shear strength of joint.

Summary and Significant Findings

Two reinforced concrete exterior beam-column joints were tested: the specimen in its as-built form (JE1) and the specimen retrofitted with a concrete column jacket (JER1). The configuration and details of the each specimen are presented in Fig. 8. Concrete strength was 20 MPa for JE1 and JER1, but the concrete strength for the column jacket was 41 MPa.

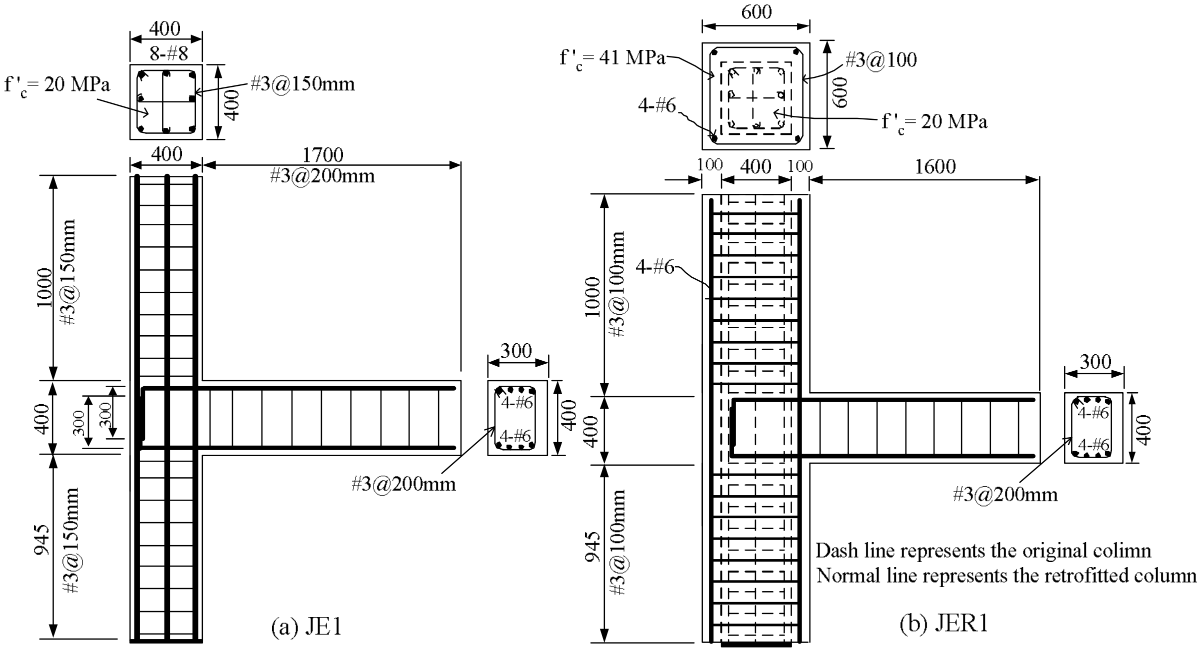


Fig. 8: Specimen configuration and details

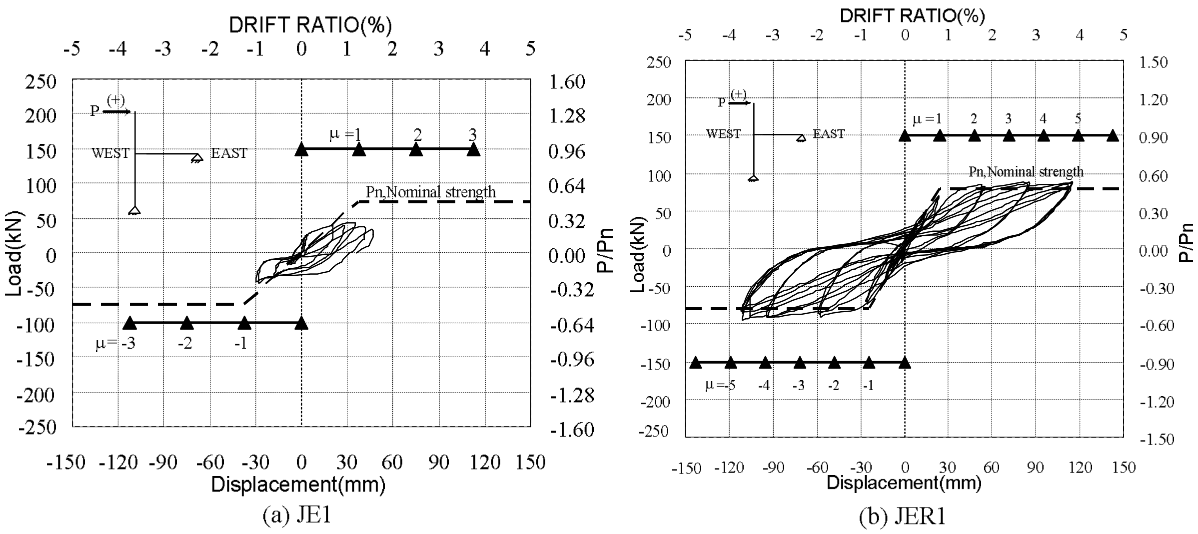


Fig. 9: Load displacement response of test specimens

Details of the original specimen JE1 include insufficient shear strength of joint and none of joint hoop (Fig. 8). The original specimen JE1 exhibited a joint shear failure mechanism. The nominal flexural strength of beam was never developed, indicating insufficient joint strength of JE1 (Fig. 9).

Retrofit specimen JER1 was strengthened by adding reinforced concrete column jacket with a thickness of 100 mm for each face (Fig. 8). Column jacketing involved adding additional longitudinal steel along the entire length and through the existing slab. No anchors were installed between new and old concrete interface. As shown in Fig. 9, the retrofit specimen JER1 developed higher strength and more ductile hysteretic behavior than the original specimen JE1.

The test results showed that the shear strength of the non-ductile beam-column joints was efficiently enhanced by the concrete jacketing.

STRENGTHENING OF LOW-RISE RC BUILDINGS WITH WEAK FIRST STORIES

Objective and Scope

For the existing old low-rise RC buildings, the strength enhancement of the structures is the most economical retrofitting strategy. A retrofitting measure by adding the reinforced concrete wing walls to strengthen the weak first story was designed and tested (Hwang and Chang 2003). The response of the original weak-first-story frame was found to be unsatisfactory due to inadequate detailing. After the removal of damaged portions, the original frame was retrofitted with the addition of RC wing walls. The performance is evaluated considering the lateral load strength and the failure mode.

Summary and Significant Findings

A two-story and two-bay non-ductile frame with RC wall throughout the second floor was tested (NFL-W) to failure and then retested after retrofitting with RC wing walls (NFL-W/rc). The test setup is shown in Fig. 10. The configuration and details of the each specimen are presented in Fig. 11. Concrete strength was 21 MPa for NFL-W.

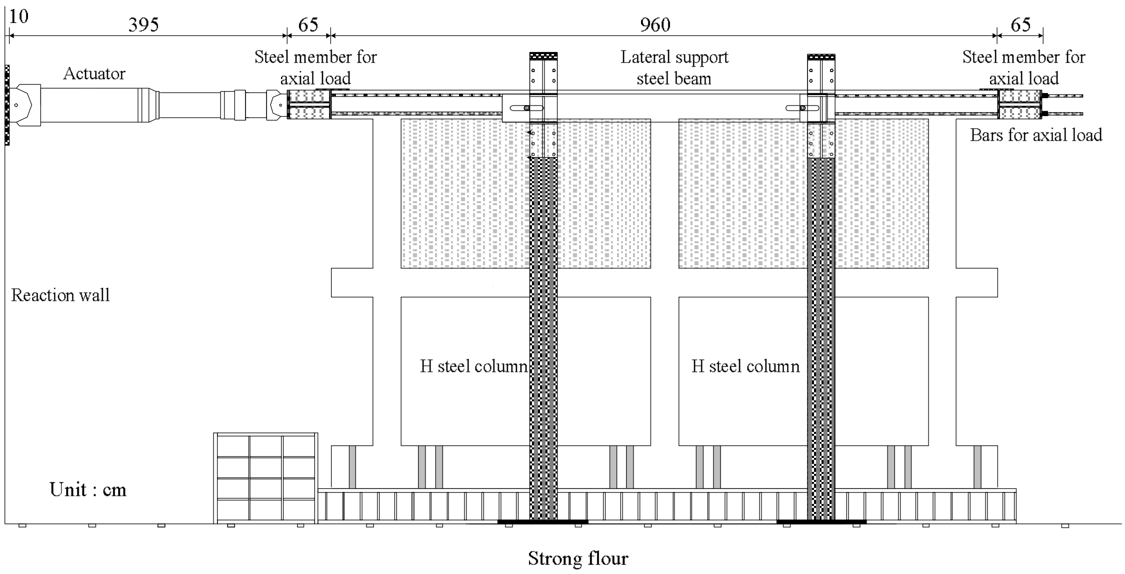
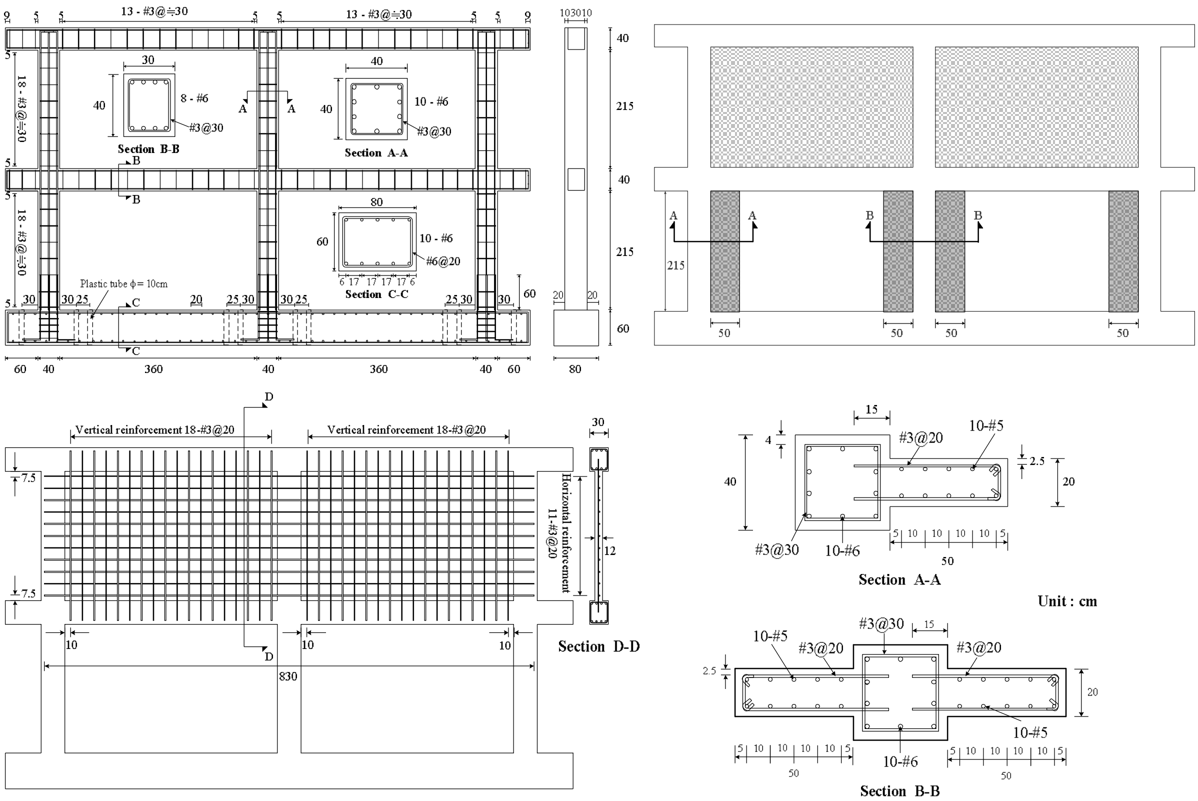


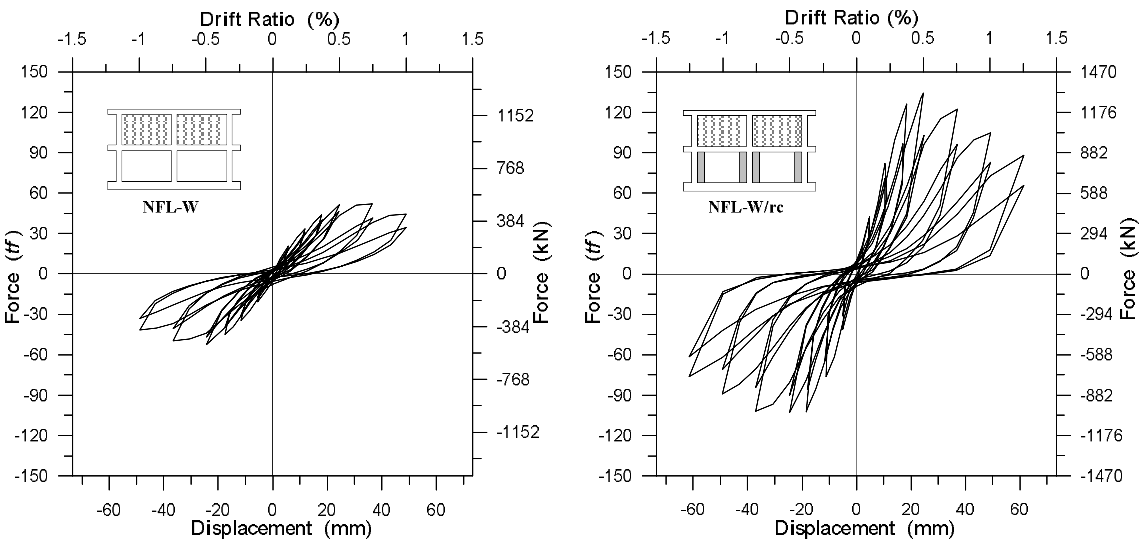
Fig. 10: Test setup

Details of the original frame NFL-W include the substandard reinforcing details such as the beam-column joints without ties, the columns with inadequate lap splices located in the high moment regions, and the insufficient transverse reinforcement in the columns with unreliable 90 end hooks (Fig. 11). The maximum force-carrying capacity developed by NFL-W was 402 kN (Fig. 12) and the shear failures coupled with bond splitting were observed in the base of columns.



(a) NFL-W (b) NFL-W/rc

Fig. 11: Specimen configuration and details



(a) NFL-W (b) NFL-W/rc

Fig. 12: Load displacement response of test specimens

Retrofitted frame NFL-W/rc was strengthened by adding reinforced concrete wing walls with a thickness of 200 mm (Fig. 11). As shown in Fig. 12, the retrofit frame NFL-W/rc developed stiffer response and higher strength than the original frame NFL-W. The addition of wing wall can also prevent the failure of beam-column joint as well as the splitting of lap splice in the column base.

Based on the experimental observation, the retrofitting with wing walls is quite effective in increasing seismic strength for the low-rise RC buildings with weak first stories.

CONCLUSIONS

The poor performance of the old RC structures with substandard reinforcing details had been widely observed during the Chi-Chi earthquake. Seismic retrofit of these numerous vulnerable buildings is an important societal issue to be resolved. Above problems will be further complicated by a near-field ground motion such as Chi-Chi earthquake. Moreover, the lack of analytical tools may jeopardize the development of the performance-based retrofitting for older RC structures. International collaboration to broaden the research program is needed.

ACKNOWLEDGEMENTS

This paper summarizes some current work of researchers in Taiwan. Their valuable individual contributions to the technical literature are noted. We made every effort to correctly represent their work in a condensed form, and apologize for any unintentional misrepresentations.

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