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STRENGTH AND DEFORMABILITY OF CONFINED RECTANGULAR REINFORCED CONCRETE COLUMNS WITH SUPPLEMENTAL PEN-BINDER

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ABSTRACT

Some parts of Indonesia are located in a region with high seismic risk. In this region, it is compulsory to have a structure that consistently meets the stringent requirements of earthquake resistant buildings. Consistent implementation of the earthquake resistant design will result in a structure that can survive a strong earthquake. One of the seismic provisions of SNI 03-2847-02 [1] requires that reinforced concrete columns of a structure be confined using hoop reinforcement with seismic hook. The concept of confinement in reinforced concrete columns is intended for when the cover spalls off a tied column does not fail immediately because the strength of the core is enhanced by triaxial stresses resulting from the confining effect of the transverse or hoop reinforcement. As a result, the column can undergo large deformation, eventually reaching a second maximum load, when the transverse reinforcement yields. Installation of this kind of confining reinforcement is so tedious, especially for large dimensions columns commonly used in high rise buildings, flyovers and bridges. The research study reported in this paper introduces a simple device called "pen-binder" that can be attached onto the non-compliance confining reinforcement at construction sites. The use of pen-binder to hold the confining reinforcement in r/c column improves strength and ductility of column very significantly. In general, column specimens with code non-compliance confining reinforcement plus pen-binder show better strength and ductility than column specimens with code compliance confining reinforcement. A parametric study has also been carried out to find out the effect of confinement ratio. The parametric study revealed some very important observations regarding the behaviour of confinement of rectangular reinforced concrete columns with supplemental pen-binder

KEYWORDS: Column, Confinement, Pen-binder, strength, ductility

1 INTRODUCTION

The concept of confinement in reinforced concrete columns is intended for when the cover spalls off a tied column does not fail immediately because the strength of the core is enhanced by triaxial stresses resulting from the confining effect of the transverse or hoop reinforcement. As a result, the column can undergo large deformation, eventually reaching a second maximum load, when the transverse reinforcement yields. The provision of transverse or confining reinforcement in the current SNI/ACI Code is based on the work of Richart et al. (1929), and is developed such that the compressive strength of the confined core of a column after cover spalling is equal to the compressive strength of the gross section of the column before cover spalling.

Inelastic deformability of reinforced concrete columns is important for overal strength and stability of structures during earthquake. Deformability of columns can be achieved through proper confinement of the core concrete. Many research studies on reinforced concrete columns confined using confining reinforcement with 90-degree hook show that opening of 90-degree hook initiates failure, leading to buckling of the outer longitudinal reinforcing bars. It is also concluded in those research studies that the use of confining reinforcement with 90-degree hook can result in poor seismic performance of the structure (Sheikh and Yeh 1990; Saatcioglu and Razvi 1992; Wehbe et al. 1999).

The research study reported in this paper introduces a simple device called ”pen-binder” to be attached onto the non-compliance confining reinforcement at construction sites. The use of this ”pen-binder” is expected to improve the structural performance of the code non-compliance confining reinforcement to be at least the same as that of the code compliance one

2 EXPERIMENTAL PROGRAM

2.1 Test Specimens

The specimens tested in this study were 18 column specimens, with 170 mm x 170 mm in cross section and 480 mm in height. Figure 1 illustrates the geometry of a typical column and strain gauges placement.

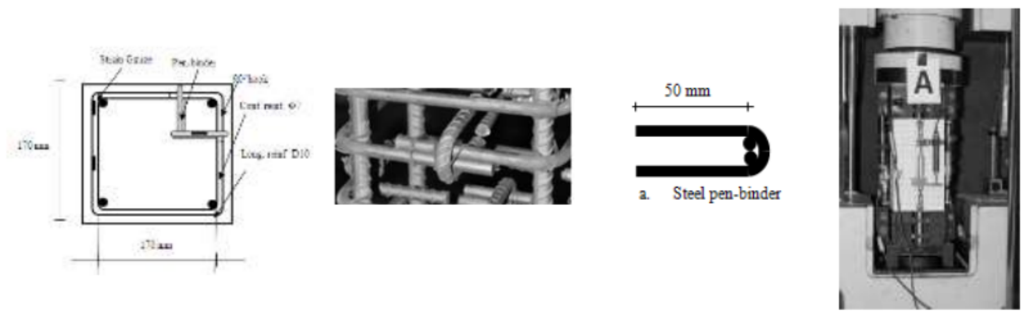

Figure 1 : Test Specimen, pen-binder geometry and test setup

The test series reported here were designed to investigate three parameters influencing the behaviour of columns, these are volumetric ratio, the angle of hook applied and the configurations of confining reinforcement. Two types of volumetric ratio ($A_{sh}/(s.h_c)\%$) are used in this case, i.e: spacing confinement, s =35 mm (1.9%) and s= 70 mm (0.9 %) . Different configuration of confining reinforcement used in the test specimens are illustrated in Figure 2.

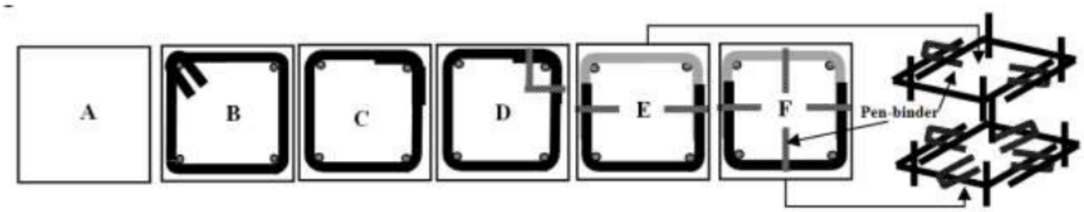

Figure 2: Configuration of confining reinforcement

A summary of all test specimens and their properties is provided in Table 1.

Table 1 : Details of test specimens

Test Specimens f_c'=32 MPa/ Configuration		Confining reinforcement (Dia. 7.3 mm, f_{yh} =336 MPa, E=172721 MPa)		Pen-binder (Dia.7.65mm)	
		s(mm)	$A_{sh}/(s.h_c)$%	Material	
K0-0-0	A				Longitudinal reinf. 4-D10, f_y=414 MPa, E=207390 MPa, ρ=1.23%)
K135-0-35	B	35	1.9	Steel (f_y=414 MPa,E=177041 MPa)	
K90-0-35	C				
K90-2P1-35	D				
K90A-2P1-35	E				
K90A-4P1-35	F				
K135-0-70	B	70	0.9	Steel (fy=414 MPa,E=177041 MPa	
K90-0-70	C				
K90-2P1-70	D				
K90A-2P1-70	E				
K90A-4P1-70	F				

Configuration A is concrete column without reinforcement, configuration B is column with code compliance confining reinforcement, C and D are code non-compliance confining reinforcement without and with pen-binder in 90^0 hook zone respectively, E and F are those with double C confining reinforcement with pen-binders installed in two sides and all sides of confining reinforcement, respectively. Double C configurations of confining reinforcement are commonly used for largae size columns.

2.2 Test Setup

The column specimens were tested using a Dartec compression testing machine with a 1500 kN load capacity (Fig. 1). The specimens were externally confined in the top and bottom regions by steel brackets. LVDTs (Linear Variable Differential Transducers) were placed on each column face to measure axial deformations of the specimens. Strain in confining reinforcement was measured using electric strain gauges (Figure 2). The specimens were loaded slowly. LVDTs were monitored throughout loading to insure concentric loading and the resulting data were recorded by data logger. The loading was continued until a significant drop in load capacity was observed.

3 TEST RESULTS

All column specimens showed similar initial behavior, the ascending branches of load-strain relationships were almost linear up to beginning of cover spalling. The first crack appeared on column faces at a concrete strain of approximately 0.2 percent. The measured peak load and the corresponding axial strain curve for each configuration is shown in Figure 3. Columns specimens with volumetric ratio 1.9% show different behaviour at all configuration confinement reinforcement. The poorest behavior among the four configuration was shown by configuration E, after spalling of the cover the longitudinal bar start to buckle slip and push the confinement outward, resulting in loss of confinement and rapid deterioration of the specimen. Although the specimen confined with supplemental pen-binder, a lack of ductility as compared to other specimens is quite obvious. Column specimens with volumetric ratio 0.9% was not shown different behaviour significantly for each configuration, the specimen was not shown ability to confined concrete core, poor ductility behaviour was shown by this specimens for all configurations.

Column deformability reflects the ability of columns to deform without a significant loss of strength. Deformability of columns tested in this research program was investigated by examining axial load-axial strain relationships of core concrete. Summary of experimental results for some specimens shows in Table 2. Column axial strength improvement (*K*) was determined from confined concrete strength($f'cc$) and unconfined concrete strength($f'co$) ratio as shown in row[9].

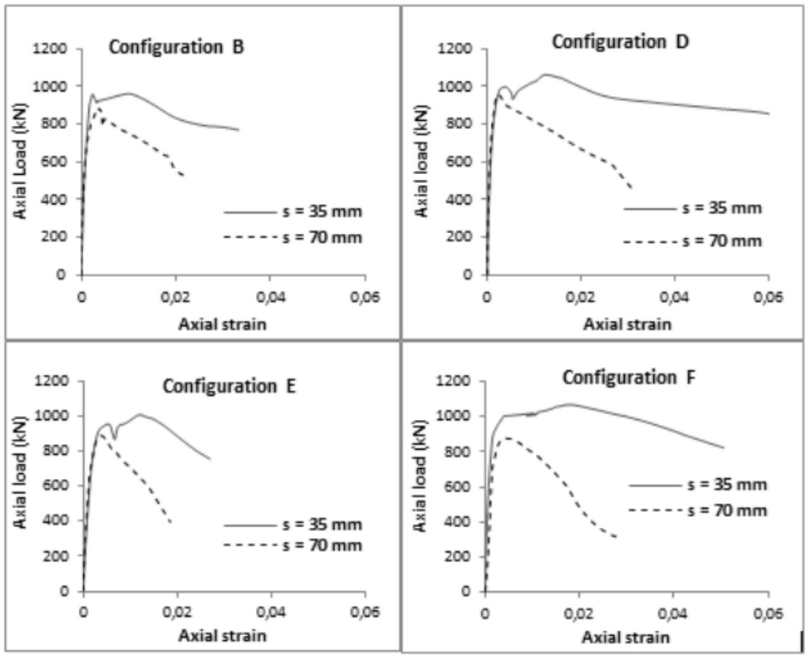

Figure 3: Load versus axial strain diagram columns specimens

Axial strain ductility ratio was used to quantify column deformability. The strain ductility ratio was defined as the ratio of axial strain of confined concrete at 15 percent strength decay beyond the peak stress (ε_{85}) divided by the strain corresponding to the peak stress of unconfined concrete (ε_1) , row [10] at Table 2 shows axial strain ductility ratio was proposed by Saatcioglu and Razvi (2002). Column [11] shown the effective confinement index was proposed by Paultre and Legeron (2008), which is defined as

$$I_c = \frac{f_{le}}{f'_{co}} \tag{1}$$

where f_{le} effective confinement pressure at peak stress, which is a measure of the restraint applied by the hoops to the lateral expansion of the confined concrete core under axial compression, for rectangular columns :

$$f_{le} = k_e.f_l = k_e.\frac{A_{sh}.f_{sh}}{sh_c} \tag{2}$$

where k_e geometric confinement effectiveness coefficient, which measures the effectiveness of the confinement reinforcement to confine concrete and varies from 1 for a continuous tube to 0 when ties are spaced more than half the core cross section minimum dimension, in which case, some part of the columns are not confined at all; A_{sh} = total section of confinement reinforcement for the set of ties in one direction ; c = cross section dimension, measured center-to-center of peripheral ties or spiral; s= center-to-center spacing between ties, and f_{sh} = stress in the confinement reinforcement at peak stress. At Table 2 the value of k_e is used the same value for all specimens (k_e =0.487).

Table 2 : Summary of test results

No.	Specimens	At P_{max}				f'_{co} (MPa)	f'_{cc} (MPa)	K= f'cc/ f'co	$\varepsilon_{85}/\varepsilon_1$	I_c (%)
		ε_{transv},	f_{sh} (MPa)	f_l (MPa)	f_{le} (MPa)					
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
1	K135-0-35	0,0031	336,0	6,1	2,92	26,99	35,96	1,33	9,25	10,84
2	K90-0-35	0,0009	148,0	2,7	1,29	26,99	38,31	1,42	2,68	4,77
3	K90-2P1-35	0,0040	336,0	6,1	2,92	26,99	40,45	1,50	10,03	10,84
4	K90A-2P1-35	0,0027	336,0	6,1	2,92	26,99	38,00	1,41	3,83	10,84
5	K90A-4P1-35	0,0026	336,0	6,1	2,92	26,99	40,67	1,51	9,64	10,84
6	K135-0-70	0,0011	190,0	1,7	0,83	26,99	32,68	1,21	2,77	3,06
7	K90-0-70	0,0009	150,3	1,4	0,65	26,99	31,25	1,16	1,92	2,42
8	K90-2P1-70	0,0009	155,3	1,4	0,68	26,99	35,90	1,33	4,35	2,50
9	K90A-2P1-70	0,0014	247,0	2,2	1,08	26,99	32,81	1,22	2,11	3,98
10	K90A-4P1-70	0,0026	336,0	3,0	1,46	26,99	32,24	1,19	2,76	5,42

Based on Tabel 2, results confirm previous findings. Volumetric ratio improve ductility ratio and confinement index significantly. The increase in the volumetric ratio of confinement reinforcement resulted in higher confining pressure on concrete and produced strength and ductility enchancement. Column with low volumetric ratios exhibit brittle behavior, showing high rate of strength decay immediately after peak load or poor ductility ratio. On the other hand, column with higher volumetric ratio of steel are able to deform significantly without a significant strength decay. The improvements observed in deformability are more pronounced in column with supplemental pen-binder. Specimen with configuration D gives the highest improvement in column strength and ductility. A stable confining reinforcement is essential to continue providing effective confinement against the lateral expansion of concrete beyond the peak stress. Therefore the pen-binder plays important role to hold confining reinforcement which will improve ductility ratio and effective confinement index significantly

Reduction in confinement spacing increases effectiveness of confinement and improves column strength and ductility. Spacing of confinement reinforcement is an important parameter that affects the distribution of confinement pressure and stability of longitudinal reinforcement. Closer spacing of confinement reinforcement is known to increase the uniformity of lateral pressure, thereby improving the effective confinement index. The effectiveness of confinement reinforcement diminishes quickly with increasing tie spacing. Pen-binder hold confining reinforcement significanly at tie level, the lateral pressure between the ties reduce with the distance from the longitudinal reinforcement, this reduction occurs at a faster rate than that of the pressure at the tie level. Figure 4 shows effect of volumetric ratio to *K*, ductility ratio and effective confinement index.

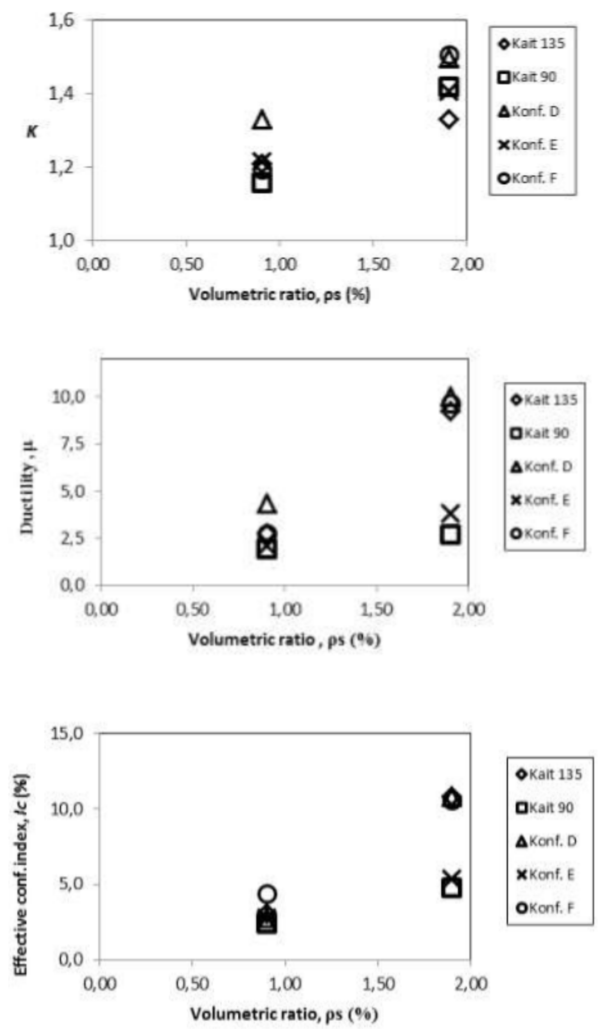

Figure 4: Effect of volumetric ratio to the *K*, ductility and effective confinement index

4 CONCLUSIONS

The increase in the volumetric ratio of confinement reinforcement resulted in higher confining pressure on concrete and produced strength and ductility enhancement.
Cconfiguration with additional pen-binder at 90^0 hook zone of non-compliance hoop reinforcement (i.e. configuration D) shows the highest strength and ductility enhancement.

The effectiveness of confinement reinforcement diminishes quickly with increasing tie spacing, suppelemtnal pen-binder hold confining reinforcement significantly at tie level.

5 ACKNOWLEDGEMENTS

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