RESULT AND DISCUSSION

1. Mechanical Properties of Material

Compressive strength of concrete cylinders at 28 days were mixed for casting the reinforced concrete column specimens as shown in Table 2

Table 2 Test result of concrete compressive strength for column specimens

Specimen	Compressive Force (kg)			Average P_c (kg)	Average Strength (ksc)
	Sample No. 1	Sample No. 2	Sample No. 3		
RB6(7.5)	44,350	49,400	48,800	47,517	269
RB6(10)	42,930	48,120	43,760	44,937	254
CDR6/2(7.5)	50,890	42,590	44,170	45,883	260
CDR6/2(10)	47,480	52,400	50,650	50,177	284
CDR6/1(10)	57,730	63,070	54,080	58,293	330
No Tie bar	62,750	63,280	63,400	63,143	357

Because the results of compressive strength for column specimens were different, this will affect the comparison of ultimate strength of concrete column. Therefore the axial force of column test in Appendix C shall be normalized by dividing these forces by the concrete cylinder, P_c in Table 2.

Tensile strength of round bars, RB6, RB9 and deformed bars, DB12 and Welded Wire Reinforcement, CDR6 were shown in Appendix Tables 2, 3, 4 and 5 respectively.

2. Test Observation and Data Analysis

The effect of confinement of WWR is discussed here with respect to two variables: volumetric ratio of WWR and longitudinal spacing.

The axial stress and strain were calculated by dividing the load by the nominal cross-section of concrete column. The strain values were derived from the average of the two LDVT readings. At about 70 – 80% of the peak values, tiny cracks at the surface of both ends of the column began to appear as shown in Figure 21. The peak stress was reached when one or more surfaces of the column showed clearly covering failure. Sometimes with the sound of fracture then strength decreased earlier after ultimate load was reached.

The strain gages inside the column were used to indicate lateral strain of transverse reinforcement so that the lateral pressure due to confinement was induced by transverse reinforcement.

Figure 12 Test set-up

Figure 13 CDR6/2(7.5) showing clear signs of covering failure

3. The effect of confined column by transverse reinforcement

The value of P_{ny} , P_{nu} and Δ_y , Δ_u can be found by relationship between normalized axial force and deformation of specimens (Figure 14). The straight line had been drawn to parallel with the part of curve that seem to linear, intersect of straight line with normalized axial force and deformation curve will be yield point, P_{ny} and Δ_y were found. P_{nu} , Δ_u were found at maximum normalized axial force.

There is no universally accepted ductility for concrete column under uni-axial compression load. Mau (1998) suggested that by inspecting the normalized axial force and deformation curves, the ratio of Δ_u / Δ_y can be shown as ability of ductility of column after its yield.

Comparison of Δ_u / Δ_y had been observed, ductility of each specimens was compared by the ratio of Δ_u / Δ_y .

Average value for P_{ny} and Δ_y of each specimens are listed in Table 3.

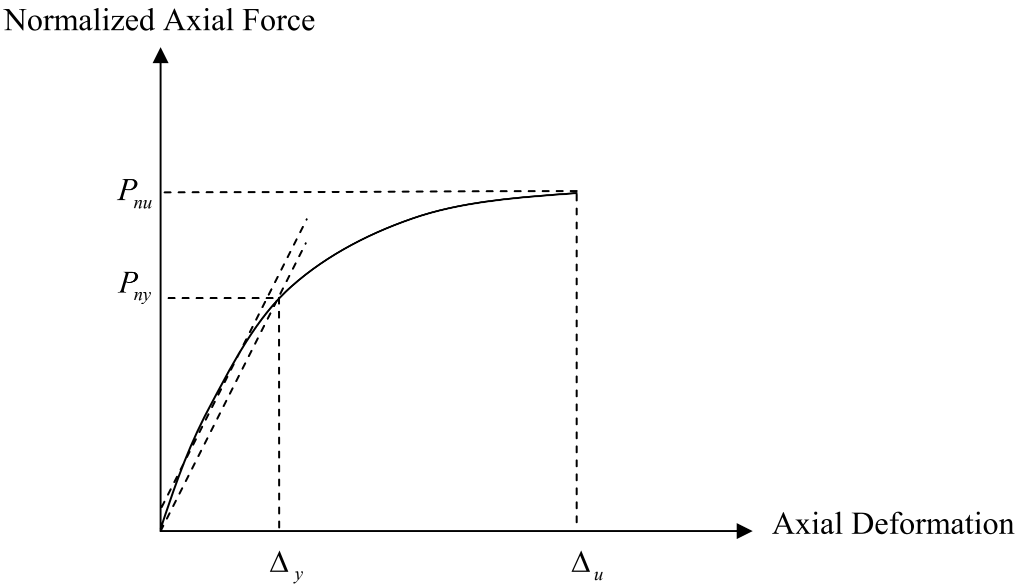

Figure 14 Theoretical relationships between normalized axial force and deformation of test specimen

Source: Satjapan (2004)

Table 3 Effect of confined column by transverse reinforcement

Specimen	ρ_{sh} (%)	Normalized Axial Force		Axial Deformation		$\frac{\Delta_u}{\Delta_y}$
		Yield (P_{ny})	Ultimate (P_{nu})	Yield (Δ_y)	Ultimate (Δ_u)	
RB6(7.5)	0.90	0.90	1.12	0.195	0.350	1.79
CDR6/2(7.5)	0.90	0.89	1.05	0.210	0.380	1.81
RB6(10)	0.68	0.92	1.06	0.180	0.290	1.61
CDR6/1(10)	0.45	0.73	0.88	0.210	0.330	1.57
CDR6/2(10)	0.68	0.90	1.01	0.220	0.360	1.64
No Tie bar	-	-	0.79		0.24	

3.1 Ductility of column due to spacing of transverse reinforcement.

3.1.1 Refer Table 3, RB6 (7.5) has Δ_u / Δ_y=1.79 and P_{nu} = 1.12 and RB6 (10) has Δ_u / Δ_y=1.61 and P_{nu} = 1.06. It is concluded that RB6 (7.5) has ductility slightly greater than RB6(10). Figure 15, showed force and deformation of confined column by round bar with different spacing.

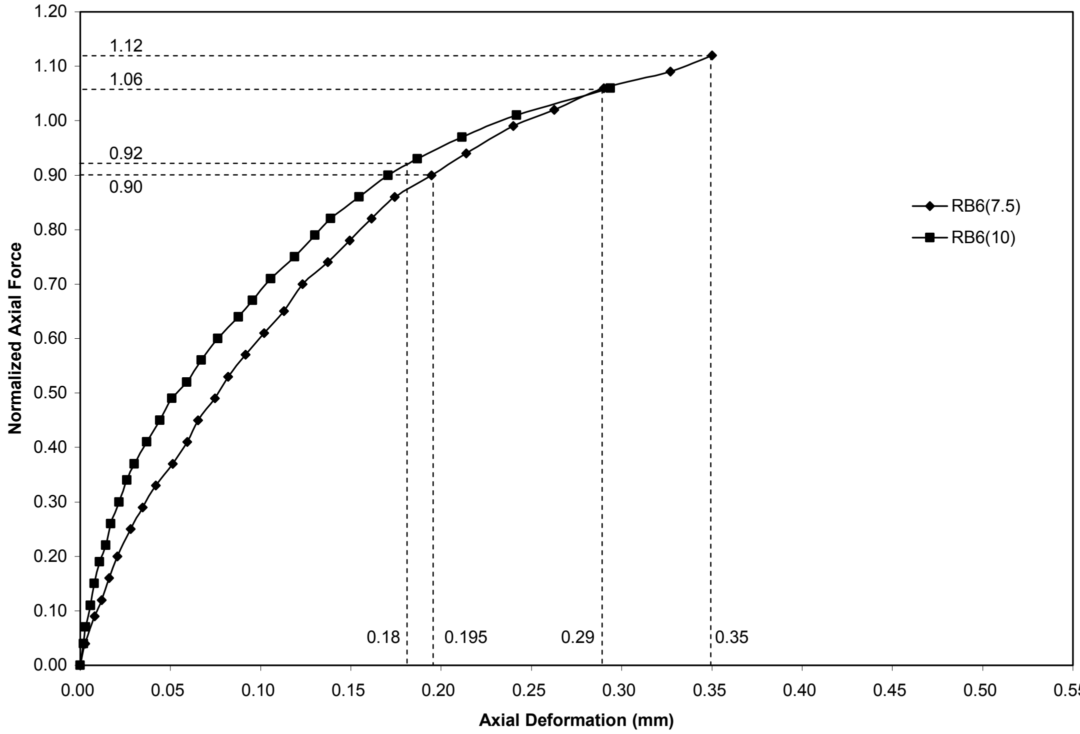

Figure 15 Comparison between normalized axial force and deformation of column confined by Round bar 6mm (RB6) with spacing 7.5 cm and 10 cm

3.1.2 Confined column by welded wire reinforcement 6mm (CDR6). Regarding to Table 3, CDR6 can be separated into 3 groups CDR6/2(7.5), CDR6/1(10), CDR6/2(10) according to number of grids and longitudinal spacing. CDR6/2(7.5) has Δ_u / Δ_y = 1.81 and P_{nu} = 1.06 greater than other two groups that means it is more ductile than another group as well. CDR6/1(10) has only Δ_u / Δ_y = 1.37 and P_{nu} = 0.88 which has minimum ductility of groups. Figure 16, shows force and deformation of confined column by welded wire reinforcement with different longitudinal spacing.

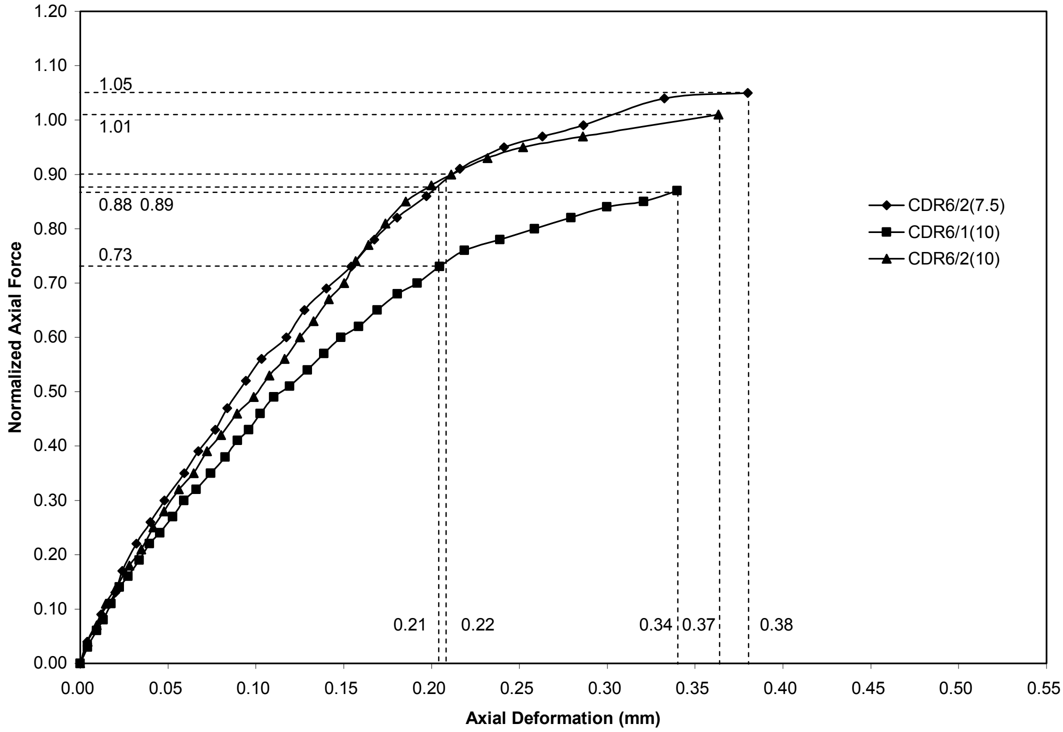

Figure 16 Comparison between normalized axial force and deformation of column confined by welded wire reinforcement 6mm (CDR6) with spacing 7.5 cm and 10 cm

Longitudinal spacing of transverse reinforcement has more effect to strength and ductility of confined column. Columns which have shortened longitudinal spacing shall harden and are more ductile than longer longitudinal spacing. The effect of different grid types is significant. 2x2 grids have results which seem to be better than only one grid.

3.2 Comparison between round bar and welded wire reinforcement as transverse reinforcement

Confined column by round bar and welded wire reinforcement were separated into two groups as per volumetric ratio of WWR. First group $\rho_{sh} = 0.90$

consists of CDR6/2(7.5), RB6 (7.5). Second group $\rho_{sh} = 0.68$ consists of RB6 (10), CDR6/2(10) and $\rho_{sh} = 0.45$ for CDR6/1(10).

3.2.1 First group $\rho_{sh} = 0.90$, CDR6/2(7.5) and RB6 (7.5) has Δ_u / Δ_y = 1.81 and 1.79 respectively that means CDR6/2(7.5) has ductility slightly greater than RB6 (7.5) and when compared with axial force, RB(7.5) has capacity of axial force a little bit greater than CDR6/2 (7.5) as shown in Figure 17 due to the effect of compressive strength of concrete.

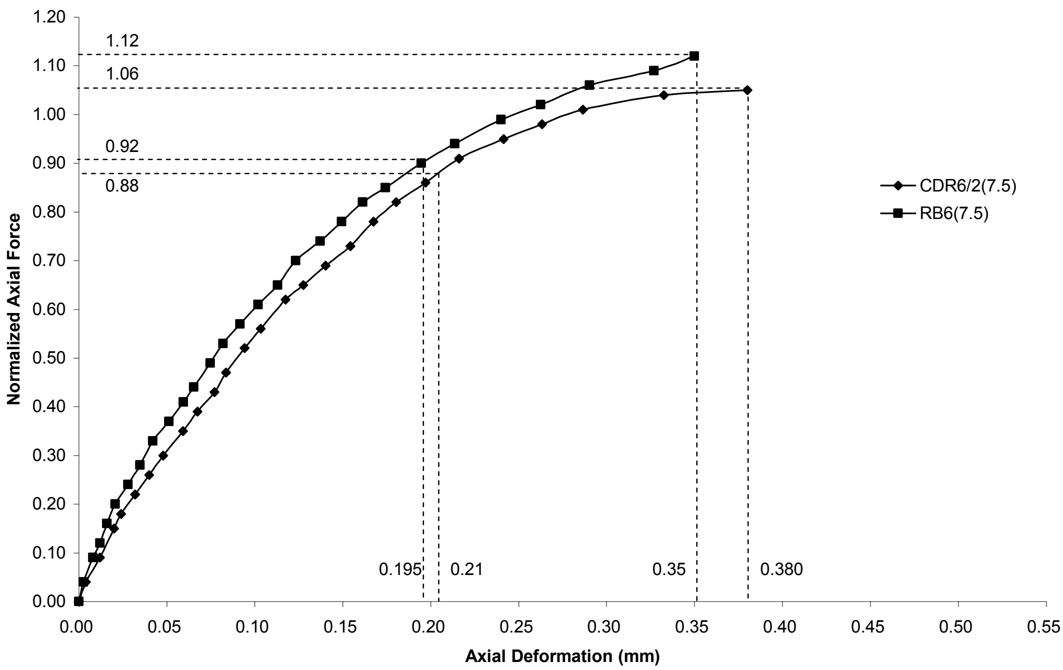

Figure 17 Comparison between normalized axial force and deformation of column confined by CDR6/2(7.5) and RB6 (7.5)

3.2.2 Second group $\rho_{sh} = 0.68$ consists of CDR6/2(10.0) and RB6 (10.0) has Δ_u / Δ_y= 1.64 and 1.61 respectively that means CDR6/2(10.) has ductility equal to RB6 (10) when compared with CDR6/1(7.5) which has Δ_u / Δ_y= 1.57, it seems lowest. Because it has only $\rho_{sh} = 0.45$, volumetric ratio is confirmed as having on confined column in terms of ductility. The effect of confinement by welded wire reinforcement can be increased ductility of column. In Figure 18, shows the axial force and axial deformation of confined column by CDR6/1(10), CDR6/2(10) and RB6 (10).

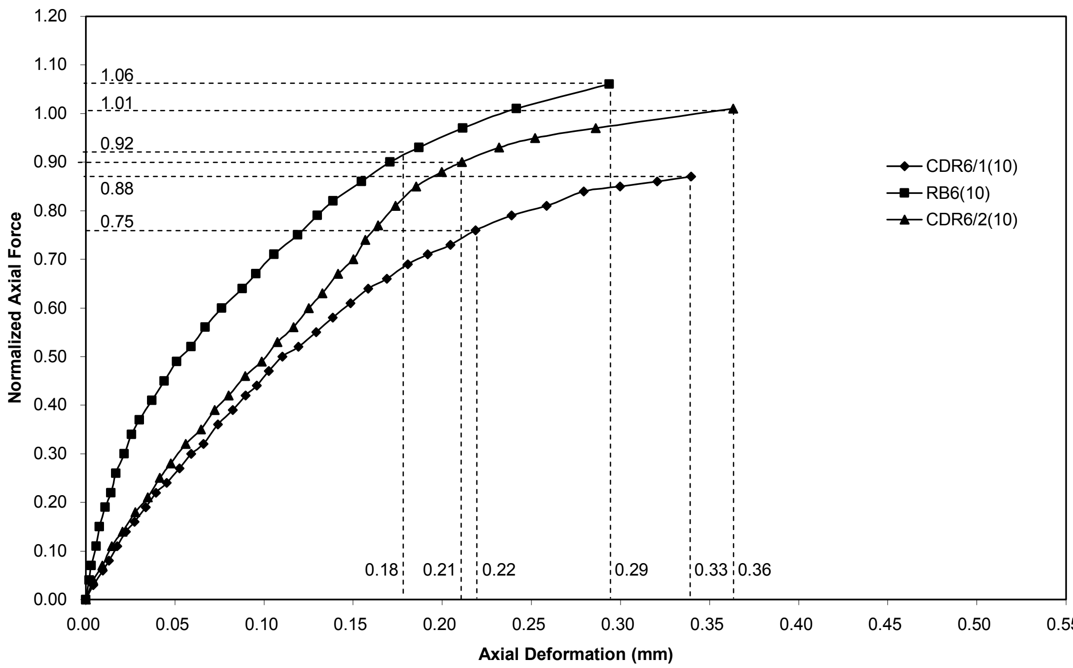

Figure 18 Comparison between normalized axial force of column confined by CDR6/1(10), CDR6/2(10) and RB6 (10)

Confined column by conventional round bar seems to have strength slightly greater than column confined by welded wire reinforcement. But if considering ductility of column, CDR6 has ductility slightly greater than RB6 therefore it can be concluded that CDR6 and RB6 have efficiency to confined column and provide strength and ductility which are not different.

4. <u>The efficiency between welded wire reinforcement and round bar</u>

The tensile stress – strain characteristic were tested according to ASTM standard, ASTM A185-94 for WWR and ASTM A370 – 94 for round bar.

Welded Wire Reinforcement (WWR), three coupons were tested for each wire configuration, their average stress – strain curves which are shown in Figure A4. The dimension of the wires and the young's modulus and yielding stress are listed in Appendix Table A5. ASTM A185-94 calls for the determination of yielding stress at fixed strain of 0.02% offset. This method was used to determine the yielding stress.

Round bars (RB) were tested according to ASTM A370 – 94. Three samples were selected for tensile test. The average stress – strain curves are shown in Figure A1.

Table 4 Comparison of stress between WWR and RB

Type of Specimens	Yield stress ksc	Ultimate stress ksc	Elongation (%)
CDR6	5,633	6,324	3.20
RB6	3,114	4,445	34.57

From Table 4 it can be concluded that welded wire reinforcement has higher tensile strength than round bar but elongation is very small when compared with round bar.

From experimental results, the efficiency of welded wire reinforcement and round bar used as transverse reinforcements in reinforced concrete columns are slightly different in term of strength and ductility. Welded wire reinforcement may be used instead of conventional round bar as transverse reinforcement, because it can be prepared in factory before being installed to column which may reduce time for construction and labor.

5. Comparison of Experimental and Theoretical Results

Analysis of confined column under uni-axial loading by transverse reinforcement was compared to results from experimental.

Table 5 Axial compression force from experimental and theoretical results

Specimen	ρ_{sh} (%)	f'_{cc} / f'_{co} Saatcioglu	f'_{cc} / f'_{co} S.T. Mau	Normalized Axial force P_{nu}	f'_{cc} / f'_{co} Experimental
CDR6/2(7.5)	0.90	1.291	1.396	1.05	1.329
RB6(7.5)	0.90	1.220	1.383	1.12	1.417
CDR6/2(10)	0.68	1.210	1.183	1.01	1.278
RB6(10)	0.68	1.183	1.204	1.06	1.329
CDR6/1(10)	0.45	1.180	1.104	0.88	1.113
No Tie bar	-	-	-	0.79	

5.1 The experimental results were greater than theoretical average results around 6.1% and it can be concluded that the results from confined theory can be used to calculate capacity of confined column by transverse reinforcement. The value of f'_{cc} / f'_{co} showed the relationship between maximum compression of column confined by transverse reinforcement and no tie bar column.

5.2 The results calculated by S.T. Mau correlate closely to results from experiment, because they were calculated by considering the ratio of longitudinal spacing with depth of column (S/D) and volumetric ratio of transverse reinforcement which are important variables for confined column. S/D ratio is to represent the effect of spacing in reducing the effective confining stress. For Saatcioglu theory, concrete covering was assumed to spall and remained only core of concrete but in the experimental, peak stress was reached before the spalling of covering.

6. Mode of Failure

The mode of failure of all specimens confined by transverse reinforcement are not different, starting from tiny crack at around 70 – 80% of peak load and after that covering of specimens were break and spalled from core of concrete column. The ultimate load was reached at this stage.

No Tie columns are different from column that is confined by transverse reinforcement. After column reached ultimate load, covering of column exploded by confined pressure because transverse reinforcement was not provided.

Figure 19 Tiny crack occurriing at 70 – 80 % of peak load (No Tie bar column)

Figure 20 Column exploded after reaching ultimate load (No Tie bar column)

Figure 21 Tiny cracks occurring at 70 – 80 % of peak load (RB6(7.5))

Figure 22 Covering crack (RB6(7.5))

Figure 23 Covering spalling at ultimate load RB6(7.5)

Figure 24 Failure of welded wire reinforcement (CDR6/2(10))

CONCLUSIONS

1. All test specimens of confined column under uni-axial load by welded wire reinforcement (WWR) as transverse tie reinforcement showed small cracks at 70% - 80% of ultimate load and appear at the both ends of the column due to maximum bearing stress at the end, although special transverse reinforcements were provided to protect cracking from maximum bearing stress. After that, the axial force and deformation curve became more non-linear. When one or more surfaces of the column showed clear signs of covering failures, the column still carried more load due to effect of confinement. Ultimate load was reached when one or both of concrete and transverse reinforcements failed.

2. The most dominant factor in strength of confined column was the longitudinal spacing of the transverse reinforcement. When the spacing to width ratio (S/D) decreased volumetric ratio of transverse reinforcement increased and strength of confined column increased.

3. Comparison of welded wire reinforcement and round bar as transverse reinforcement with equal longitudinal spacing indicated that CDR and RB specimens were able to withstand the same uni-axial load and ductility.

4. Ductility of confined column by WWR reinforcement and RB, expressed as a deformation ratio, was suggested. It gives the maximum deformation at rupture compared to deformation at yielding point. Because in yielding region, axial force and axial deformation are in proportion and slightly deformed after yielding region, stress and strain are not in linear and will increase in deformation rapidly until rupture.

5. The experimental results were greater than theoretical results around 6.1% and it concluded that the results of confined theory by S.T. Mau can be used to calculate the ultimate capacity of column confined by transverse reinforcement.

LITERATURE CITED

ACI Committee 318. 2002. **Building Code Requirements for Reinforced Concrete and Commentary (ACI 318-02/ACI 318R-02).** American Concrete Institute, Detroit.

Baris, B. 2005. "An analysis model for stress-strain behavior of confined concrete". **Engineering Structures** 27(2005): 1040-1051.

Chan, W. L. 1995. "The Ultimate strength and deformation of plastic hinges in reinforced concrete frame works". **Mag. Concrete Res**. 7(21): 121-132.

Kappos, A. J., M. K. Chryssanthopoulos and C. Dymiotis. 1999. "Uncertainty analysis of strength and ductility of confined reinforced concrete members". **Engineering Structures** 21(1999): 195-208.

Lim, H. J. and C. I. Liao. 2004. "Compressive strength of reinforced concrete column confined by composite materials". **Composite Structures** 65(2004): 239-250.

Luccioni, B. M. and V. C. Rougier. 2005. "Plastic damage approach for confined concrete". **Computer & Structurals** 83(2005): 2238-2256.

Mau, S. T., J. Holland and L. Hong. 1998. "Small – Column Compression test on Concrete Confined by WWF". **Journal of Structural Division ASCE** 124(3): 252-261.

Razvi, S. R. and M. Saatciglu. 1989. "Confinement of Reinforced Concrete Column with Welded Wire Fabric". **ACI Structural Journal** 86(5): 615-623.

Richart, F. E. 1933. "Reinforced concrete column investigation tentative". Final Report of committee 105. **ACI Structural Journal** 86(5): 615-623.

Richart, F. E., A. Brandtzaege and R. L. Brown. 1929. **The failure of plain and spirally reinforced column in compression**. 1st. ed. Univ. llinois Eng. Exp. Sta. Bull No.190. 120 p.

Saatciglu, M. and M. Grira. 1999. "Confinement of Reinforcement Concrete Column with Welded Reinforcement Gride". **ACI Structure Journal** 96(1): 29-39.

Saatciglu, M., A. H. Salamat and S. R. Razi. 1992. "Strength and Ductility of Confined Concrete". **ACI Structure Journal** 118(6): 1590-1607.

Saatciglu, M., A. H. Salamat and S. R. Razi.. 1995. "Confined Columns under Eccentric Loading". **Journal of Structure Division ASCE** 121(11): 1547-1556.

Samphan, K. 1988. **Behavior of confined column by rectangular transverse reinforcement**. Thesis for Master of Engineering (Civil Engineering), Kasetsart University.

Satjapan, L. 2004. **Behavior of confined column under eccentric loading by welded wire reinforcement**. Thesis for Master of Engineering (Civil Engineering), Kasetsart University.

Yalcin, C. and M. Saatciglu. 2000. "Inelastic analysis of reinforced concrete columns". **Computer & Structures** 77(2000): 539-555.