

DISCRETE CONFINEMENT BY METAL SHEET STRIPS ON CONCRETE COLUMNS UNDER AXIAL COMPRESSION

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ABSTRACT: This paper investigated the axial compressive strength of concrete columns discretely confined with metal sheet strips. Totally 54 cylindrical columns, in size of 15 cm in diameter and 75 cm in height, with various patterns of sheet confinement, were experimentally studied under uniaxial compression. The varying factors included the width of metal sheet strips, number of used strips, and number of applied layers. The experimental results revealed that axial strength could be improved by means of discrete confinement depending on the amount of applied metal sheet in terms of confinement area and confinement volume. The uniaxial compressive response was improved both in terms of strength and ductility when more strips and/or more layers of the metal sheet were applied. Compared to the full confinement using one piece of metal sheet, the discretely confined columns did not show any local failure or wrinkles of the metal sheet before failure. The wrinkles associated with bi-axial action in metal sheet was shown to be relieved with the discrete confinement technique. The failure mode of discretely confined columns in this study started with the rupture of the metal sheet jacket and was followed by the crushing of the inner core concrete. The equation of gained confinement effectiveness and effective confining stress of the studied columns were compared with the recent numerical study.

Keywords: Strengthening, Concrete column, Metal sheet, Discrete confinement

1. INTRODUCTION

Axial strengthening of concrete columns can be achieved by many techniques. The most popular techniques at present, in addition to the section enlargement technique (or concrete jacketing), include use of high-tensile strength, durable, thin and light-weighted materials such as fiber reinforced plastics (FRP). By confinement effect, application of FRP wrapping was found to improve axial strength as well as ductility of the strengthened concrete columns, when applied as full wrapping [1, 2] or partial wrapping [3]. The increased strength depended largely on the volume of the FRP confinement, although it did not linearly vary with the confinement effectiveness [3]. So far, it was also found in many types of research that confinement effectiveness of the FRP strengthening system depended on many factors, including column shape, fiber type, number of plies, ply orientation, strength of the core concrete/ the FRP/ the bonding materials, slenderness ratio, and etc. [1, 4-10] Many predicted equations were proposed [11-15] and numerical models were developed [16-19]. With many considerations, the FRP strengthening system required engineering expertise in production, design, installation and maintenance processes.

In recent years, an emerging research at Khon Kaen University laboratory has been explored to evaluate the potential of using the metal sheet as an alternative strengthening material. The metal sheet

has been chosen as an alternative material to the FRP because it possesses many properties similar to the FRP, while the material is available almost everywhere in Thailand. The metal sheet has high tensile strength, comparable to conventional construction steel. It is also thin and light-weighted, and rust resistant on its galvanized surface. Yet, the material had never been applied as a strengthening material to concrete members. So far, there have been some investigations in applying metal sheet in the axial strengthening of concrete columns [20-27]. It was found that confining the concrete columns using a metal sheet with epoxy resin (as the bonding material) could increase the load carrying capacity of the concrete specimens when a sufficient amount of metal sheet was applied. Ductility of the metal sheet confined specimens was also obviously increased. However, due to its rigidity in the axial direction, the metal sheet confinement mechanism was found to be much more complicated than the mechanism observed in the use of FRP. It was observed in [22-23] that some wrinkles appeared in the metal sheet jacket prior to failure of the specimens. (See Figure 1, for example). The wrinkles were attributed to the biaxial action of metal sheet jacket which did not only resist the lateral expansion of core concrete but also axially deformed under uniaxial compression. In addition, the wrinkle associated with the full wrapping of confined concrete raised skepticism regarding possible imperfections of bonding between the

concrete and the metal sheet and/or between the metal sheet layers. Furthermore, applying one large full metal sheet as in the case of full wrapping for the whole column may not be deemed practical considering factors such as installation time, amount of the required bonding material in order to achieve sufficient interfacial bonding condition, etc. Possibility for promoting metal sheet as an alternative confining material for concrete columns thus depends on the credibility of metal sheet installation technique itself.



Fig. 1 Wrinkle of a metal sheet for fully wrapped confined concrete.

In this paper, axial compression of the concrete columns confined by means of discrete metal-sheet strips is explored. A technique with a series of discrete metal sheet strips, instead of a single full piece of sheet with full column size, is presented. The objective is to ease metal sheet installation process for the strengthening of concrete columns and allow for improvement of confinement quality. Samples of concrete columns with the stripwise system were experimentally studied for improved axial load capacity.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Three materials were used in this study; concrete, metal sheet, and epoxy resin. The average compressive strength of concrete (f_c') was 32.5 MPa at 28 days. The galvanized metal sheet used in this study was 0.23 mm thick, with yield strength and tensile strength of 550 and 760.5 MPa respectively. The epoxy resin, Sikadur®- 31 CF Normal, was used as the bonding material between the concrete and the metal sheet, and also if applicable between layers of the metal sheet.

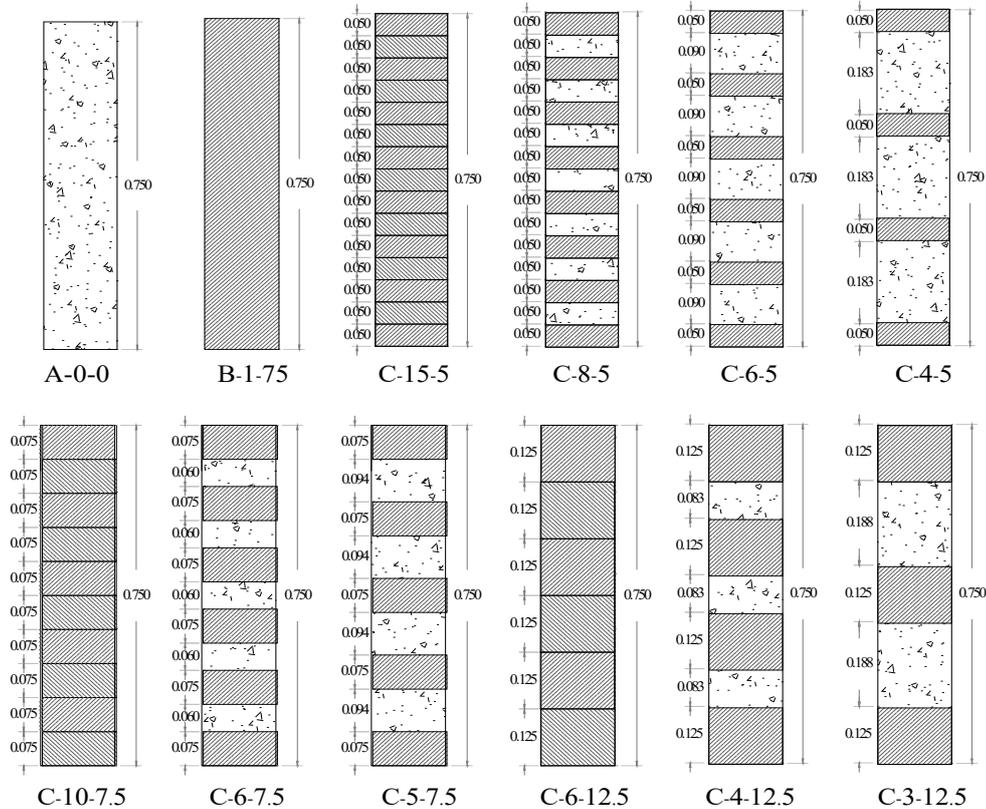


Fig. 2 The test columns.

2.2 Detailed patterns of strip confinement

In total, 18 combinations of unreinforced plain concrete columns were designed with different metal strip patterns. Each combination consists of 3 samples, therefore, the experimental program comprised in total 54 concrete columns in the present study. All concrete columns were prismatic, with a circular cross section of 15 cm diameter and 75 cm height. They were categorized into three groups. Group A represented unconfined concrete columns (denoted as A-0-0) whereas concrete columns in Group B were fully wrapped with one large piece of full metal sheet (denoted as B-1-75). In Group C, the rest of 16 confined concrete were the samples with various metal sheet strip arrangements (denoted as C-x-y, where x was the number of strips used and y was the strip width). Without any subscript in the symbol, only one layer of metal sheet was applied in the confined columns. The subscript, if noted, indicated that more than one metal sheet layer was applied, with the number of layers as subscripted. Configurations of the test specimens were shown in Figure 2, where the corresponding details were given in Table 1. The variables b_f , S_f widththe stand for A_f , % V_f , % of the discrete metal sheet strip, the clear spacing between metal sheet strip, the percentage of confining volume and the percentage of confining area, respectively.

To apply metal sheet confinement to a column, it was necessary to make sure that the surface of the column was dry and clean. In this study, epoxy resin was applied throughout each piece of metal sheet. The overlapping part was designed to be one-quarter of the perimeter of the column. The test specimens were loaded in the axial direction using the universal testing machine and were displacement controlled. Avoiding information at the column ends, the compressometer was used with a setting of 50-cm gauge length at the middle part for measuring the axial strains of concrete columns during the loading. Additionally, a set of strain gauges was attached on the outer layer of each metal sheet strip to record both lateral strain and axial strain of each metal strip as shown in Figure 3.

3. RESULTS

From the experiment, axial compressive strengths (f'_{cc}) of all specimens were collected in Table 1. The results could be compared using confinement effectiveness defined as a ratio of ultimate compressive strengths of the confined and the unconfined concrete columns (f'_{cc}/f'_{co}).

3.1 Fully Confined Concrete Columns

Compared with the unconfined specimens (column A-0-0), the strength of fully confined columns with a large piece of full metal sheet wrapping (column B-1-75) gained approximately 23% higher, i.e. the confinement effectiveness was 1.23. Prior to structural failure under axial compression, it was found that the column B-1-75 was associated with some wrinkles at metal sheet jacket. The metal sheet jacket subsequently ruptured and led to the failure of column B-1-75 as shown in Figure 4. This onset of wrinkles was triggered by local yielding of the sheet jacket under axial loading [27]. Similar to the concept of classical buckling, the wrinkling effect is considered to be affected by the effective length of metal sheet jacket.

As the local buckling was expected to be lessened when applying the metal sheet strips instead of one large continuous piece, the other idea was to discretely confine column by using metal sheet strips instead of using one piece of metal sheet to cover the full height of the columns. A set of the columns discretely confined with a series of smaller strips laid adjacent to each other (without any spacing) was then conducted for comparison with the one-piece metal sheet. Similarly, both patterns of metal sheet application gave a full confinement to the columns with the same amount of metal sheet. Three sizes of metal sheet strips were selected, including 5-cm, 7.5-cm and 12.5-cm wide, which were denoted as C-15-5, C-10-7.5, and C-6-12.5, respectively.

The three sets of columns failed after the metal sheet rupture and no wrinkle of metal sheet jacket was observed as shown in Figure 5. It was found that confinement effectiveness of discretely confined samples were 1.38, 1.36 and 1.44 for the 5 cm, 7.5 cm, 12.5 cm strip sizes, respectively. These values were better than the case of using the one-piece full-length metal sheet. It was found that using strips instead of one large piece also facilitated the installation process and better quality control of the bonding part could be expected.



Fig. 3 The experimental instruments and setting.

Table 1 Details of the concrete columns in this study and the corresponding axial strengths.

Column	Number of strips	Number of layers	b_f (cm)	s_f (cm)	V_f %	A_f %	f'_{cc} [MPa]	Remarks
A-0-0	0	1	0	n/a		0	32.5	Unconfined sample
B-1-75	1	1	75	n/a	0.613	100	39.8	Full confinement by a single full-column sized metal sheet
C-15-5	15	1	5	0	0.613	100	44.8	Discrete confinement by metal sheet strips
C-8-5	8	1	5	5	0.327	53.33	37.7	
C-6-5	6	1	5	9	0.245	40	36.3	
C-4-5	4	1	5	18.3	0.164	26.67	33.5	
C-10-7.5	10	1	7.5	0	0.613	100	44.3	
C-6-7.5	6	1	7.5	6	0.368	60	38.3	
C-5-7.5	5	1	7.5	9.4	0.307	50	32.9	
C-6-12.5	6	1	12.5	0	0.613	100	46.8	
C-4-12.5	4	1	12.5	8.3	0.409	66.67	42.5	
C-3-12.5	3	1	12.5	18.8	0.307	50	29.6	
C ₂ -8-5	8	2	5	5	0.654	53.33	41.0	
C ₃ -8-5	8	3	5	5	0.981	53.33	44.5	
C ₂ -6-7.5	6	2	7.5	6	0.736	60	44.7	
C ₃ -6-7.5	6	3	7.5	6	1.104	60	47.7	
C ₂ -4-12.5	4	2	12.5	8.3	0.818	66.67	46.8	
C ₃ -4-12.5	4	3	12.5	8.3	1.227	66.67	49.5	



Fig. 4 Failure of the column confined with a one-piece full-wrap metal sheet (B-1-75).



Fig. 5 Failure of the column discretely confined (C-10-7.5) with metal sheet strips.

Figure 6 shows the axial stress-strain relation of fully confined concrete columns. It could be seen that the metal sheet confinement helped increasing

not only the axial strength of the columns but also ductility. Applying discrete metal sheet strips instead of one continuous piece to wrap the whole column could provide higher strength increases and slightly more ductile behaviors for the case of fully confined concrete. Very close response was observed in the specimens with 5-cm and 7.5-cm strip sizes.

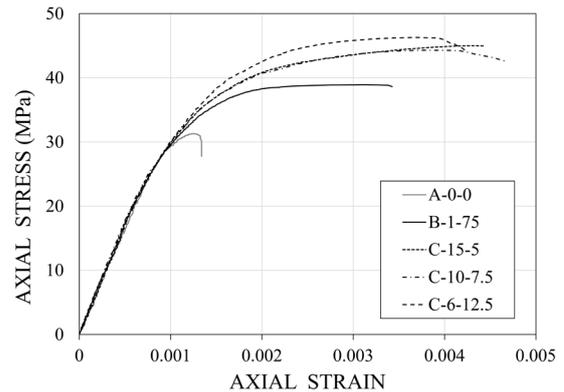


Fig. 6 Axial stress-axial strain relations of the fully confined concrete columns.

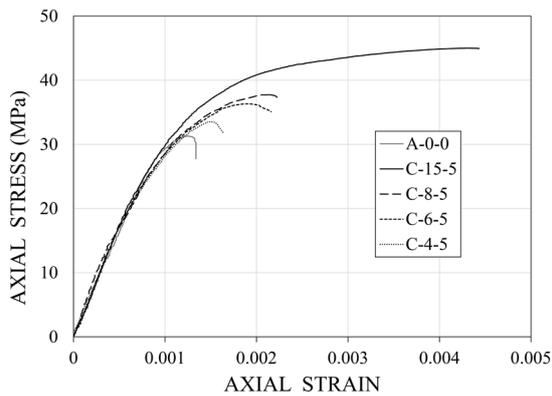
3.2 Partially Confined Concrete Columns

An additional experiment was set to evaluate the benefit of discrete confinement for the case of partially confined concrete columns. Effect of confinement area on the confined compressive strength of the columns was investigated using one-

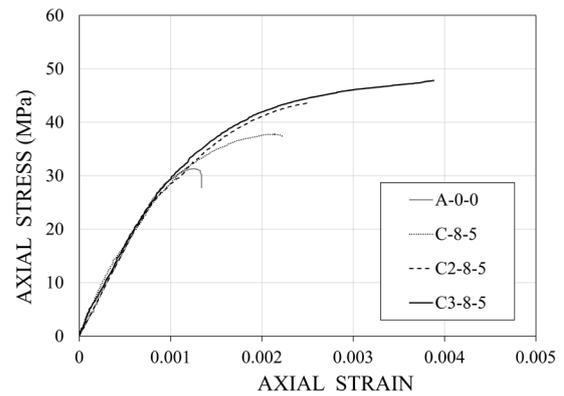
layer metal sheet application. Columns with one layer application of 5-cm, 7.5-cm and 12.5-cm strips showed similar trends. Relationships between the axial stresses and the axial strains were plotted in Figure 7.

Effect of confinement volume on axial strength increase could be studied by mean of varying layers for the applied metal sheet for each strip size. For

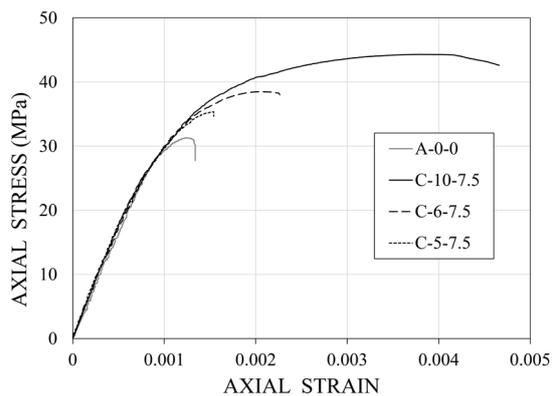
this part of the study, strips were kept fixed in their specific positions, while a number of layers was varied from one to three. The results in Figure 8 showed that the axial strength of the concrete columns increased when adding a number of applied layers.



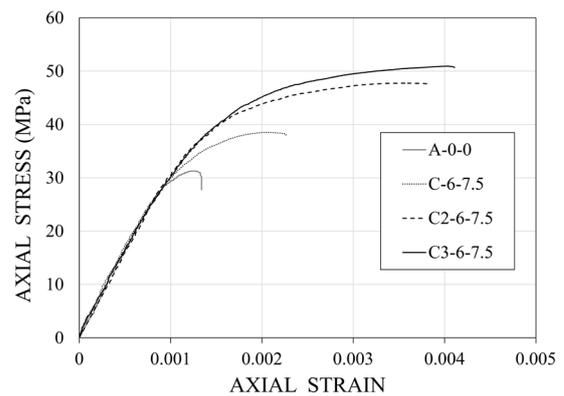
a) $b_f = 5$ cm



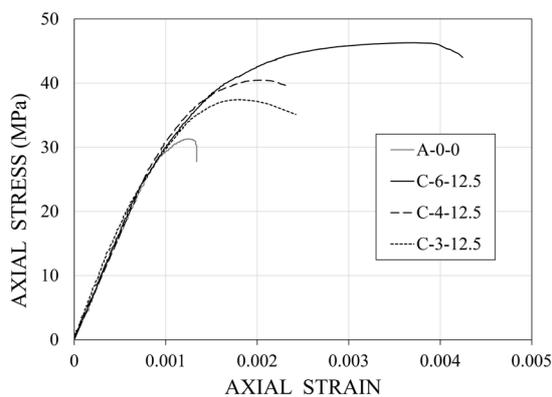
a) $b_f = 5$ cm



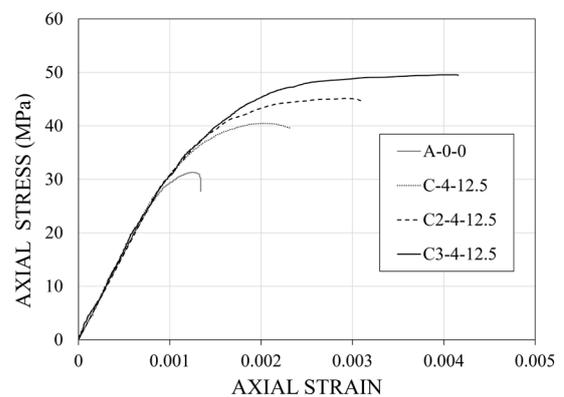
b) $b_f = 7.5$ cm



b) $b_f = 7.5$ cm



c) $b_f = 12.5$ cm



c) $b_f = 12.5$ cm

Fig. 7 Axial stress-strain relation of the partially confined concrete columns with varying confinement area.

Fig. 8 Axial stress-strain relation of the partially confined concrete columns with varying confinement volume.

It could be seen that, with higher confinement area or volume of metal sheet strips, the confined columns were improved in term of axial strength as well as ductility. All samples failed after rupture of the metal sheet strips located in the mid-height zone of the samples as shown in Figure 9. The failure in concrete and metal sheet could be observed, as shown similar to what appeared in Figure 9, i.e., all of the confined specimens failed by initiation of the metal sheet rupture and followed by crushing of the inner concrete. No opening of the overlapped ends of the metal sheet jacket was noticed. It was observed that appearance of wrinkles across the loading direction disappeared for the strip-type confined specimens. All samples failed after the rupture of metal sheet strip located in the mid-height zone of the samples.



Fig. 9 Failure of the partially confined column with metal sheet strips (C-4-12.5).

3.3 Effective Confining Stress

Under a force equilibrium condition as illustrated in Figure 10 for discrete confinement, the confining force in the concrete P_c and the tensile force carried by the metal sheet P_m can be written as:

$$P_c = P_m \quad (1)$$

Given f_c the average compressive stress in concrete in the normal direction to the cut plane, $f_{m\theta}$ the tensile stress in metal sheet in the circumferential direction, t_m the metal sheet thickness, D the column diameter, n number of the metal sheet layers, b the metal sheet strip width, and s' the strip clear spacing measured from edge of particular strip to edge of consecutive strip, the resultant compressive force in concrete can be computed from:

$$P_c = f_c(b + s')D \quad (2)$$

and the tensile force carried by metal sheet can be computed from:

$$P_m = 2f_{m\theta}ntb \quad (3)$$

Substituting Eq. (2) and Eq. (3) in Eq. (1), we get:

$$f_c = \frac{2f_{m\theta}ntb}{D(b + s')} \quad (4)$$

Here, f_c is seen as the average effective confining stress (f_i) of discrete confinement system.

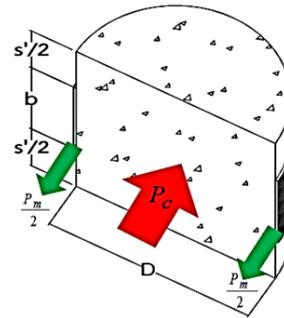


Fig. 10 Forces in concrete and in a strip of the metal sheet during loading.

From the experiment, strains were measured in metal sheet jacket at dominant strips around mid-height of columns at the time of peak load and at the time of failure. Circumferential and axial stress in metal sheet jacket were checked. The averaged stress occurred in a strip was still shown to be elastic at the time of peak load and subsequently developed to be inelastic prior to rupture of metal sheet jacket at the failure. Based on the circumferential stress induced in each metal sheet strip, effective confining stress induced in discretely confined concrete columns could be derived at the time of peak load, hence, peak effective confining stress by using Eq. (4). With the series of columns in this study, it was found that the circumferential stress induced in the metal sheet at the peak load ranged from 0.4 to 0.6 times the specified yield strength of the metal sheet. This was in a good agreement with the result from the recent computational study of the discretely confined columns [25, 26], in which the bi-axial action in the metal sheet strips was numerically investigated for the metal sheet confined concrete columns. The average value of the circumferential stress was adopted for the determination of effective confining stress (f_i) following Eq. (4).

For the discretely confined columns, the confinement effectiveness obtained from this experimental study could be related to confinement

ratio (f_1/f'_{co}) as shown in Figure 11. The best-fit correlation of the tested columns in this study was shown to be in a quadratic relation. It was seen that the confinement was much more effective when using metal sheet strips of a larger width.

In Figure 12, the derived relation of confinement effectiveness from this experimental study was also compared with the finite element results of the discretely confined columns of the similar dimensions and properties [26]. The different response observed by columns in this study might be caused by possible stress hardening of the metal sheet strips in which its effect was neglected in the past numerical study.

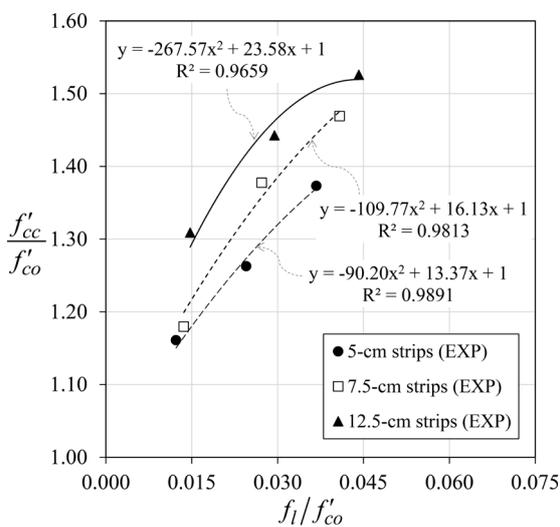


Fig. 11 Relation of confinement effectiveness and confinement ratio from this experimental study.

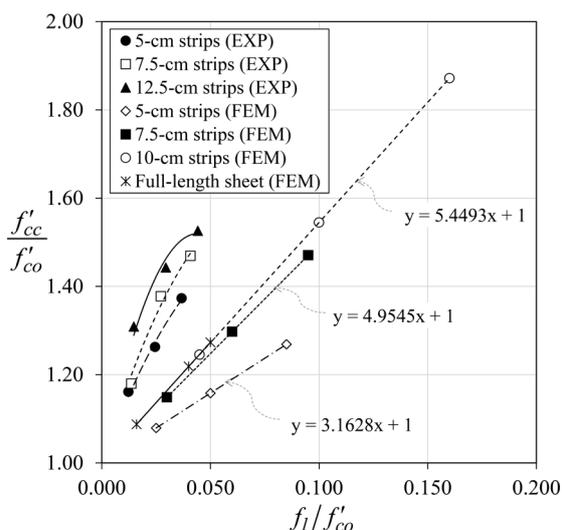


Fig. 12 Comparison of gained confinement effectiveness with the past numerical study [26].

4. CONCLUSIONS

In this study, strengthening of concrete columns by metal sheet with discrete confinement technique was investigated. It was found that the strengthened columns showed enhanced axial compressive strength and ductility, depending on the applied area of confinement and the number of layers. Using strips could increase more axial capacity in term of strength and ductility, and the wrinkle effect which was normally found in the one-piece full wrap system was not observed in the strip-type confinement. The failure mode of the discretely confined columns in this study started with the rupture of metal sheet jacket and followed by the crushing of inner core concrete. Compared to the recent numerical study, the confinement equation obtained by the experimental results provided higher axial strength prediction at the same effective confining stress.

5. ACKNOWLEDGEMENTS

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