



Contribution of Transverse Reinforcement Configuration on Concrete Shear Capacity of RC Column

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Abstract – Proper design of transverse reinforcement in the RC column is needed to maintain its ability to deform under axial and shear load safely. Even though mandatory building codes for transverse support of the RC column exist, shear failure was still found in the last high earthquake in Pidie, Aceh, in 2016. Therefore, as an attempt to improve RC column strength and elasticity, the effect of transverse reinforcement configuration was evaluated experimentally to a column subjected to an axial and shear load. The experiment was conducted by using four-column specimens with a cross-section 200 x 200 mm. Four types of transverse reinforcement configurations were applied in each column. The test was carried out by loading an axial load always and shear load gradually until its failure. The test results show that the configuration of transverse reinforcement has a significant effect of maintaining column stiffness, which was subjected to compressive axial load and shear load. Furthermore, the arrangement of transverse reinforcement influences the compressive strength significantly and enhance the concrete shear capacity of a column due to its confinement effect.

Keywords: column strength, concrete shear capacity, concrete confinement, transversal reinforcement configuration

Introduction

Column ductility is a crucial aspect to be fulfilled in the design for earthquake-resistant buildings to avoid its collapse. A column with sufficient flexibility will be able to maintain its stiffness until a massive deflection and ready to deform inelastically. It is following the principle of structural design, which has a robust column-weak beam. Furthermore, Insufficient ductility provided by columns can be one of the causes of structural collapse during an earthquake. Flexural failure and shear failure may occur in column structures (Fauzan, 2012; Balitbang PUPR, 2016) due to its inability to properly deform to withstand earthquake loads.

Proper design of transversal reinforcement in a column is needed to provide sufficient ductility in the plastic hinge area resulting in appropriate confinement on concrete loaded with compressive load, buckling in longitudinal reinforcement, and shear failure (Mander *et al.* 1988). Moreover, they found that the effect of concrete confinement increases the strength and ductility of concrete loaded with compressive loads. This result is in line with other studies (Shin *et al.* 2010; Murat and Salim. 1992).

Based on the previous study of the reinforced concrete column with a new stirrup loaded by compressive axial load and shear load, conclude that configuration form of stirrup has a significant influence in ensuring the column stiffness loaded by compressive axial load and shear load. However, the results showed that column shear capacity was higher than the results of theoretical analysis (ACI, 2011). It may occur because the theoretical calculation ignores the compressive strength of the confined concrete provided by the additional transverse reinforcement.

Therefore, this study aims to investigate the contribution of the configuration form of transverse reinforcement on the concrete shear capacity of a reinforced specific column, which is subjected to constant compressive axial load. Besides, this study is a development study from previous research.

In this study, experimental data obtained by Munawir *et al.* (2012) was used. The specimen has a cross-

section of 200 x 200 mm² and column length 580 mm, which was subjected to constant compressive axial load 0.2 P_o and shear load. The configuration form of transverse reinforcement was the parameter of this study. They were normal (S0), arms (S1), crossties (S2), and diamond (S3). The results showed that the transverse reinforcement configuration increases concrete confinement, which resulted in increased column ability to carry axial compressive loads and concrete shear capacity.

Materials and Methods

Materials

Influence of axial load on column behavior subjected to the shear load

Based on the results of Prisley *et al.*, (1996) which is shown in Figure 1, smaller deflection can be obtained by given higher axial load to the column when the column reached ultimate shear load as the effect of the confinement on the column elements which were subjected to the axial force. Moreover, Ou *et al.* (2013) mentioned that the shear capacity of a column with high strength of reinforcement could be increased by the increase of compressive axial load. Al-Osta *et al.* did a further study., (2018) concluded that the increment of the compressive axial capacity of a column-beam joint in the early stage could increase the shear capacity of the column. This result is in line with the results of previous studies by Saidi and Samsunan (2010) on reinforced concrete columns without the addition of extra transverse reinforcement. They found that given axial loads in the column subjected to lateral forces reduced the deflection that occurred when the ultimate load was achieved.

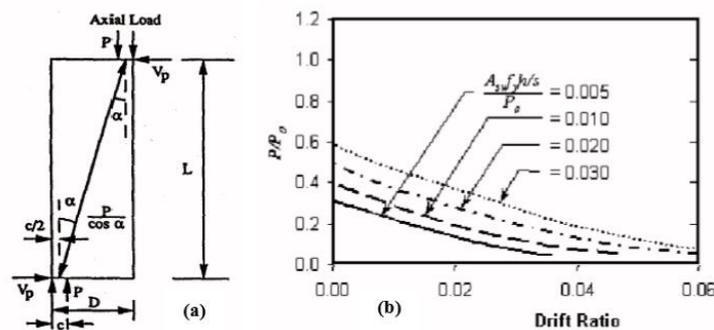


Figure.1 (a) compressive load contribution to the shear capacity of a column; (b) relationship between displacement ratio and column axial load based on the variation of the transverse reinforcement configuration form (Priesley *et al.*, (1996)).

Effect of concrete confinement on RC column loaded by axial load

Confined concrete has different stress and strain relationship with unconfined concrete. In unconfined concrete, given axial loads produces uniaxial stresses. Created axial stress caused lateral expansion (lateral pressure) and vertical cracks. If the compressive strength of the material is reached, the concrete will be failed. The presence of confinement on concrete causes the movement of lateral stresses when axial loads are given and produce triaxial pressures. Imran (2010) mentioned that concrete strength and its ability to deform increase along with increasing lateral demand on the concrete. The better the concrete confinement, the higher the lateral stress that is mobilized when the concrete stands the axial loads, thus the strength of the concrete increases. The concept is in line with the model proposed by Murat *et al.* (1992).

Passive lateral pressure developed by transverse reinforcement as the concrete expands under the influence of axial compression. It was mentioned that an increase in the volumetric ratio of reinforcement could directly increase the confinement pressure. It leads to a rise in both the strength and ductility of confined concrete. However, column deformability reduces with the axial compression. Furthermore, the constitutive model of confined concrete developed by Murat *et al.* (1992) was adopted by Yalcin *et al.* (2000) in their numerical study. The lateral confinement pressure is calculated based on the geometry and material properties. In the model, the efficiency of reinforcement is also taken into account.

Concrete confinement can be produced by providing sufficient transverse reinforcement. Uniform lateral tension in the concrete core can be generated when the transverse reinforcement reaches its yielding stress as f_{yh} :

$$f_l = \frac{2f_{yh}A_{sp}}{d_s s} \tag{1}$$

where d_s is the diameter of the transverse reinforcement, A_{sp} is the area of the transverse reinforcement, and s is a spacing of the transverse reinforcement.

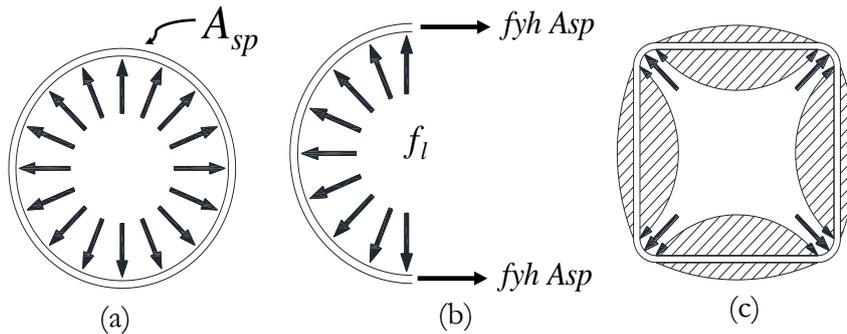


Figure. 2 (a) effect of concrete core confinement on the spiral stirrup, (b) generated load on the half of the spiral transverse reinforcement cross-section, (c) confinement effect of the rectangular transverse reinforcement (Priesley *et al.*, (1996)).

The form of the transverse reinforcement affects the confinement area of the concrete core. Figure 2(c) shows the generated confinement effect in the rectangular transversal reinforcement has a substantial confinement effect at each corner of the transverse reinforcement due to the presence of reinforcement in the lateral direction. The hatched area in Figure 2 (c) is an area that has no confinement. The addition of reinforcement on rectangular transverse reinforcement can increase the area of confined concrete, as can be referred to in Figure 3. Increasing the compressive strength of the core in confined spaces covered by transverse reinforcements causes a broad stress distribution in the unconfined area and causes sudden failure.

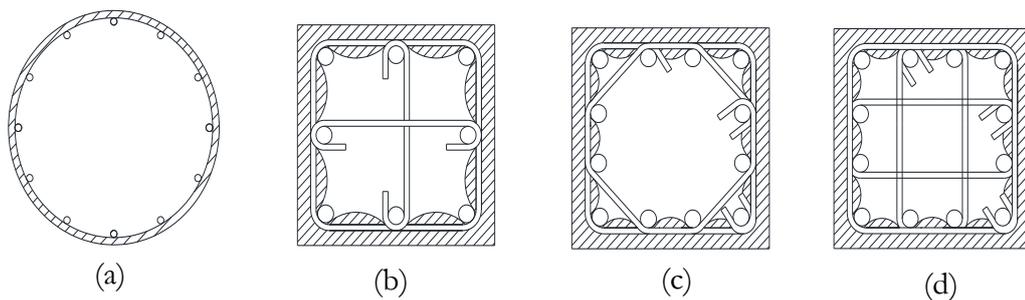


Figure 3. (a) effect of concrete core confinement on the spiral stirrup; (b) impact of concrete core confinement on rectangular stirrup with additional *cross-ties* reinforcement; (c) effect of concrete core confinement on rectangular stirrup with extra *orthogonal* reinforcement; (d) effect of concrete core confinement on rectangular stirrup with overlapping transverse reinforcement (Priesley *et al.*, (1996)).

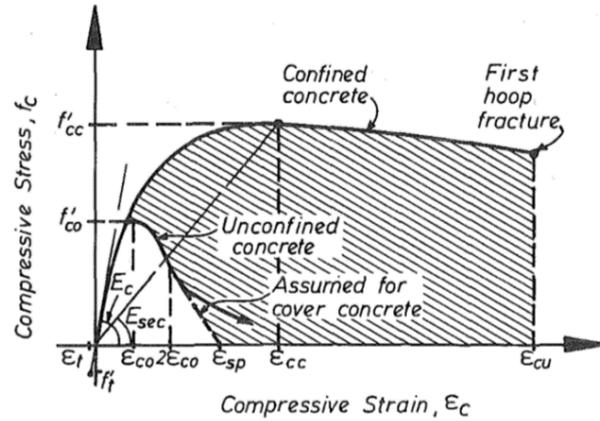


Figure 4. Model of stress-strain relationship of concrete subjected to compressive load (Priesley *et al.*, (1996)).

Mander *et al.* (1988) have proposed the stress-strain relationship, as shown in Figure 4. Equation (2) can be applied for rectangular or spiral stirrup to predict the amount of compressive strength of confined concrete.

$$f'_{cc} = f'_{co} \left(-1.254 + 2.254 \sqrt{1 + \frac{7.94 f'_l}{f'_{co}}} - 2 \frac{f'_l}{f'_{co}} \right) \tag{2}$$

where f'_{cc} and f'_{co} are confined concrete strength and unconfined concrete strength, respectively. While f'_l is effective lateral stress, as can be seen in Figure 2. Effective lateral confinement can be calculated by equation (3) and (4). As for spiral transverse reinforcement:

$$f'_l = K_e f_l \tag{3}$$

The rectangular transverse reinforcement with the ratio of reinforcement in x and y-direction are yielding as:

$$f'_{lx} = K_e \rho_x f_y h \tag{4.a}$$

$$f'_{ly} = K_e \rho_y f_y h \tag{4.b}$$

The K_e is a coefficient from the concrete mix and lateral stress f_l function, for the spiral and rectangular transverse reinforcement, are 0.95 and 0.75, respectively (Mander *et al.*, 1988). Another study by Murat *et al.* (1999) addressed the coefficient of K_e as in Equation 5.a and 5.b, it reflects the efficiency of reinforcement arrangement and is equal to unity when the confinement pressure is near-uniform. It is directly defined as the coefficient of K_e by:

for normal-strength concrete,

$$K_e = 0.26 \sqrt{\left(\frac{b_c}{s}\right) \left(\frac{b_c}{s_l}\right) \left(\frac{1}{f_l}\right)} \leq 1.0 \tag{5.a}$$

for normal-strength concrete,

$$K_e = 0.15 \sqrt{\left(\frac{b_c}{s}\right) \left(\frac{b_c}{s_l}\right)} \leq 1.0 \tag{5.b}$$

However, to get the simple calculation, the proposed coefficient of K_e by Mander *et al.* (1988) was used in this study.

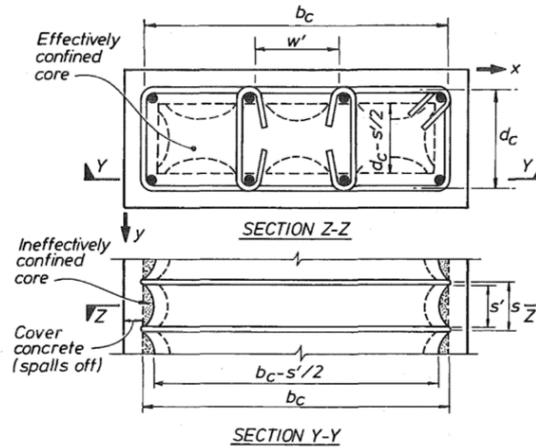


Figure 5. Cross-section of a column (Priesley *et al.*, 1996)

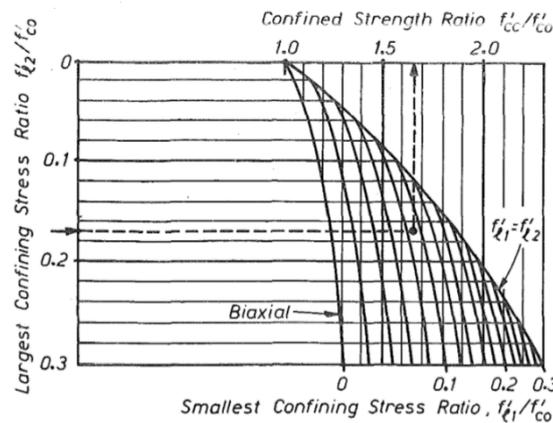


Figure 6. The increment of confined concrete strength with orthogonal confinement stress (Priesley *et al.*, 1996)

The ratio of transverse reinforcement can be evaluated based on Figure 5 and the following Equation 6.a and 6.b.

$$\rho_x = \frac{A_{sx}}{sd_c} \tag{6.a}$$

$$\rho_y = \frac{A_{sy}}{sb_c} \tag{6.b}$$

For rectangular stirrup with different effective lateral stress of f'_{lx} and f'_{ly} , f'_{cc} can be calculated by the relationship of $\frac{f'_{cc}}{f'_{co}}$ which can be seen from Figure 6, where $f'_{lx} > f'_{ly}$.

Methods

This study used data from the previous study conducted by Saidi *et al.* (2011) and Munawir *et al.* (2012) on the experimental test of reinforced concrete columns with additional transverse reinforcement. The test was carried out using four specimens, which had a cross-sectional area of 200 x 200 mm² and a height of 580 mm. The longitudinal reinforcement was 12D11,6 with $f_y = 356,5$ MPa and transverse reinforcement Ø5,4 mm with $f_y = 611,3$ MPa; yield strain = 0.0024, rupture strain = 0.010 and modulus elasticity of transverse reinforcement is 254706,13 MPa. The test results show that the transverse reinforcement is brittle. The concrete strength was 24,19 MPa.

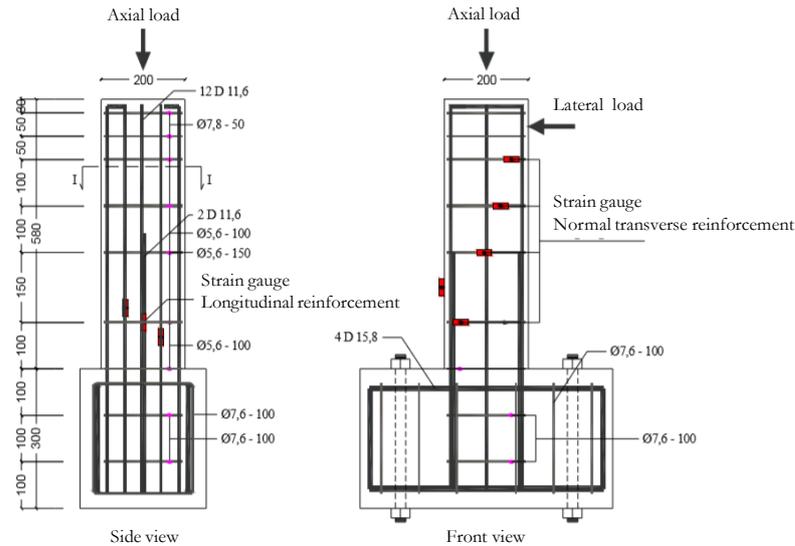
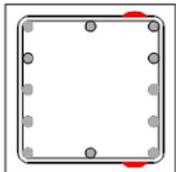
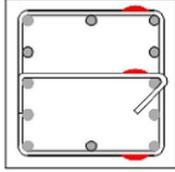
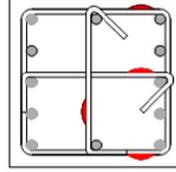
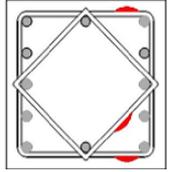


Figure 7. Detail of specimen

Table 1. Detail of stirrup configuration

Compressive axial load (P_o)	Transverse Reinforcement Configuration			
	0.2 P_o	without additional transverse reinforcement	with additional transverse reinforcement parallel with a shear load	with cross ties additional transverse reinforcement
Configuration type				
Specimen	S0P1 Normal type	S1P1 Arm type	S2P1 Crossties type	S3P1 Diamond

In column specimens, strain gauges were installed to measure strain that occurred in both reinforcement and concrete. Strain gauges were installed in longitudinal reinforcements, stirrup, additional stirrup, and the compressed concrete area. Details of the tested specimen can be seen in Figure 7. Transverse reinforcement configuration was a study parameter. More information can be seen in Table 1. P_o was the calculation result of the maximum axial capacity of the column referring to ACI (2011), which was 1248 kN.

The column had a pinned support by a beam with a cross-section of 300 x 300 mm² and a height of 60 mm when the test was carried out. The upper edge was connected to the load-bearing that can behave as roller support, and it was compared to axial load cells. During the test, deflection, reinforcement strain, and crack patterns were recorded and observed each incremental of the load until its failure. Details of setting criteria can be seen in Figure 8.

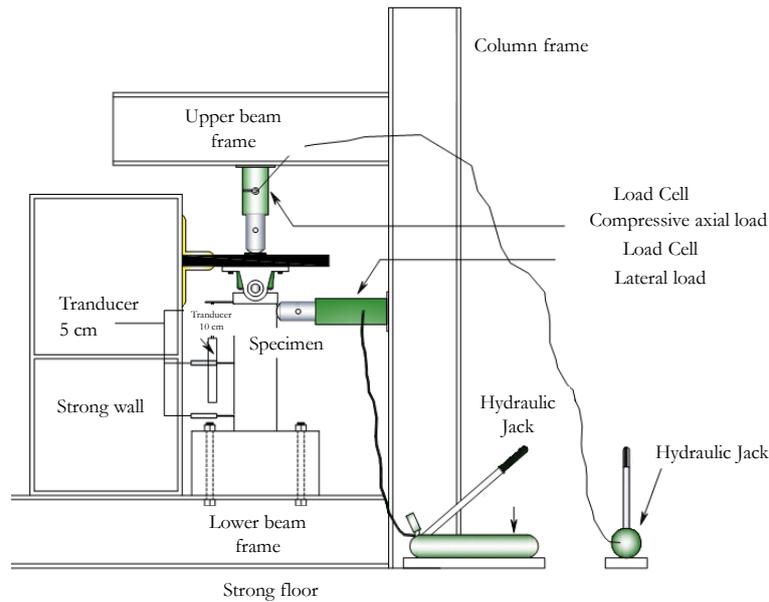


Figure 8. Detail of setting test

Results

In this article, the experimental results related to the research parameter described previously were discussed. The discussion of the test results was associated with the effect of the transverse reinforcement configuration on the shear strength of the column and the impact of the confinement of the concrete core produced by the transverse reinforcement configuration.

Transverse reinforcement configuration effect on column shear capacity

Observed deflection that occurred in column specimens due to the shear load given in the horizontal direction was measured at an altitude of 475 mm from the support, as shown in Figure 7. Figure 9 below shows a graph of the shear load and deflection relationship, which occurred on the column subjected to constant compressive axial load $0.2 P_o$ for each transverse reinforcement configuration.

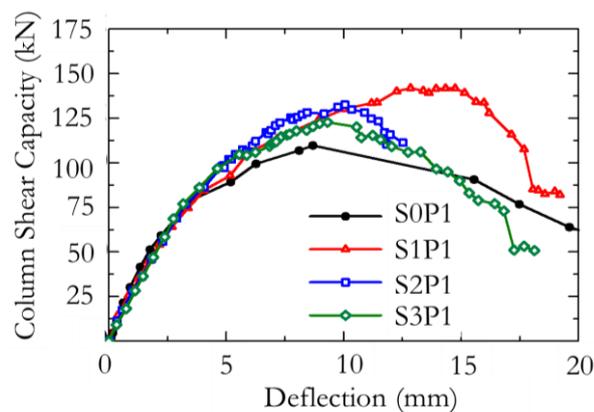


Figure 9. Relationship of column shear capacity and deflection for each stirrup configuration

Figure 9 gives the information about the difference in column stiffness at the same value of subjected shear load for each transverse reinforcement configuration, especially after the shear load exceeded 68.67 kN or when all column specimens subjected to constant axial load $0.2 P_o$ had cracked. The gradient of the curve, as shown in Figure 9, shows the column stiffness after crack tended to decrease with increasing magnitude of the acted shear load as discussed by Saidi *et al.*, (2011) and Munawir *et al.*, (2012). The increase of column stiffness in the specimen due to the additional transverse reinforcement is predicted because of the increase in the modulus of elasticity of the concrete as an effect of the presence of the core concrete

confinement (Munawir *et al.*, 2012). This prediction is based on the results of a previous study conducted by Mander *et al.* (1988), which also concluded that the stiffness of reinforced concrete structural elements could be increased by adding extra transverse reinforcement. Additional transverse reinforcement may enhance the confined specific strength (f'_{cc}) and modulus elasticity of concrete (E_c). The results of previous studies by (Munawir *et al.*, 2012 and Saidi *et al.*, 2011) show column shear capacity based on experimental test is higher than the results of theoretical analysis. The calculation result of nominal shear capacity based on the formula set by ACI (2011) and the final column based on the configuration of stirrup can be seen in Table 2.

Table 2. Nominal and ultimate shear capacity of reinforced concrete column

Specimen	Concrete Shear Capacity	Concrete Shear Capacity Affected by Axial Load	Transverse Reinforcement Shear Capacity	Nominal Shear Capacity	Ultimate Shear Capacity (kN)
	V_c (kN)	V_p (kN)	V_s (kN)	V_n (kN)	V_u (kN)
S0P1	27.67	11.72	47.24	86.63	109.68
S1P1	27.67	11.72	70.88	110.27	141.85
S2P1	27.67	11.72	70.88	110.27	135.67
S3P1	27.67	11.72	47.24	86.63	125.86

Effect of concrete core confinement produced by the transverse reinforcement configuration on ultimate column shear capacity

Table 3 shows the compressive strength of confined concrete for each column configuration at an axial load of $0.2P_o$, which is calculated based on the approach proposed by Mander *et al.*, (1988). The result reveals that the test specimen with the addition of transverse reinforcement has a higher compressive strength of the confined concrete than the tested sample with standard transverse reinforcement configuration. The incremental ratio of compressive strength between confined concrete and unconfined concrete is following the results obtained by Antonius *et al.* (2004) and Murat *et al.*, (1992). Based on the illustration of the stress distribution shown in Figure 3, reinforcement of columns with the addition of extra support on the transverse reinforcement minimize the curved part or the part of the concrete that does not subject to the confinement effect; thus the confined area of the concrete core becomes larger. Additional reinforcement that supports the middle part of the transverse reinforcement can improve lateral confinement point as formed in the corner of the stirrup.

Table 3. The calculation result of confinement concrete strength

Specimen	f'_c (MPa)	f'_{cc} (MPa)	Ratio f'_{cc}/f'_c
S0P1	24.19	29.03	1.20
S1P1	24.19	30.24	1.25
S2P1	24.19	31.21	1.29
S3P1	24.19	32.66	1.35

The configuration of the diamond type of transverse reinforcement has a higher confined concrete strength. It is under the research conducted by Mohle and Cavanagh (1985) and Shin *et al.*, (2010). Followed by arm type of transverse reinforcement, crossies type of transverse reinforcement, and typical type of transverse reinforcement configurations. It occurs because the difference in the confined lateral stress acting on the concrete core is closely related to the transverse reinforcement ratio. The transverse reinforcement configuration strongly influences the confined lateral stresses produced by transverse reinforcement. It depends on the effective transverse reinforcement area or the number of useful transverse reinforcement legs in the x or even y-direction (Shin *et al.*, 2010), in this case, the stirrup configuration with diamond form has the most significant number of legs.

Discussion

By referring to the relation with the constant axial load given for each tested transverse reinforcement configuration as shown in Figure 9, it is estimated that the shear capacity increased due to the influence of compressive stress generated by the concrete confinement effect on the concrete column core. It is influenced by the transverse reinforcement configuration and ability to reinforce steel to deform inelastically after yielded. Shin *et al.* (2010) stated in the results of their research that the ratio of displacement ductility in the column increases with the more complicated configuration of the additional transverse reinforcement and the ratio of the volume of the transverse reinforcement. The effect of the concrete

confinement when the transverse reinforcement was yielded is equal to the deviation value of the column shear capacity based on the experimental test, as listed in Table 2 until the column reaches the maximum shear capacity.

The shear capacity of reinforced concrete columns has increased with the addition of transverse reinforcement. It can be seen in Figure 10 that the arm type configuration has the largest shear capacity compared to other transverse reinforcement configurations. It follows the crossties, diamonds, and typical arrangements.

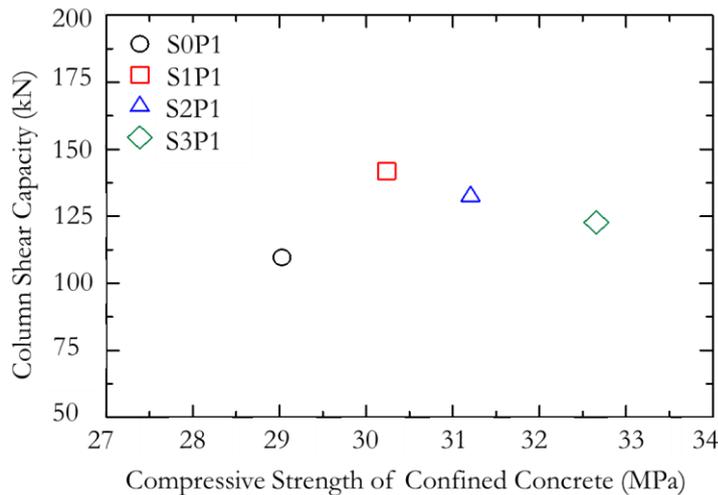


Figure 10. Relationship of column shear capacity and confined concrete strength

Table 4. Comparison of calculated nominal shear capacity of the column

Specimen	Shear Capacity without Confined Concrete Effect (kN)				Nominal Shear Capacity	Shear Capacity with Confined Concrete Effect (kN)				Nominal Shear Capacity
	fc	Vc	Vp	Vs		fcc	Vc	Vp	Vs	
S0P1	24.19	27.67	11.72	47.24	86.63	29.03	30.92	13.09	47.24	91.25
S1P1	24.19	27.67	11.72	70.88	110.27	30.24	31.56	13.36	70.88	115.80
S2P1	24.19	27.67	11.72	70.88	110.27	31.21	32.06	13.57	70.88	116.51
S3P1	24.19	27.67	11.72	47.24	86.63	32.66	32.80	13.88	47.24	93.92

The nominal shear capacity of reinforced concrete column was calculated based on confined concrete strength to see the influence of transverse reinforcement configuration on column shear capacity. Table 4 shows the comparison of the calculated nominal shear capacity of the column based on confined concrete strength with unconfined concrete strength, according to ACI (2011). Both confined concrete strength with unconfined concrete strength were used the same equation proposed by ACI (2011), the difference only in the value of confined concrete (fcc).

The nominal shear capacity of reinforced concrete columns based on confined concrete strength has slightly increased compared to the nominal shear capacity of reinforced concrete columns based on unconfined concrete strength. However, the value of the nominal shear capacity of the column is still lower than the experimental test result. Confinement of concrete core influences compressive concrete strength dominantly as mentioned in Table 3. It is only contributed to the concrete shear capacity (Vc), which has increased significantly. In some way, the value of shear capacity given by transverse reinforcement is more dominant because the contribution of transverse reinforcement depends on the direction of the shear force. In this case, the shear force is only in one lateral direction (x-direction). Therefore, the increment of the shear capacity of the column is not significant. Besides affecting the compressive strength, confined concrete effect influences the ductility of reinforced concrete columns subjected to compressive axial load as well (Shin *et al.*, 2010).

Conclusions

Based on the results of the study, it can be concluded that to increase the strength of the shear capacity of the column. It can be done by increasing the number of transverse reinforcement. It can give the effect of the confining of the concrete core. The type of transverse reinforcement configuration influences the compressive strength significantly due to the limiting of the concrete core effect. It causes in increasing the capacity of concrete shear. Diamond and crossties type give a better capacity for concrete shear.

The use of appropriate transverse reinforcement is highly recommended in the design of reinforced concrete column structures to increase its strength. However, a related study still needs to be carried out to get better information.

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