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Cyclic behavior of reinforced concrete L- and T-columns retrofitted from rectangular columns

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ABSTRACT

An innovative seismic retrofit method was proposed to address the weak first-story issue of reinforced concrete row houses in Taiwan. The proposed method is to turn as-built rectangular columns to L- and T-columns by adding flanges in the weak direction of as-built rectangular columns to strengthen their seismic capacities. The longitudinal reinforcement in the retrofit part of the retrofitted column is not continuous into the beam and foundation above and below the column to ease construction difficulty associated with post-installation of such reinforcement. Large-scale L- and T-columns retrofitted from rectangular columns with the proposed retrofit method were tested in this research using lateral cyclic loading. Test results showed that the retrofitted columns exhibited ductile, flexural dominated behavior. As compared with the original rectangular columns, the proposed retrofit method was effective in increasing the lateral strength of the column. Due to the discontinuity of the longitudinal reinforcement, the retrofitted columns showed lower lateral strengths but less damage and higher ductility than the counterpart monolithic columns. A pushover analysis model was developed for the proposed retrofitted column that accounts for the effects of discontinuity of longitudinal reinforcement in the retrofit part. Comparison of pushover analysis and test results showed that the pushover model generally captured well the force-displacement behavior of the retrofitted columns.

1. Introduction

One of the common building types in Taiwan is the low-rise reinforced concrete (RC) row houses as shown in Fig. 1(a). The houses are usually three to five stories high and are built along streets. Due to the need for commercial use, parking garages, or living rooms, walls along the street direction in the first story of the house are usually eliminated (Fig. 1(b)). Moreover, rectangular columns with the weaker direction placed along the street direction are usually used to minimize the interference with the living space (Fig. 1(b)). As a result, during earthquake loading, these row houses are vulnerable to weak-story failure mechanism in the first story along the street direction. Fig. 2 shows an example of weak-story failure of a row house in Taiwan during the 1999 Chi-Chi earthquake. It can be seen that the first story of the house was deformed significantly along the street direction while the stories above showed little damage.

Common seismic retrofit methods that can be used in row houses to improve the weak-story issue include RC jacketing [1–6], infill walls [7,8] and steel braces [9,10]. RC jacketing was considered in this research because infill walls and steel braces are often not welcomed by buildings owners as they can significantly interfere with the living spaces. Previous studies [1–6] have shown that RC jacketing is an effective seismic retrofit method for as-built RC columns. With an appropriate surface treatment of the as-built column, such as roughening [1,5,6], steel connectors [3,5,6], or dowels [3,5], test results showed that columns retrofitted with RC jacketing were able to increase the flexural stiffness and strength to achieve similar behavior to counterpart monolithic columns. Some test results showed monolithic behavior can be nearly achieved even without any surface treatment of the as-built column [5,6]. However, some test results [3] showed that without any surface treatment to the as-built column, the damage was restricted to the RC jacket due to the loss of bond between the jacket and the as-built column, which resulted in a sudden drop of strength after the maximum strength. In addition to enhancing the flexural behavior, RC jacketing can also enhance the shear strength of the column, thus resulting in better displacement ductility [2]. Despite the effectiveness of RC jacketing in seismic retrofit, conventional design of RC jacketing still requires additional living space.

An innovative retrofit method was proposed in this research to address the weak-story issue and to minimize the interference with the

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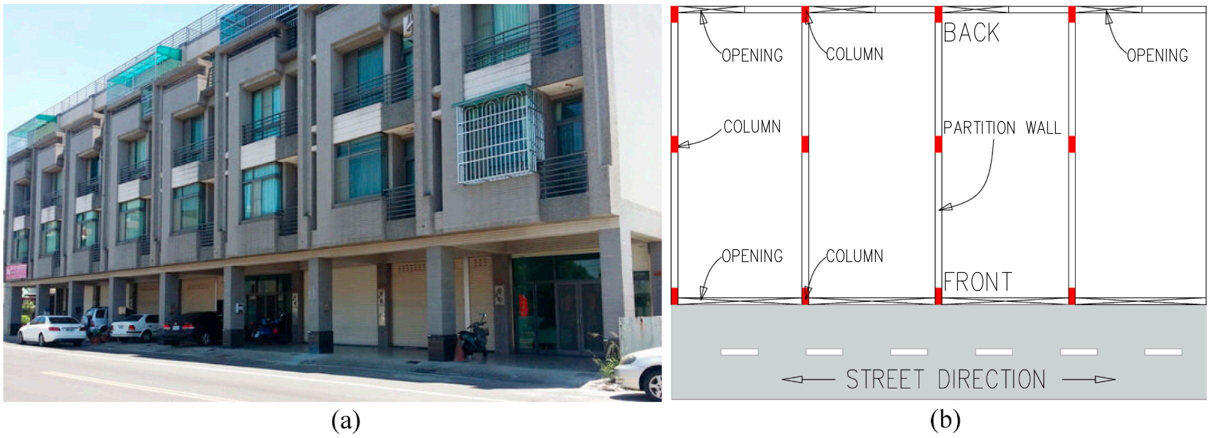

Fig. 1. (a) Typical row houses in Taiwan; and (b) plan view of the first story of typical row houses.

Fig. 2. Failure of the first story of row houses along the street direction during the 1999 Chi-Chi earthquake.

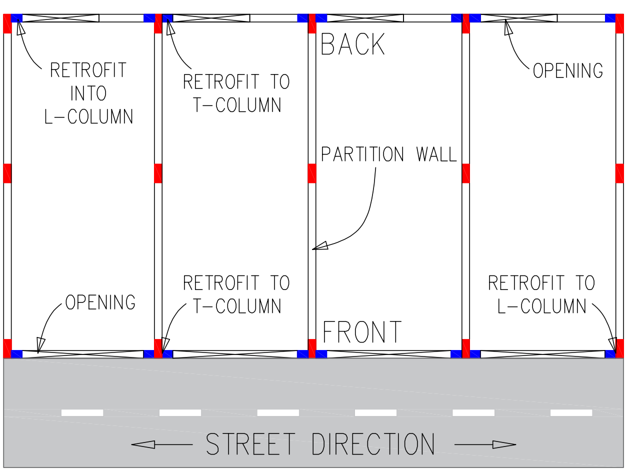

Fig. 3. Plan view of the first story with proposed retrofitted columns.

living space. In the proposed method, the rectangular columns at the corners of row houses in the first story (Fig. 3) are converted into L- or T-columns by adding flange sections on one or two sides of the column, respectively. The added flange sections occupy the space that would otherwise be occupied by non-structural walls, thus minimizing interference with the living space. The longitudinal reinforcement in the flange sections are not required to extend into the foundation or the beam, thus greatly increasing constructability. Three large-scale column specimens consisting of one L- and two T-columns retrofitted from rectangular columns were tested under cyclic loading. Test results were compared with monolithic L- and T-columns and original rectangular columns to investigate the effectiveness of the proposed retrofit method in increasing the lateral strength and seismic performance of as-built columns.

2. Experimental program

2.1. Specimen design

Three large-scale retrofitted column specimens were tested in this research. Two monolithic columns tested as part of an earlier investigation by the authors [11,12] were also included herein for comparison purpose. Table 1 lists the design parameters of the five columns including actual concrete and reinforcement strengths. The maximum aggregate size of the concrete was 20 mm. The nomenclature for the column specimens is described as follows: “L” and “T” represent L- and T-columns, respectively; “M” and “R” represent monolithic and retrofitted columns, respectively; “C” and “W” represent a column or a wall design concept for the reinforcement in the retrofit part of the retrofitted column, respectively. Fig. 4 shows the dimension and reinforcement design of the three retrofitted columns and two monolithic columns. The column specimens represent the lower half part of the first story column and hence were tested in a cantilever manner (single curvature) with lateral loading applied on the top of the specimens.

The three retrofitted columns were first constructed as rectangular columns with a section dimension of 350 × 600 mm and a design that is typical of columns currently used in row houses in Taiwan. After 28 days of curing, the rectangular columns were retrofitted to a L-column (column LRC) and two T-columns (columns TRC and TRW). The difference between columns TRC and TRW was the reinforcement design in the retrofit part of the column. The reinforcement design in the retrofit part of TRC followed the design concept of a column while that of TRW followed that of a wall. As a result, 14-D22 longitudinal bars and D10 transverse reinforcement spacing at 90 mm were used for TRC. In contrast, 10-D10 longitudinal bars and D10 transverse reinforcement spacing at 180 mm were used for TRW.

Because the retrofit part of the column in real application is located between a grade beam and a floor beam and post-installation of reinforcement into a beam is difficult due to dense longitudinal and transverse reinforcement, it was proposed in this research that longitudinal reinforcement in the retrofit part was not extended into the beams below and above the column. As a result, the longitudinal reinforcement in the retrofit parts of the three retrofitted columns were not continuous into the foundation of the specimen and hence was not effective to take flexural tension. However, it was effective to take flexural compression and to provide confinement to core concrete