Potential of new innovative confinement for square reinforced concrete columns

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Abstract. The most popular shape of column section used in reinforced concrete buildings is square or rectangle. Besides longitudinal bars, it is normally reinforced with traditional rectilinear or square shape of transverse steel (stirrups) or confinement. It is well known that circular spiral of reinforcing bars used in circular columns serve better ductility or performance compared to rectilinear stirrups in rectangular columns. Up to present, the use of spiral is limited only to circular columns. This is because for rectangular or square columns, it is not easy to shape the spiral on site during construction. The study focuses on the potential application of new innovative rectilinear or square spiral when used for rectangular or square concrete columns. The result of the study is that the proposed new innovative confinement which introduces the use of rectilinear or square spiral without any discontinuity or seismic hooks like those in the stirrups, as well as the introduction of interlocking system has successfully improved the ductility and performance of the columns. With this new innovative confinement, the confined core area is increased, the congestion can be avoided (no seismic hooks), and effectiveness of confining influence is improved (overlapped confining area through interlocking system).

1. Introduction

Indonesia is a country that is prone to earthquakes. Because there are several continental plates, besides having active land faults. This is a challenge for structural engineer to anticipate damage to building structures as an earthquake effect. As an example the last case is an earthquake that occurred in Lombok – Nusa Tenggara Barat and Donggala - West Sulawesi.

Several cases of structural damage due to the earthquake caused by the inability of building columns to accept loads, especially earthquake loads as cyclic load. This is the background of the need for the concept of "strong columns - weak beams" where the column must have a strength of 20% greater than the beam structure. The strength of the column is not only determined by the dimensions of the cross section, the number of main reinforcement or quality used, but the confinement system in the column which serves to confinement the core stress of the concrete and shear force is a factor that influences the strength of the column itself. However, in reality, the confinement system is not getting serious attention.

Until now, the shape of the column section found in designing and construction is square and circle in the shape of confinement that follow the cross section of the column with a circular hook or spiral system. However, the cross-sectional shape that is chosen is in the shape of a square with easy consideration to be made and implemented even though the circular shape has better artistic value and
cross-section stability. However, there is some evidence that the failure of square section reinforced concrete columns with hook system is located in the hook area when passing the peak load compared to a circular spiral system that is able to defend itself when receiving peak load [1]. Therefore, square section reinforced concrete columns give an opportunity innovations carried out by engineers to develop and propose a confinement system in the shape of the column.

Several proposals have been done by previous researchers to increase the strength of a square column [2], as in Figure 1. where it utilizes a square column with a confinement system in the shape of hooks to strengthen the center area of the concrete core with a hook amplifier which aims to reduce the curvature of the concrete core [3], such as in Figure 2, where they use the same column shape with different confinement systems. Other studies Yin utilize the shape of a square column but use confinements with various variations as in Figure 3, where [4]: (a) conventional confinements, (b) single reinforcement, (c) fine mesh grid, (d) stirrups with welding systems, (e) hexagonal spiral stirrups, (f) spiral ellipse stirrups, (g) multispiral, (h) spirals with cross reinforcement, (i) Spirals with Cross Strengthener and (j) Spiral Interlocking System.

Several other proposals to improve the performance of reinforced concrete columns are the use of high quality steel for the main reinforcement and confinement [5], the use of fiber steel reinforcement for confined circular columns [6], even the use of welded wire fabric for confine reinforcement [7-12]. Whereas to maintain the performance of reinforced concrete columns after designing and construction proposed external confinement systems using steel angle collars [13].
1.1. Proposed confinement system and potential methodology

Based on the previous researchers' proposals regarding the confinement system in a square column, it provides an opportunity for writers to participate and innovate in the development of a ductile, effective and efficient confinement system. As the first step to do this research is to determine the shape of the column which is a square column, while the confinement system is selected in the shape of conventional (stirrup hook) and circular spiral. Then, the potential analysis of square columns with each of these confinement systems is carried out.

The results of the potential analysis for a square column with a conventional confinement system in the shape of hooks are where the strength lies in the effective core area and corresponds to the column shape. The weakness is that the failure area of the confinement system occurs in the hook area, the concrete core curve is large enough, the buckling in longitudinal reinforcement and requires a long time in its manufacture. The opportunity that can be obtained with this stirrup system is where the square shape has a capacity that can increase column ductility. Whereas the constraints obtained are that with a more effective and efficient confinement system, this system will gradually be abandoned from the concept of designing and construction reinforced concrete structures. So the potential to be considered to be developed in this research is by utilizing the effectiveness of concrete core as an opportunity to increase column capacity, utilizing a confinement shape that corresponds to the shape of the column in order to increase the ductility of the column. By eliminating hook connections in an effort to capture the opportunity to increase the ductility of the column, and reduce the curvature of the concrete core and longitudinal reinforcement in anticipation of reduced column ductility.

While the potential obtained from the analysis of square columns using a spiral confinement system is its strength lies its continuous compactness, reduced curvature of the concrete core and a fast manufacturing process. The weakness of this confinement system is the ineffectiveness of the concrete core area so that the concrete core does not become effective, nor can it adjust to the shape of a square column. The opportunity obtained from this system is its increasing ductility due to continuous spiral compacting. While the threat obtained in this system are the column capacity that is not optimal due to the ineffective area, from the potential analysis several things can be taken into consideration to determine a new confinement system include : by utilizing spiral confinement compactibility used to capture the opportunity to increase ductility, by eliminating the ineffective area of the circular spiral confinement system and creating a shape that matches the shape of the column as an attempt to capture the opportunity to increase ductility and column capacity.

From the results of the potential analysis obtained the initial hypothesis that the ductility of the column will increase if: the effectiveness of the concrete core area by shaping a confinement in accordance with the shape of the column, manufacturing compactable shape of confinement in the shape of a spiral, the absence of reinforcement in the corner area, curvature of the concrete core in the corner area to be reduced by utilizing a longitudinal reinforcement bundling system, preferring to use a interlocking system between the main spiral confinement (concrete core) and reinforcement bundle spiral. So as a proposal in this study is a confinement system on a reinforced concrete square column that uses a square spiral that utilizes a longitudinal reinforcement bundling system in an effort to reduce the curvature of the concrete core with an interlocking system of confinement between concrete core confinement and reinforcement bundle confinement.

As a first step, it is necessary to first study the square spiral confinement system on reinforced concrete square columns as an indicator of ductility of the innovative confinement system and compare it with conventional confinement and circular spiral systems.

2. Literature review

Testing of the specimens that have been proposed [2] as in table 1, where the specimen are divided into two groups, namely specimens without reinforcement and with reinforcement.
Table 1. Specification of specimens [2].

| Specimens | Dimension (mm) | Concrete Cover (mm) | Longitudinal Reinforcement | Confinement | $f_{cu}$ (MPa) |
|-----------|----------------|---------------------|-----------------------------|-------------|----------------|
| C-1       | 200x200x600    |                 |                           | Kolom Beton Polos | 29.05          |
| C-2       | 200x200x600    | 6.25              | 20R8                       | Φ2@75       | 29.05          |
| C-3       | 200x200x600    | 6.25              | 20R8                       | Φ2@25       | 29.05          |

From the test results obtained that C-1 specimens for plain columns, brittle failure and diagonal cracks occur 24 degrees in the direction of the axis of the test object. The same form of failure occurs in all other specimens. This failure is caused by concrete spalling. From the test results, it was found that the increase in ductility was obtained by reducing the spacing to a third of the original distance from 75 mm to 25 mm, as indicated [14] and the main reinforcement experienced buckling together with the release of the hook from the 90° position and the results of this test were in accordance with the previous theory [15].

Whereas in the research that other researchers have done [3], with specifications of the test object as in table 2.

Table 2. Column specimens [3].

| Specimens | Dimension (mm) | Concrete Cover (mm) | Longitudinal Reinforcement | Confinement | $f_{cu}$ (MPa) |
|-----------|----------------|---------------------|-----------------------------|-------------|----------------|
| Specimen 1| 200x200x500    | 10                  | 20T10                       | φ4@25       | 33.5           |
| Specimen 2| 200x200x500    | 10                  | 20T10                       | φ4@25       | 33.5           |
| Specimen 3| 200x200x500    | 10                  | 20T10                       | φ4@25       | 33.5           |

From the results of this test illustrates the confinement that occur in non-earthquake detailing using 90° of hooks and no ties to the longitudinal reinforcement. Columns with non-earthquake detail have limited confinement effects, increased strength that are smaller and have limited ductility. This is needed to perfect the confinement model in order to determine the amount of confinement and or the confined concrete stress-strain relationship that occurs to accommodate the type of non-seismic detail.

While from the research Yin et al., showed that most of the specimens tested with a spiral-shaped confinement produced a compressive strength and a higher energy capacity compared to confinements in a square shape [4]. Among the specimens are multi-spiral shapes (specimens (g) and (h)) and a cross-linked spiral form (specimen (i)), which is more effective than hook confinements [16].

3. Method
As stated in the background, the confinement to be used are conventional confinements, circular spirals and square spirals where as a constant factor using the same volumetric ratio [16] as in Table 3 and dimensions of concrete specimens 150 x 150 x 450 mm as in Fig. 4, and using plain reinforcing steel dia. 6 mm for confinement and dia. 10 mm for longitudinal reinforcement.

The manufacturing process of specimens through concrete mixing is preceded by a mix of designs that use 0.5 water content where each confinement system is 3 pieces. Through a maintenance period of 28 days, compressive axial testing [14], of these specimens used a hydraulic machine with a capacity of 200 tons with a strain rate of 0.6. This test is done to get information and data about column behavior by using each confinement system in the chart of load - displacement.

Table 3. Volumetric ratio.

| Type of Confinement   | Ratio | Space (mm) | $f_{cu}$ (MPa) |
|-----------------------|-------|------------|----------------|
| Sengkang Konvensional| 0.01781| 56         | 20             |
| Spiral Lingkaran      | 0.07191| 50         | 20             |
| Spiral Persegi        | 0.01787| 50         | 20             |
4. Result and analysis

By using $f_{c'} = 20$ MPa, $f_y = 35$ MPa and $f_{ys} = 25$ MPa, the results of compressive axial testing as in Fig.5, for conventional confinement systems (hooks) indicate that the peak load is 414,414.32 N occurs at strain 0.0156, then a decrease in load capacity 20,312.75 N per mm of displacements. For specimens with circular spiral confinements, it shows that the peak load occurs at strain 0.012, then a decrease in capacity of 18,226.35 N per mm of displacement. Whereas for the specimen with a square spiral confinement, it shows that the peak load occurs at 0.016 strain, then a decrease in capacity of 15,038.5 N per mm of displacement.

![Graph showing load-displacement for different confinement types](image)

**Figure 5.** Load-displacement graph of specimens with confinement variations.

The loading conditions during post peak response in the descending branch area of each specimen are as shown in table 4. This shows that the specimen using a square spiral confinement is able to maintain high strength when the strain is high compared to specimens that use other confinements.
Table 4. Comparison between Key Parameters of Each Specimen.

| No. | Parameter          | Unconfined | Tied      | Circular Spiral | Square Spiral |
|-----|--------------------|------------|-----------|-----------------|---------------|
|     | $\varepsilon_{c,\text{max}}$ (mm/mm) | 0.0060     | 0.0148    | 0.0087          | 0.0150        |
| 1   | $f_{c,\text{max}}$ (MPa)         | 9,311      | 18,418    | 20,372          | 21,811        |
|     | $\varepsilon_{0.85}$ (mm/mm)     | 0.0096     | 0.0250    | 0.0210          | 0.0233        |
| 2   | $f_{c,0.85}$ (MPa)            | 7.91       | 15.66     | 17.312          | 18.542        |
|     | $\varepsilon_{0.5}$ (mm/mm)     | 0.0161     | 0.0386    | 0.0417          | 0.0490        |
| 3   | $f_{c,0.5}$ (MPa)             | 4.66       | 9.21      | 10.192          | 10.912        |

5. Conclusions
From the observations it was found that concrete columns that have reinforcement systems have higher strength and resistance to external loads compared to plain concrete. Reinforced concrete columns with spiral confinement systems have better ductility compared to reinforced concrete columns that are confined using conventional confinement systems (hooks). Whereas reinforced concrete columns using a square spiral confinement system have better ductility compared to reinforced concrete columns that use circular spiral confinements. For this reason, further research is needed on specimens that use interlocking confinement systems with a combination of square and circular spirals for cross section of square columns.

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