STRENGTHENING OF DEFICIENT RC COLUMNS BY STEEL ANGLES AND BATTENS UNDER AXIAL LOAD

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ABSTRACT

This paper presents the effectiveness of the strengthening technique for deficient reinforced concrete columns using steel angles and battens. The compressive strength of concrete was chosen as 9 MPa to represent poor concrete quality. The experiment consisted of a control reinforced concrete column and columns that were strengthened by steel angles and battens. In this study, the effectiveness of different configurations of battens was investigated; different amounts of battens as well as different spacing while maintaining amount of steel. The results showed that both load carrying capacity and ductility of the strengthened columns could be significantly improved. While maintaining the same amount of battens, different spacing does not show significant difference in load carrying capacity but affects ductility. The experimental results showed that using steel angles and battens is effective for strengthening reinforced concrete even when the compressive strength of the concrete is very low.

Keywords: RC columns, strengthening, steel angles and battens,

1. INTRODUCTION

The column is a key element that carries load from upper story down to foundations. Losing load carrying capacity in the column, caused by strength deterioration or material deficit, may lead to catastrophic failure of structures. In Thailand, most of structures are low-rise and reinforced concrete buildings. The cost of rebuilding the structures can be prohibitively high and strengthening techniques that could upgrade the structures with an acceptable cost is more preferable.

To elevate load carrying capacity of reinforced concrete columns, section enlargement, steel jacketing, steel encasing, or wrapping with FRP are among the available techniques. Section enlargement, in which the column is enlarged by concrete and rebar, is a cost effective technique (Ramirez 1996). However, the technique considerably alters the space utilization of the building. Confining existing columns with FRP is widely studied (Wu et al. 2006). The capacity of column could be increased by adding confinement around the column. This technique is very efficient and dimensions of the column are merely changed. However, the high cost associated with this technique could prevent the technique from being practical. Steel caging, in which steel angles are placed at all column corners and fixed together by steel battens, is drawing more attention and

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widely investigated (Adam et al. 2009; Baladamenti et al. 2010; Campione 2012; Cirtek 2001; Giminez et al. 2009a; Giminez et al. 2009b). The advantages of this technique are ease of installation; slight changes in column dimensions, and promising performance. However, literatures reveals that the performance on deficit concrete, especially for very low compressive strength (below 10 MPa), has not been sufficiently investigated.

The purpose of this paper is to evaluate the performance of using steel angles and battens in strengthening deficient reinforced concrete columns. The distribution of axial force in steel angles and battens used in the strengthening was also monitored and discussed.

2. EXPERIMENTAL PROGRAM

2.1. Description of test specimens

Test specimens were chosen to represent typical reinforced concrete columns used in low-rise buildings in Thailand. The dimensions of the specimens were: 200 × 200 mm in width and 700 mm. in height. The column heads were designed to simulate the joint between the column and beam as well as to protect column at high level of loading. The columns were reinforced with 4ϕ12 mm deformed bars with ϕ6 mm stirrups every 150 mm. The detail of the column is shown in Figure 1. There were 4 identical specimens under this experiment.

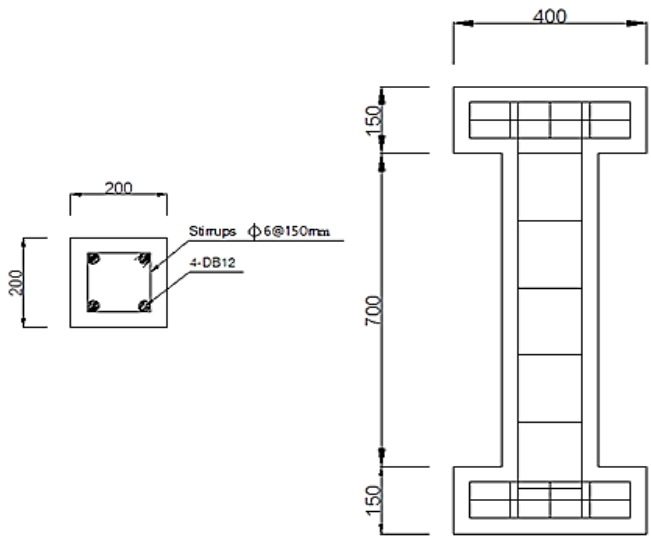


Figure 1 Geometry and reinforcement details of the reinforced concrete column

Three columns were strengthened by fixing four steel angles (L40 × 4 mm) to the corners of the columns using Crocodile 621 non-shrink grout. The length of the angles was 680 mm, leaving a small gap between angle ends and column heads. The purpose of these gaps was to prevent direct transmission of load to the steel angles. The steel battens were welded on the sides of the steel angles subsequently. The steel battens for specimen B are 200 × 50 × 4 mm at 150 mm spacing (center to center). The same size of steel battens was used in specimen C but an extra strip was

added near to column ends in order to add more confinement. Smaller steel battens were used in specimen D, i.e. 200 × 25 × 4 mm at 75 mm spacing. This is to keep the same amount of steel battens to specimen B but with closer spacing. Details of strengthening are shown in Figure 2. It should be noted that the welding of steel battens should be performed in a way that the battens were welded around the column before moving to the next, otherwise, the cooling of welding might cause the angle to bend.

2.2. Material properties

The concrete used for making the columns was poor in quality to represent a deficient column. The poor concrete was prepared by adding extra water and delaying the pouring time to 4 hours after adding water. The compressive strength (cylindrical specimens) at 28 days was between 9.10 MPa.

The yield strength of longitudinal rebar is 580 MPa. The steel used in the strengthening was four L40 × 4 mm angles with yield strength of 335 MPa and steel battens with yield strength of 412 and 304 MPa for the strip of 50 mm and 25 mm wide, respectively.

2.3. Test setup and testing program

Loading of columns was performed by using Shimadzu universal testing machine UH-F2000 kNA with capacity of 2000 kN. The specimens were tested when the concrete was 30 days old.

Electrical resistance strain gages were mounted on steel angles and battens as shown in Figure 2 to monitor the stress along the steel angles and different battens. LVDTs were placed on both sides of column to measure total deformation of the columns. The load was applied with a controlled displacement rate of 0.3 mm/min.

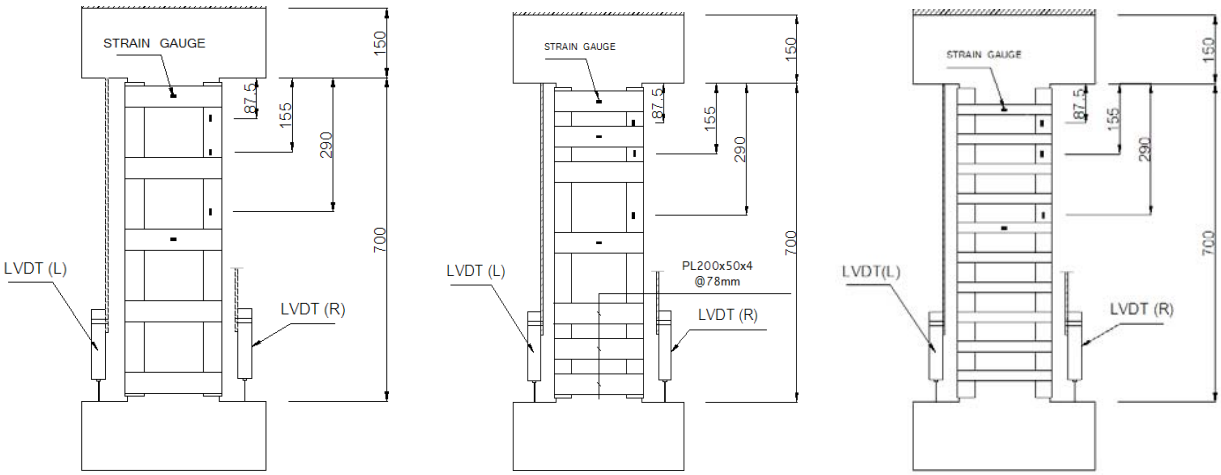
3. RESULTS AND DISCUSSION

3.1. General behavior

All strengthened columns showed notable increase in ultimate load, as well as ductility as shown in Table 1 and Figure 4. The failure of strengthened columns began with having small cracks on concrete surfaces that were not covered by steel angles. This level of load was higher than the ultimate load of the control column. With increasing load toward failure, cracks were concentrated around the steel angle ends (below column heads) and the concrete expanded. The expansion of concrete was partly confined by the steel battens until they were slightly bent. The failure of columns took place when any of the steel angles started to buckle then the concrete spalled off. This type of failure gives warning signs to occupants of the building if it is over loaded.

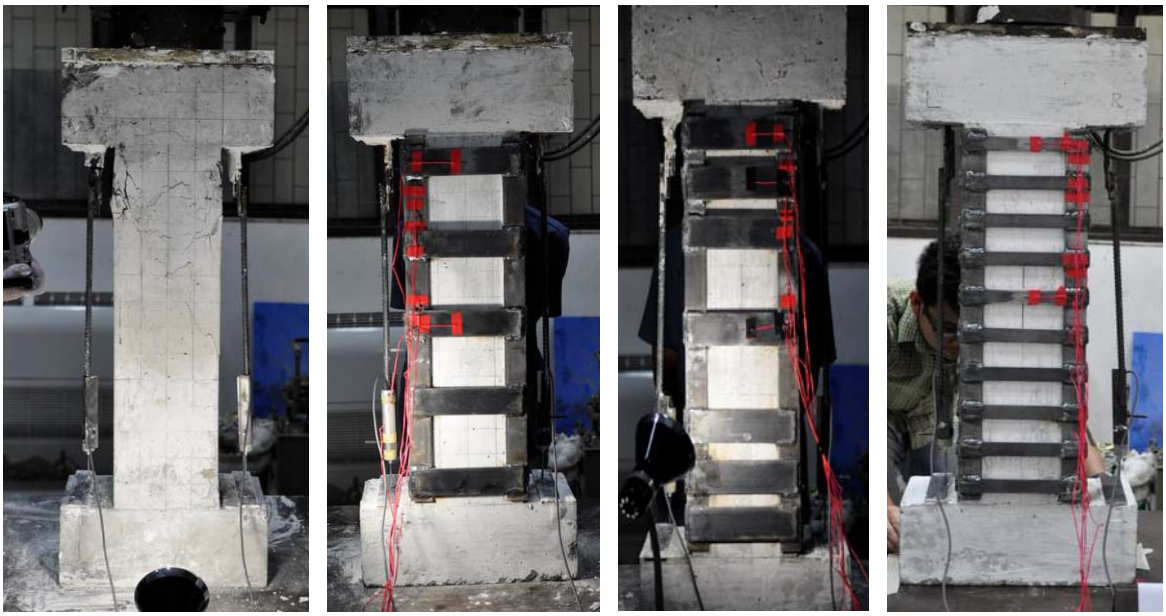
Specimens A and C were compared to the design recommendations (Cirtek 2001), the ultimate loads obtained from the tests were notably higher than the prediction. Specimen B was not taken into comparison as extra steel battens around column ends were presented and could not be considered in the design recommendation. It should be noted that the design recommendation only

consider effects of confinement provided by steel angles and neglecting axial load carried by steel angles.



a) Specimen A b) Specimen B c) Specimen C

Figure 2 Details of strengthening



(a) Control column (b) Specimen A (c) Specimen B (d) Specimen C

Figure 3 Reinforced concrete columns

3.2. Distribution of axial load between steel and concrete

Figure 5 shows the strain measured in the steel angles and battens compared with normalized load (N/N_{max}) with respect to ultimate load (N_{max}). It was found that compressive stress at the mid length of steel angles was higher and was gradually reduced toward its ends. Stress in the steel angle was initiated by shortening of concrete and bonding agents between the steel angles and concrete. The composite action of column and steel angles was not fully developed. For specimens A and C, the

distributions of compressive stress over the length of steel angles of two specimens were similar. However, for specimen B, the transfer of shear between steel angle and concrete core appeared to be better, as the stress in steel angle at L/4 was higher compared to specimens A and C. Nevertheless, the composite action of column and steel angles was not fully formulated, partly because the development of length between steel angles and concrete may not be sufficient. For longer steel angles, the transfer of shear could be better and might allow composite action to be fully developed.

Table 1 Load carrying capacity of columns

Specimen	*Prediction (kN)*	*Ultimate Load, N_{max} (kN)*	*ΔN (kN)*
Control	573	607	
A	727*	1035	428
B	N/A	1066	459
C	750*	1031	424

Remark: * Cirtek 2001

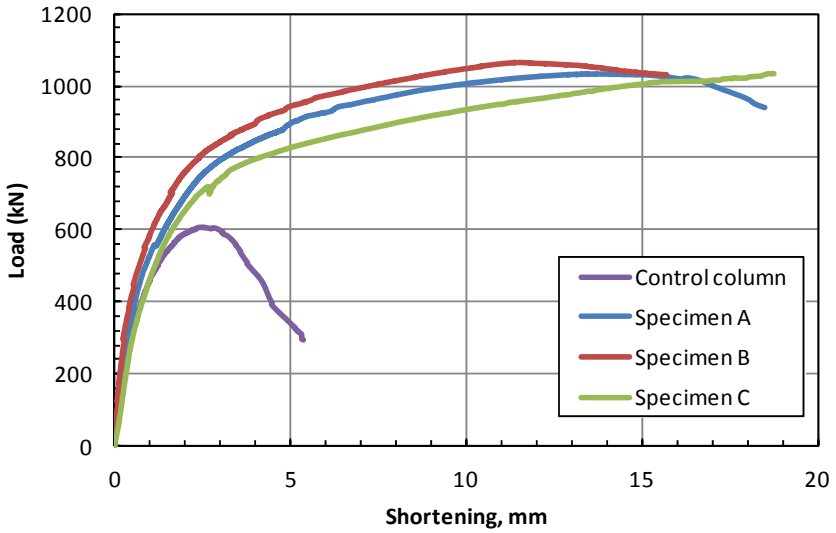


Figure 4 Load shortening curve for all columns

3.3. Steel batten arrangements

Specimen A and specimen C, in which both specimens posses same amounts of steel batten/length were compared. However, wider battens were used in specimen A with wider spacing, while narrower battens were used in specimen C with closer spacing. It was found that prior to the first crack, strain in steel battens did not show any significant difference. However, beyond the first crack, specimen C tended to have higher shortening and expansion. This could be attributed to the size of batten closed to column ends. Wider battens in specimen A provide better confinement, which was more dominated around the column ends. Similar behavior was observed in specimen B, which the extra steel battens were added to column ends.

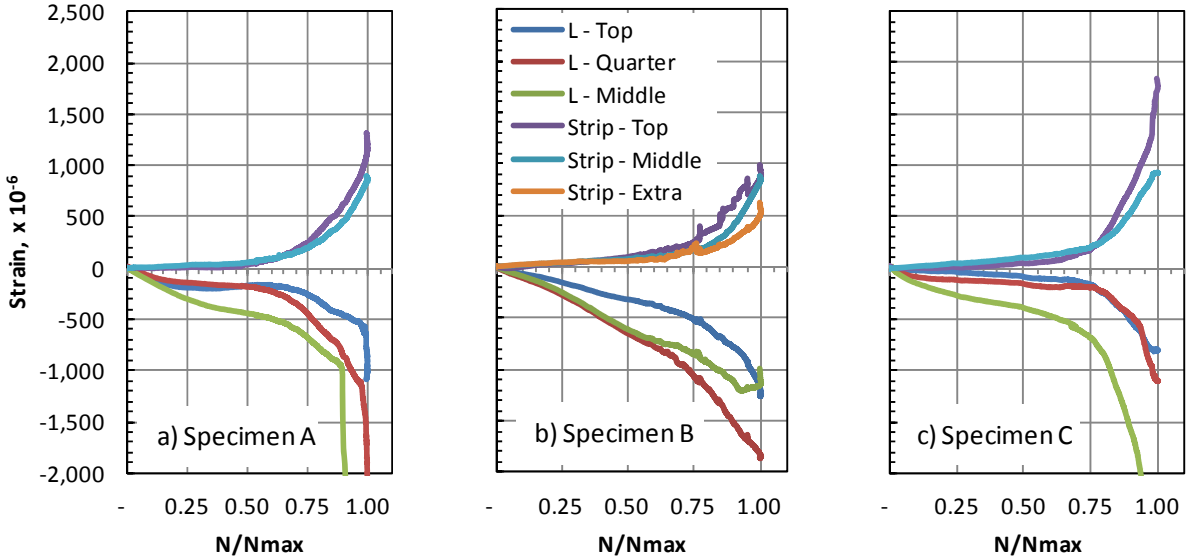


Figure 5 Strain value measured in angles and battens

4. CONCLUSIONS

Encasing the deficient reinforced concrete column with steel angles and battens could significantly improve strength and ductility. It was found that both confinement and composite action contributes to the gaining of strength. Near column ends, confinement played a larger role in improving the strength of the column as axial force developed in low steel angle. Action of composite section is more dominant as the transfer length increases.

REFERENCES

Adam JM, Ivorra S, Pallares FJ, Gimenez E, and Calderon PA (2009). Axially loaded RC columns strengthened by steel caging: finite element modeling. Construction and Building Materials. 23, pp. 2265-2276.

Badalamenti V, Campione G, and Mangiavillano ML (2010). Simplified model for compressive behavior of concrete columns strengthened by steel angles and strips. Journal of Engineering Mechanics. 136(2), pp. 230-238.

Campione G (2012). Load carrying capacity of RC compressed columns strengthened with steel angles and strips. Engineering Structures. 40, pp. 457-465.

Cirtek L (2001). RC columns strengthened with bandage – experimental programme and design recommendations. Construction and Building Materials. 12, pp. 341-349.

Giminez E, Adam JM, Ivorra S, Moragues J, and Calderon PA (2009a). Full-scale testing of axially loaded RC columns strengthened by steel angles and strips. Advances in Structural Engineering. 12(2), pp. 169-181.

Giminez E, Adam JM, Ivorra S, Moragues J, and Calderon PA (2009b). Influence of strips configuration on the behavior of axially loaded RC columns strengthened by steel angles and strips. Material and Design. 30, pp. 4103-4111.

Ramirez, JL (1996). Ten concrete column repair methods. Construction and Building Materials. 10(3), pp. 195-202.

Wu YF, Liu T, and Oehlers DJ (2006). Fundamental principles that govern retrofitting of reinforced concrete columns by steel and FRP jacketing. Advances in Structural Engineering. 9(4), pp. 507-533.