# Reinforced Concrete Columns Confined with Prestressed Steel Straps under Axial Loading

Sayan Sirimontree[1], Suraparb Keawsawasvong[1], and Chanachai Thongchom[1*]

[1] *Department of Civil Engineering, Thammasat School of Engineering, Thammasat University, Pathumthani 12120, Thailand*
[*] *Corresponding author. E-mail: Tchanach@engr.tu.ac.th*

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This paper presents an experimental study on reinforced concrete columns strengthened with prestressed steel straps. A total of five specimens is constructed. A cross-section of all specimens is 150x150 millimeters. A height of all specimens is 1.20 meters. A studied variable is a spacing of steel straps, which are 150 and 75 millimeters. All columns are subjected to a compressive force without an eccentric load. The experimental data is recorded in the term of the load-deformation relationships, and also modes of failure. Based on the experimental data, the reinforced concrete column strengthened with steel straps can enhance the axial load bearing capacity by 30 to 33 percent and can increase the ductility by 71 to 118 percent. A spacing of steel straps has no significant influence on an axial load bearing capacity, but it affects the ductility when compared to the control specimen.

**Keywords:** Column, Steel strap, Confinement, Reinforced concrete, Strengthening.

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## 1. Introduction

Strengthening/repair is an effective alternative way to increase the load-bearing capacity and ductility of reinforced concrete structures. There are several ways to strengthen the reinforced concrete structures such as ferrocement [1–5], fiber-reinforced polymer (FRP) materials [6–19], steel jacket, or steel angle/strips [20–22], etc. As pointed out by several researchers, the strengthening methods can enhance the stiffness, load-carrying capacity, or ductility of structures. Strengthening of reinforced concrete columns with ferrocement was studies by researchers [1–5]. Many previous works regarding the use of FRP wraps to strengthen columns have been carried out [6–14]. Compared to steel, the advantage of the fiber-reinforced polymer is lightweight, high tensile strength, and high corrosion resistance. However, the disadvantage of fiber-reinforced polymer is high initial cost and low fire resistance.

For the steel straps material, it can easily find and install by compared to those of FRP. This technique do not require technicians in the installation processrs. This paper presents an experimental study on reinforced concrete columns confined with prestressed steel straps. A total of five reinforced concrete rectangular columns are carried out. The columns are confined with prestressed steel straps with different spacing (150 and 75 millimeters). All columns are tested under static load. The load-displacement relationship and modes of failure are depicted and discussed in the paper.

## 2. Experimental program

### 2.1. Tested specimens

A total of five reinforced concrete columns were cast to investigate the effect of the steel strap. All specimens had the same dimensions. The cross-section of all columns was 150×150 millimeters and the high was 1.20 meter. The columns were reinforced with four longitudinal bars with the diameter of 12 millimeters (DB12) and transverse bars with the diameter of 6 millimeters (RB6) that had a spacing of 150 millimeters. The concrete covering was 20 millimeters. Two specimens were set as control specimens (without steel straps). The other three reinforced concrete columns were confined with steel straps. Two of them (CS-150(A) and CS-150(B)) were confined with steel straps that had a spacing of 150 millimeters. In order to observe the spacing of the steel straps effect, one specimen (CS-75) was confined with steel straps which had a spacing of 75 millimeters. Fig.

1 shows the details of the tested specimens.

### 2.2. Material properties

In this study, the average compressive strength at 28 days was 23 MPa. Two diameters of steel reinforcement were used. The measured yield strength and the ultimate strength of 12-mm diameter (deformed bar) were 586 and 717 MPa, respectively. The measured yield strength and ultimate strength of 6-mm diameter (round bar) were 423 and 538 MPa, respectively. For the steel strap, the width and thickness were 19 and 0.8 millimeters, respectively. The measured yield strength and ultimate strength of the steel strap were 466 and 520 MPa, respectively.

### 2.3. Specimen preparation

All specimens were cast in the same concrete batch. After 24 hours, all specimens were demolded and then were cured using plastic wrap. After 28 days, the specimens (CS-150(A), CS-150(B), and CS-75) were confined with prestressed steel straps with a designed spacing of 150 or 75 millimeters. A steel strap was prestressed using a steel strap hand tool. The elongation of steel straps was about 2.0 millimeters (about 4.2 kN). After that, the steel grip was used to lock the steel strap. Fig. 2 shows a steel strap and a steel strap hand tool.

### 2.4. Test setup and instrumentation

Fig. 3 shows a typical test setup of all tested specimens. The load cell with a capacity of 5000 kN was used. To measure displacements in the vertical direction, two linear variable differential transformers (i.e., LVDT1 and LVDT2) were set up at two opposite sides of the specimen (see Fig. 3). To ensure a uniform loading taking place at both top and bottom of the specimen, a capping was used. The axial load was applied to the top of the specimen. The axial load and displacements were automatically recorded until the specimen failed. The modes of failure were observed.

## 3. Experimental results and discussion

### 3.1. Load and displacement relationships

Fig. 4 shows the relationships of load and displacement for all tested specimens. The maximum loads and the corresponding deflections of all specimens are summarized in Table 1.

Columns CC(A) and CC(B) were the control columns (without steel straps). The maximum load of columns CC(A) and CC(B) were 600 and 630 kN (average of 615 kN), respectively. The axial displacements corresponding to the maximum load of columns CC(A) and CC(B) were 2.22 and 2.46 millimeters (average of 2.34 millimeters), respectively.

For confined specimens, columns CS-150(A) and CS-150(B) were confined with steel straps that had a spacing of 150 millimeters. The maximum load of columns CS-150(A) and CS-150(B) were 780 and 820 kN (average of 800 kN), respectively. The axial displacement corresponding to the maximum load of columns CS-150(A) and CS-150(B) were 4.23 and 3.76 millimeters (average of 4.00 millimeters), respectively.

Column CS-75 was confined with steel straps that had a spacing of 75 millimeters. The maximum load and the corresponding axial displacements were 720 kN and 5.11 millimeters, respectively.

Based on the test results, the reinforced concrete confined with steel straps with a spacing of 150 and 75 millimeters can increase the maximum load by 30 and 33 percent, respectively when compared to the control columns. The maximum axial the displacement at the failure of reinforced concrete confined with steel straps with a spacing of 150 and 75 millimeters can also increase 71 and 118 percent, respectively.

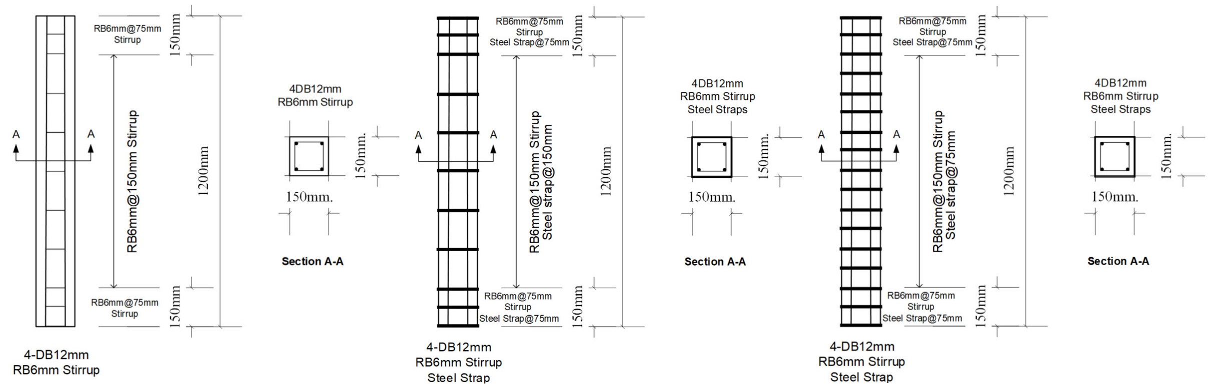
### 3.2. Failure modes

Fig. 5 shows the failure modes of columns. For unstrengthened column (Specimens CC(A) and CC(B)), the specimens failed by concrete crushing near the top of the specimen and then propagated towards the middle of the specimen, as shown in Fig. 5a and Fig. 5b, respectively. Due to the spalling of concrete covering, the bucking of the longitudinal steel bar (DB12) was observed (see. Fig 5).

For the confined column, the failure modes of reinforced concrete confined with steel straps with a spacing of 150 millimeters CS-150(A) and CS-150(B) are shown in Figs. 6a and 6b, respectively. Fig. 7 shows the failure mode of reinforced concrete confined with steel straps that had a spacing of 75 millimeters (Specimen CS-75). For confined columns, the rupture of one steel strap was found at the biggest crack at the center of the specimen. Consequently, the axial load dropped. Finally, the concrete was gradually crushed at the center of the specimen.

## 4. Conclusion

In this study, the behavior of reinforced concrete columns confined with steel straps was investigated. A total of five specimens was constructed. The cross-section of all specimens was 150×150 mm and the high was 1.2 meter. The effect of the steel strap spacing (150 and 75 millimeters) was investigated. Based on the experimental results, the conclusions can be drawn as:




**(a)** Specimen CC **(b)** Specimen CS-150 **(c)** Specimen CS-75

**Fig. 1.** Details of tested columns.

**Table 1.** Summary of the experimental results.

| Column | The spacing of steel strap (millimeter) | Maximum load (kN) | The displacement* (millimeter) |
|---|---|---|---|
| CC(A) | - | 600 | 2.22 |
| CC(B) | - | 630 | 2.46 |
| CS-150(A) | 150 | 780 | 4.23 |
| CS-150(B) | 150 | 820 | 3.76 |
| CS-75 | 75 | 820 | 5.77 |

* The deflection corresponding to the maximum load

**Fig. 2.** Steel strap (left) and steel strap hand tool (right) [23].

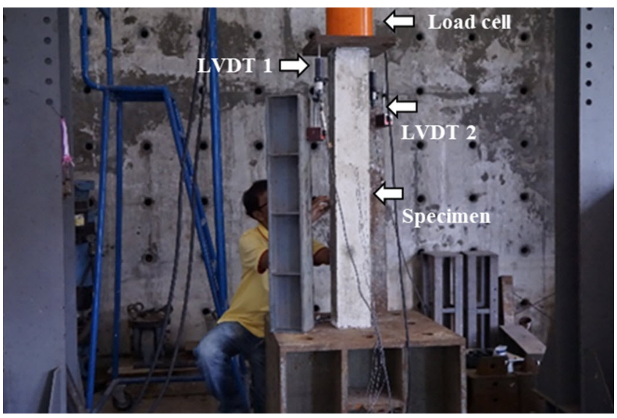



**Fig. 3.** Typical test setup.

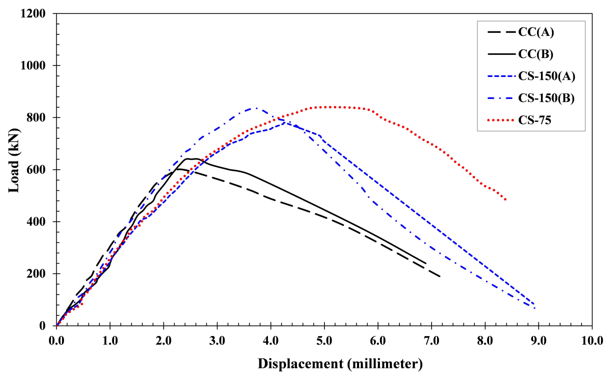



**Fig. 4.** Load-displacement relationships of specimens.

- The reinforced concrete columns confined with steel straps increased the maximum load-carrying capacity by 30 to 33 percent by compared to the control columns. The spacing of steel straps did not have a significant effect on the maximum load-carrying capacity.

- The reinforced concrete confined with steel straps increased the ductility by 71 to 118 percent by compared to the control column. The spacing of steel straps has a significant effect on the ductility of the column.

**(a)** Specimen CC(A) **(b)** Specimen CC(B)

**Fig. 5.** Mode of failure for specimen CC.

**(a)** Specimen CS-150(A) **(b)** Specimen CS-150(B)

**Fig. 6.** Mode of failure for specimen CS-150.

**Fig. 7.** Mode of failure for specimen CS-75.

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