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CONFINEMENT ACTION OF REINFORCED CONCRETE COLUMNS WITH NON-SEISMIC DETAILING

Wilson Yuk-Ming Chung[1], Eddie Siu-Shu Lam[2] and Yuk-Lung Wong[3]

ABSTRACT

Hong Kong is now recognized as an area of moderate seismic hazard. It is necessary to assess the confinement action provided by existing transverse reinforcement detailing in local reinforced concrete columns. In this study, two types of non-seismic detailing have been considered. Type L detailing incorporates 90^0 hooks, whereas type M detailing allows both 90^0 hooks and crossties not effectively anchored to the main reinforcements. Sectional analyses using OpenSees have been conducted to predict the stress-strain relationships of confined concrete with these two types of non-seismic detailing. The results are compared with those obtained from the experiments carried out in previous axial loading tests. The minimum volumetric transverse reinforcement ratios ρ_s for type L and type M detailing are suggested to be 0.5% and 1.1% respectively. Stress-strain relationships of confined concrete for non-seismic detailing are proposed by modifying the Mander's model with a reduction factor β. Appropriate values for type L and type M detailing are β=71.6% (when ρ_s > 0.5%) and β=67.1% (when ρ_s > 1.1%) respectively.

Keywords: confinement, concrete, column, non-seismic detailing, axial load

INTRODUCTION

Hong Kong is now recognized as an area of moderate seismic hazard (GB50011-2001). Before the enforcement of the Code of Practice for Structural Use of Concrete (2004) in 2005, reinforced concrete

[1] Research Student, Department of Civil & Structural Engineering, The Hong Kong Polytechnic University, Hong Kong, 03900529r@polyu.edu.hk
[2] Associate Professor, Department of Civil & Structural Engineering, The Hong Kong Polytechnic University, Hong Kong, cesslam@polyu.edu.hk
[3] Associate Professor, Department of Civil & Structural Engineering, The Hong Kong Polytechnic University, Hong Kong, ceylwong@polyu.edu.hk

columns were allowed to be designed without any seismic provision (Lam *et al* 2002). Previous studies have indicated that existing reinforced concrete columns have limited ductility (Lam *et al* 2003). Transverse reinforcements were specified with large spacing at 300mm typical and having 90-degree hooks (Fig. 1). Crossties were not required to be effectively anchored to the main reinforcements. Therefore, it is necessary to assess the confinement action provided by existing transverse reinforcement detailing.

Confinement action of reinforced concrete columns has been investigated by many researchers (Légeron *et al* 2003 and Lokuge 2005). Among others, Mander *et al* (1988) and Saatcioglu and Razvi (1992) proposed stress-strain relationships of confined concrete with seismic detailing. In this study, we attempt to predict the stress-strain relationship of concrete with non-seismic detailing by modifying the Mander's model. OpenSees (Mazzoni *et al* 2005) is implemented to predict the extent of confinement action provided by the non-seismic detailing. Results predicted by OpenSees are then compared with those obtained from the experiments conducted in previous axial loading tests (Chung *et al* 2006).

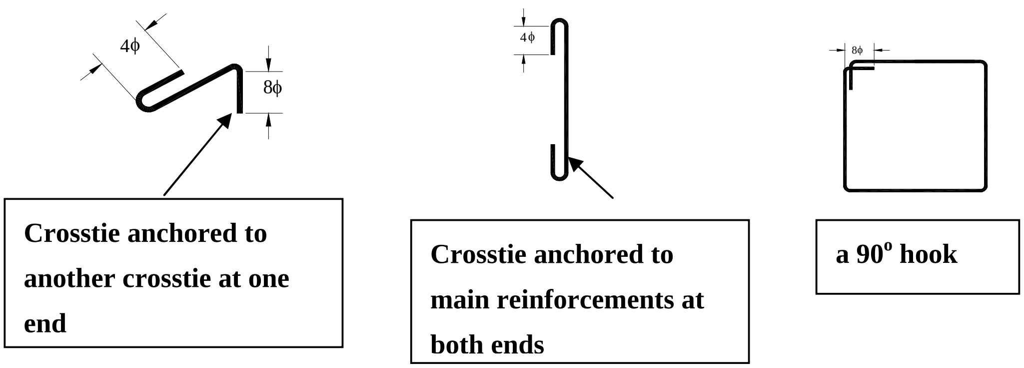

Figure 1. Details of crossties and transverse reinforcements

EXPERIMENTAL RESULTS

In a recent study, axial loading tests were conducted on rectangular reinforced concrete column specimens, including 12 reinforced concrete column specimens and 5 plain concrete column specimens (Chung *et al* 2006). The quarter-scaled specimens are 200mm square and 500mm height. All the specimens are heavily reinforced with 20T10 main reinforcements or 3.93% steel ratio. Arrangements of the transverse reinforcements are shown in Fig. 2 and Table 1. Type L detailing incorporates 90^0 hooks in its non-seismic detailing. Type M detailing allows 90^0 hooks and, in addition, crossties are not effectively anchored to the main reinforcements. Table 1 shows basic properties of the specimens. Volumetric transverse reinforcement ratio ρ_s (according to Paulay and Priestley 1992) of the specimens is in the range of 0.22% to 2.24%. The specimens are identified based on the types of transverse reinforcements. For instance, "T4L25" represents a specimen with type L transverse reinforcements of 4mm diameter bar size at 25mm spacing.

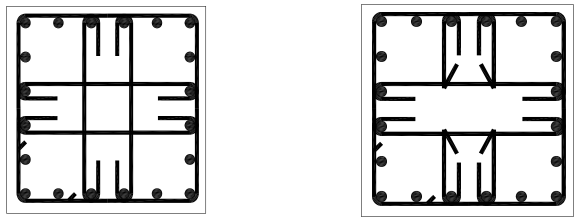

Figure 2. Arrangement of transverse reinforcements

Table 1. Basic properties of the specimens

Specimen	**Cover**	**Cylinder Strength (N/mm^2)**	**Transverse reinforcement**	ρ_s	**Type**
T4L25	12	33.5	T4@25	2.24%	L
T4M25	12	33.5	T4@25	2.24%	M
T2L25	11	20	T2@25	0.88%	L
T2M25	11	20	T2@25	0.88%	M
T2L50	11	17.5	T2@50	0.44%	L
T2M50	11	30	T2@50	0.44%	M
T2L75	11	27.5	T2@75	0.29%	L
T2M75	11	27.5	T2@75	0.29%	M

Table 2 compares the maximum confined concrete stresses of the specimens obtained from the axial loading tests with those predicted based on Mander's model (Mander *et al* 1988). The effect of using 90^o hooks instead of 135^o hooks can be shown by comparing the performance of specimens with type L detailing. As shown in Table 2, there is up to 12% reduction in the confined concrete stress at high volumetric transverse reinforcement ratio. For type M detailing, the reduction is more obvious. It is concluded that crossties not effectively anchored to the main reinforcements are less effective in providing the confinement action. The extent of confinement actions are estimated by carrying out sectional analyses as follows.

Table 2. Maximum confined concrete stress

Specimen	σ_{cc} (N/mm^2)	σ_m (N/mm^2)	1- σ_{cc}/σ_m
T4L25	44.58	50.75	0.12
T4M25	43.62	50.75	0.14
T2L25	25.16	25.62	0.02
T2M25	24.01	25.62	0.06
T2L50	19.57	20.42	0.04
T2M50	32.34	32.99	0.02
T2L75	34.13	29.19	-0.17
T2M75	28.07	29.19	0.04

σ_{cc}: maximum confined concrete stress obtained from the experiments

σ_m: maximum confined concrete stress estimated according to Mander *et al* (1988)

SECTIONAL ANALYSES

Axial shortenings of the specimens under progressive increase in the axial load are predicted by carrying out sectional analyses using OpenSees (2005). Fig. 3 shows a typical sectional model, comprising zones of confined concrete, unconfined concrete and main reinforcements. Transverse reinforcements are presented in the sectional model indirectly by adjusting the stress-strain relationship of confined concrete. Main reinforcements are assumed to be linearly elastic perfectly-plastic materials. Fig. 4 shows the various stress-strain relationships of concrete. Unconfined concrete is defined according to Paulay and Priestley (1992), and Mander's model is used to represent confined concrete with the curve defined by (Propovics 1973).

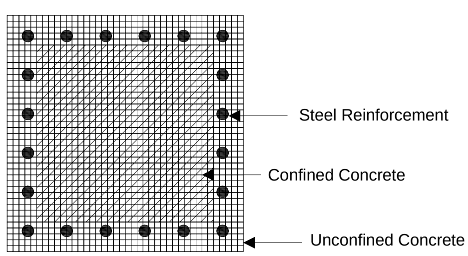

Figure 3. Sectional model

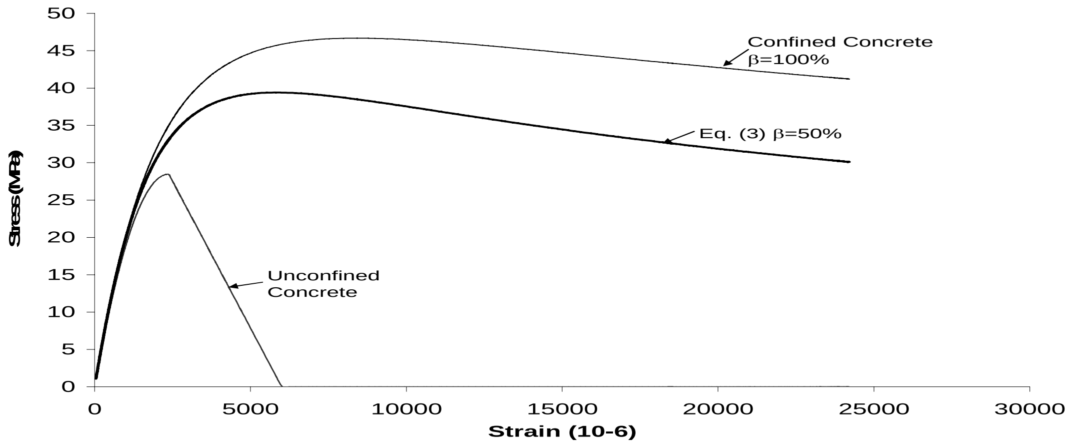

Figure 4. Stress-strain relationships of confined and unconfined concrete in compression

Sectional force **F** at particular strain of a reinforced concrete section under compression can be represented by Eq. 1. Confinement action is described by an effective confinement area ratio **c** and a reduction factor β according to Eqs. 2 and 3 respectively.

$$\mathbf{F} = \mathbf{s}_{cc}*\mathbf{c}*\mathbf{A}_c + \mathbf{s}_{uc}*(\mathbf{A}_g - \mathbf{c}*\mathbf{A}_c) + \mathbf{s}_s\mathbf{A}_s \quad (1)$$

$$\mathbf{c} = \mathbf{A}_e/\mathbf{A}_c*100\% \quad (2)$$

$$\mathbf{f}_a = \mathbf{f'}_{co} + (\mathbf{f'}_{cc} - \mathbf{f'}_{co})\beta \quad (3)$$

where $\mathbf{s}_{cc}$: Confined concrete stress

$\mathbf{s}_{uc}$: Unconfined concrete stress

$\mathbf{s}_s$: Stress reinforcement stress

$\mathbf{A}_c$: Area of concrete core (to the outside of peripheral transverse reinforcements)

$\mathbf{A}_g$: Gross sectional area

$\mathbf{A}_s$: Area of steel reinforcements

$\mathbf{A}_e$: Area of effective confinement (Paulay and Priestley 1992)

$\mathbf{f}_a$: Effective confined concrete strength

$\mathbf{f'}_{co}$: Unconfined concrete strength

$\mathbf{f'}_{cc}$: Confined concrete strength according to Mander *et al* (1998)

By varying the two parameters, **c** and β, response of a specimen under progress shortening can be estimated. Main objective of the sectional analysis is to calculate pairs of β and **c** that provide best correlation with the experimental results on (a) peak stress and (b) strain at 80% of the peak stress in the descending branch. An example is given in Fig. 5. Assuming **c**=37.87 sectional analyses are conducted by varying the parameter β to obtain the optimum value. On repeating the sectional analyses for different **c** and β, admissible combinations of **c** and β are obtained. The results are plotted in Fig. 6. By comparing specimens with the same ρ_s (e.g. T4L25 against T4M25, T2L25 against T2M25, etc.), type L detailing is able to provide better confinement action than type M detailing.

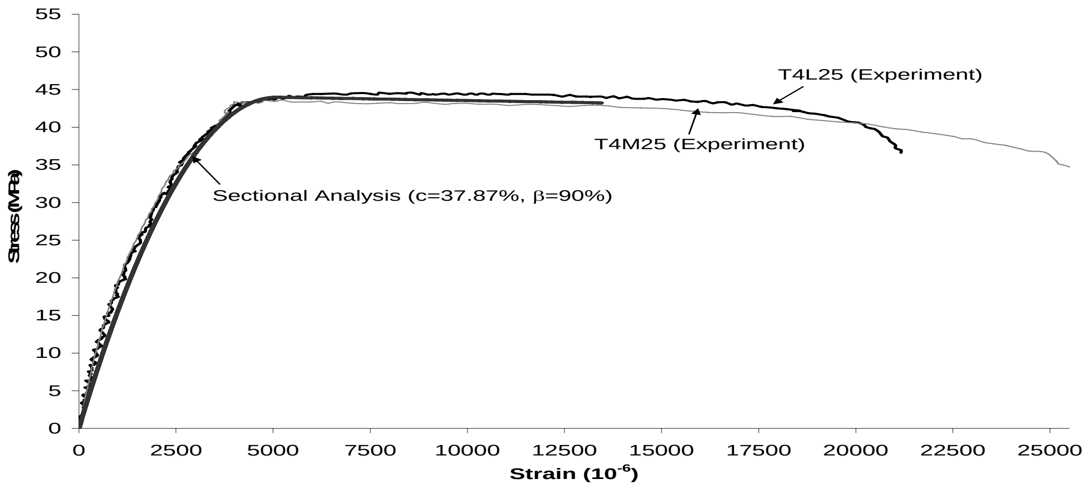

Figure 5. Stress-stain relationships of T4L25 and T4M25

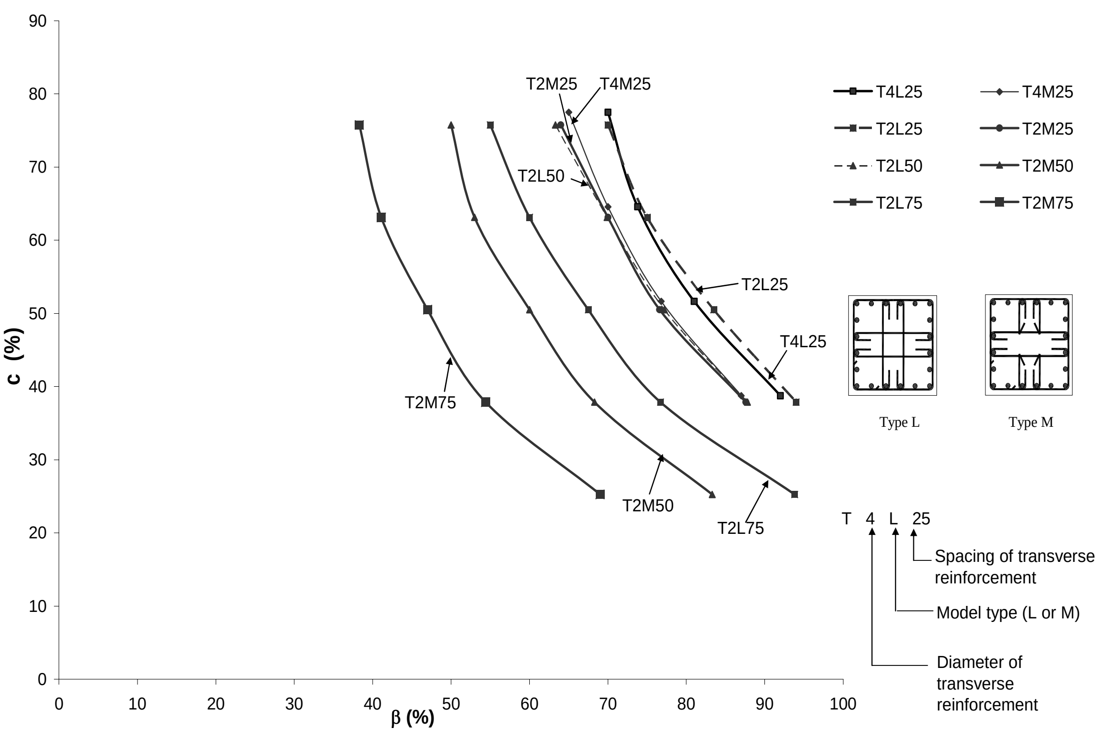

Figure 6. Variation of β against **c**

Table 3 provides the effective confinement area ratio **c** of the specimens estimated according to Paulay and Priestley (1992). The corresponding reduction factor β can be obtained from Fig. 6. The results are tabulated in Table 3 and plotted in Fig. 7. When the spacing of transverse reinforcement is 25mm, the reduction factor β is less affected by the diameter of transverse reinforcements (e.g. comparing Type L: T4@25 and T2@25). When the spacing of transverse reinforcements increases, the reduction factor β reduces drastically. There will be substantial reduction in the confinement action when ρ_s is less than some limiting value. Fig. 7 suggests that the volumetric transverse reinforcement ratio ρ_s should not to be smaller than 0.5% and 1.1% for type L and type M detailing respectively. Furthermore, type M detailing is ineffective in providing the confinement action at low volumetric transverse reinforcement ratio as compared with type L detailing.

Reasonable representation of the stress-strain relationships of confined concrete can be obtained by modifying the Mander's model with the reduction factor β at 71.6% (with $\rho_s > 0.5\%$) and 67.1% (with $\rho_s > 1.1\%$) for the respective type L and type M detailing.

Table 3. Comparisons of β, with **c** estimated according to Paulay and Priestley (1992)

Transverse reinforcement	ρ_s	**c (%)**	**β (%)**	
			Type L	**Type M**
T4@25	2.24%	71.93	71.63	67.14
T2@25	0.88%	71.60	71.64	65.97
T2@50	0.44%	61.25	70.98	54.04
T2@75	0.29%	51.71	66.78	46.44

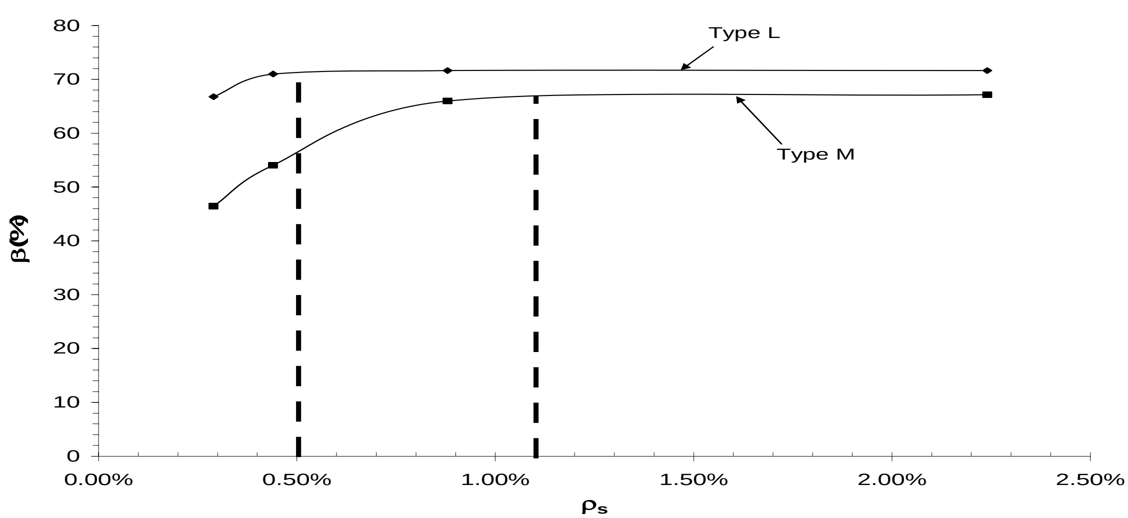

Figure 7. β against ρ_s at particular **c** estimated according to Paulay and Priestley (1992)

CONCLUSIONS

In this study, confinement action provided by two types of non-seismic detailing has been considered. The minimum volumetric transverse reinforcement ratios ρ_s for optimal confinement action are suggested to be 0.5% and 1.1% for type L and type M detailing respectively. Stress-strain relationships of confined concrete for type L and type M detailing are proposed based on modifying the Mander's model with a reduction factor β. The use of 90^0 hooks in the transverse reinforcements may reduce the confinement action. This can be represented by taking β as 71.6% (when $\rho_s > 0.5\%$). The use 90^0 hooks in the transverse reinforcements together with crossties not effectively anchored to the main reinforcement may lead to further reduction in the confinement action. In this case, β is equal to 67.1% (when $\rho_s > 1.1\%$). In further studies, cyclic loading tests will be carried out on specimens having type L or type M detailing. The proposed stress-strain relationships will be used to assist the development of hysteresis models for reinforced concrete columns with non-seismic detailing.

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