

Experimental Study on Seismic Retrofit of Reinforced Concrete Buildings using Combination of Column-Jacketing and Supplemental Beams

Chao-Hsun Huang^{1, a}, Min-Lang Lin^{2, b} and Wei-Hong Chen^{1, c}

¹ Department of Civil Engineering, National Taipei University of Technology

1, Sec. 3, Chung Hsiao E. Rd., Taipei 106, Taiwan

²National Center for Research on Earthquake Engineering

200, Sec. 3, Hsin Hai Rd., Taipei 106, Taiwan

^asteve@ntut.edu.tw, ^bmllin@ncree.narl.org.tw, ^cimmortal20092@gmail.com

Keywords: Seismic retrofit, column jacketing, supplemental beam, pushover analysis.

Abstract. To ensure the seismic safety of existing buildings, the Taiwanese government has been pushing seismic retrofit of old buildings in recent years. In these projects, one of the most frequently used techniques is column-jacketing, which is accomplished by encasing existing columns with a thick cover of concrete along with addition of longitudinal and lateral reinforcement. While this technique only strengthens individual columns, the beams which these columns are connected to are left out. As resistances provided by these beams remain unchanged, these columns must act alone to resist lateral load, making this technique less effective. In this study, an adjustment is made by adding a supplemental beam between adjacent jacketed columns to providing additional resisting moments at the beam-column joints. To verify the effectiveness of the proposed technique, a quasi-static experiment was performed on three full-scale concrete frames at NCREE. Result of the experiment indicates that with this addition, the lateral strength of the frame is significantly increased, which will help improving both the stability of the building and the effectiveness of column jacketing during potential earthquakes.

Introduction

In order to improve the seismic resistance of existing concrete buildings, National Center for Research on Earthquake Engineering (NCREE) proposed several retrofit techniques such as construction of shear walls, wing-walls, and column jacketing [1,2]. Among these measures, column jacketing has advantages including adding lateral strength in both (e.g., x and y) directions of a structure and least obstruction to ventilation and natural lighting, making it one of the most popular retrofit choice for building owners. Nonetheless, current practice for column jacketing is limited to the strengthening of individual columns; no effort is made to increase the strength of the beams which these columns are connected to. As a result, yielding tends to occur at the ends of these beams near the jacketed column face at the early stage during lateral deformation of the frame [3]. Once this happens, it would be difficult to raise the lateral strength of the structure and the effectiveness of this retrofit technique is affected consequently.

In this study, an adjustment to the current technique is made by adding a supplemental beam between adjacent jacketed columns. By providing additional resisting moments at the beam-column joints, the lateral resistance of the structure is expected to rise. To verify the effectiveness of the proposed technique, a quasi-static experiment was performed on three full-scale concrete frames at NCREE. Result of the experiment indicates that through this upgrade, the lateral strength of the frame is significantly increased, which can help improving the stability of the building as well as the effectiveness of column jacketing during potential earthquakes.

Failure Mechanism of Structures

Fig. 1 shows the elevation of a typical elementary school building in Taiwan. This type of buildings usually has a straight aisle, and all classrooms are located on the same side of the aisle. With masonry-infill constructed between classrooms, these buildings usually have a higher seismic resistance in the direction perpendicular to the aisle (the “short” direction). In the other direction, however, the structure has to rely on the frame alone. Besides, the structural performance of the building in this direction often suffers from variation in the clear length of columns, making it vulnerable in earthquakes.

To improve the seismic performance of such buildings, a retrofit plan based on column jacketing is considered (see Fig. 2). Result of a pushover analysis [4] shows that the seismic resistance of the building can be increased by 39% with this retrofit in terms of equivalent maximum ground acceleration it could sustain [3]. Nonetheless, the same analysis also reveals that once the base of a jacketed column yields, it will not generate additional contribution to the lateral strength of the structure (see Fig. 3).

For comparison purposes, an alternative plan was also analyzed. In this plan, column jacketing is conducted the same way as in the previous plan. In addition, a supplemental beam is constructed near the mid-floor between adjacent jacketed columns (see Fig. 4). Result of the pushover analysis indicates that with the extra resistance provided by these beams (see Fig. 5), the seismic resistance of the building can go up as much as 54% in terms of equivalent maximum ground acceleration, giving a 39% edge on the original plan in terms of retrofit benefits.

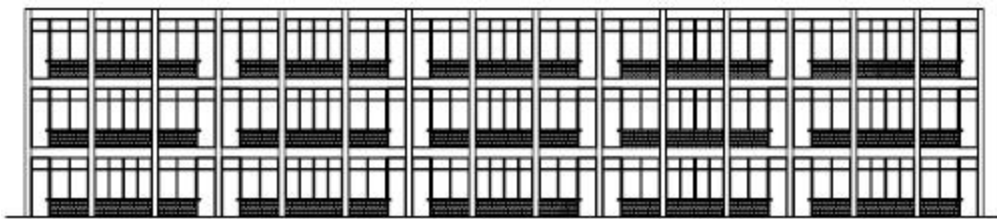


Figure 1 Elevation of a typical elementary school building in Taiwan



Figure 2 Locations of jacketed columns

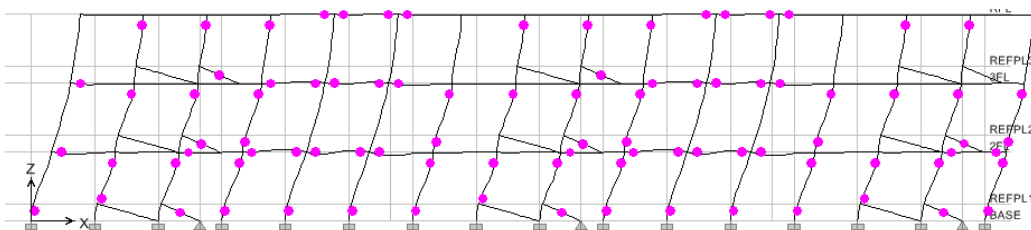


Figure 3 Formation of plastic hinges in the structure retrofitted with column jacketing



Figure 4 Locations of supplemental beams in the alternative retrofit plan

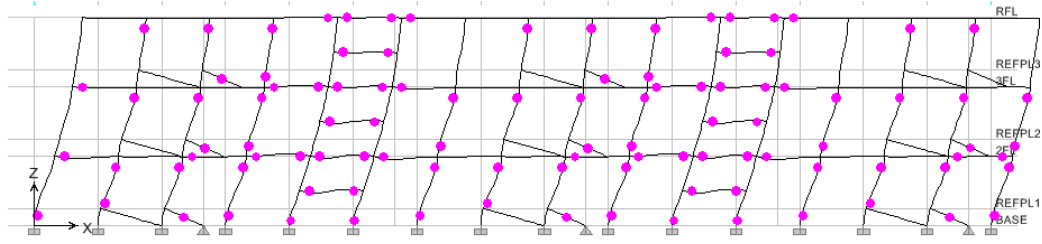


Figure 5 Formation of plastic hinges in the alternative retrofit plan

Full-scale Experiment

To verify the effectiveness of the proposed technique, a quasi-static experiment on three full-scale concrete frames, as indicated in Table 1, was performed at the structural laboratory of NCREE. The labels Proto, CJ, and CJB represent the prototype (unretrofitted) frame, the frame retrofitted with column jacketing, and the frame retrofitted with both column jacketing and supplemental beam, respectively. The strengths of materials used in these specimens are given in Table 2.

Fig. 6 shows the backbone curves obtained from the hysteresis loops of these frames under reversed cyclic loading. It is found that through the retrofit, frames CJ and CJB were able to put on a strength increase of 513 kN and 805 kN, respectively, over the prototype frame at an interstory drift level of 2% (see Table 3). In another word, with addition of the supplemental beams, the retrofit benefit of column jacketing can be increased by 57%.

Table 1 Full-scale specimens

Prototype	Column Jacketing	Column Jacketing with Supplemental Beam
Proto	CJ	CJB

Table 2 Material strengths

		Specified	Test
f_y	No.3 bars	275 MPa	341 MPa
	No.4 and larger bars	412 MPa	454 MPa
f'_c	Prototype Frame	15.7 MPa	19.3 MPa
	Retrofitting Elements	27.4 MPa	36.7 MPa
	Foundation	412 MPa	42 MPa

Table 3 Lateral strengths of specimens

Specimen	Strength		
	P_{max}	$P_{DR=2\%}$	$P_{DR=2\%}$
Proto	145 kN	145 kN	0 kN
CJ	682 kN	658 kN	513 kN
CJB	960 kN	950 kN	805 kN

Summary

In this study, a quasi-static experiment was conducted on three full-scale frame specimens to verify the seismic performance of the proposed retrofit technique. Result of the experiment indicates that with addition of the supplemental beams, the retrofit benefit of column jacketing can be increased by 57%. Considering that the addition of supplemental beam(s) will only raise the total cost of construction (including restoration of non-structural components) by 10% or less, it has a strong advantage in the benefit-to-cost point of view. As a conclusion, it is recommended that structural engineers should seriously consider using this technique in future practices for the seismic retrofit of existing buildings.

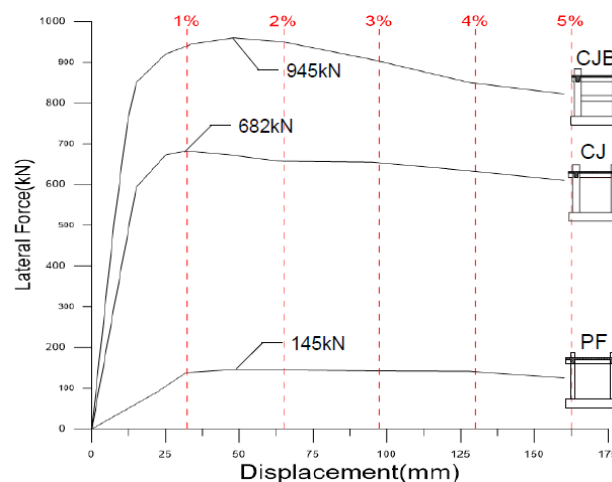


Figure 6 Backbone curves of the full-scale specimens

Acknowledgements

This work was financially supported by both the Ministry of Science and Technology (MOST 103-2221-E-027-008) and National Center for Research on Earthquake Engineering. The authors would like to show the greatest appreciation to both sponsors as well as the administration and technical staffs at NCREE who made this study possible.

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