PREDICTION OF ULTIMATE DEFORMATION OF REINFORCED CONCRETE MEMBERS WITH AND WITHOUT SEISMIC RETROFIT

Hokkaido University M2 Student ○JIRAWATTANASOMKUL TIDARUT

Hokkaido University M2 Student ANGGAWIDJAJA DHANNYANTO

Hokkaido University Professor UEDA TAMON

1. INTRODUCTION

Retrofitting of reinforced concrete (RC) columns using FRP jackets to improve shear capacity and ductility is becoming increasingly common. Therefore, a method to predict the performance of RC columns with and without retrofitting at ultimate is necessary to assure the structural performance during extreme seismic events. Although many researchers have developed methods of predicting the ultimate deformation, these methods are not taken into account effect of tension shifting induced by diagonal shear cracking. However, the analytical and experimental results has been indicated that the additional tension force based on truss mechanism significantly increases flexural deformation. To address these deficiencies, the conventional fiber model is modified by applying parameter of confinement ratio and fracture strain of FRP together with influence of tension shifting to predict the flexural deformation more accurately.

2. PREDICTING MODEL

(1) Flexural strength model

The traditional section analysis is widely used for the prediction of flexural strength of a reinforced concrete column. This analysis is performed on the column cross section by dividing the concrete area into a number of strips or fibers and assuming that plane sections remain plane at any load step.

Due to the nonlinear stress-strain relationships of materials, it is necessary to develop an iterative procedure to calculate the depth of the neutral axis for each increment of the extreme fiber concrete compressive strain. The stress-strain relationships of concrete are based on confinement effects caused by transverse reinforcement and FRP-jacketing. Many researchers have successfully developed the stress-strain relationship of concrete confined by both transverse steel and FRP reinforcement. However, this model can predict the behavior of concrete only in a pre-peak region. To extend to the post-peak region, the compressive fracture energy model proposed in the previous study[2] has been modified to consider the confinement effect as shown in Eq. (1). It was found that a = 0.86 and b = 2.25 showed a good agreement in the case of column jacketed by PET.

$$G_f = 8.8\left(f'_{cc}\right)^{a + b\frac{f_l}{f'_{cc}}} \tag{1}$$

The load-deformation response of a specimen tested[1] (see Table 1) with considering of the confinement effect in the stress-strain relationship of concrete, this sectional analysis (fiber model) can predict the load-deformation response in the ascending region well. However, shear behavior is not taken into account in this approach, despite the fact that the post-peak of load-deformation response depends upon shear behavior, especially in columns subjected to flexural-shear forces. To include the effect of shear in this fiber model, a truss analogy approach is combined with section analysis in order to predict the structural-performance precisely.

(2) Tension shift

The tension shift phenomenon has shown remarkable effects to spread plasticity after occurrence of diagonal shear cracking. Based on truss analogy approach, a model to illustrate the tension force (ΔT) of longitudinal reinforcement due to tension shift proposed by Ueda et al.[3] can be calculated as in Eqs. (2) and (3).

$$\text{If } V \le V_c \qquad \Delta T = 0 \tag{2}$$

$$\text{If } V > V_c \qquad \Delta T = \left[\cot\theta - \frac{\sin(\theta+\alpha)}{2\sin\theta\sin\alpha}\right]V_s \tag{3}$$

According to Eq.(3), the transverse reinforcement ratio, which controls the value of V_s, affects the additional tension force (ΔT). The additional tension force influences directly the flexural deformation due to the change of strain in the

Keywords: confinement, tension shifting, retrofitting, high fracturing strain, seismic loading

Contact address: Kita 13 Jo Nishi 8 Chome, Kita-ku, Sapporo, Japan, Tel: +81-11-706-6220, Fax: +81-11-707-6582

longitudinal reinforcement. θ and α in Eq.(3) refer to the angle of compression diagonal strut and the inclined angle of stirrup, respectively. In Figure 1, the tension force shifted after diagonal shear cracking is illustrated.

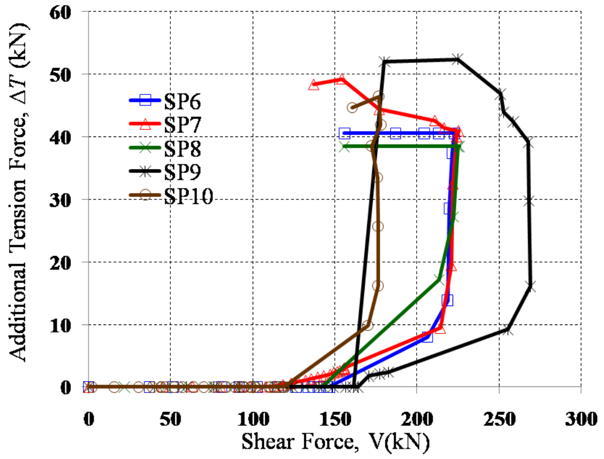

Figure 1 Additional tension force (ΔT) and shear force (V_s)

3. MODEL VERIFICATION

(1) Experimental program

Five RC column specimens tested under horizontal cyclic load and displacement control with an increment of $1\delta_y$ for each cycle [1] are investigated. The constant vertical force of 1 MPa was applied at the top of the specimen. The considered parameters were tension reinforcement ratio (ρ_t), fiber ratio (ρ_f) and shear span to depth ratio (a/d), while shear reinforcement ratio (ρ_w) was kept constant. The details of all specimens are shown in Table 1.

Table 1 Detail of specimens.

Item	Fiber	a	a/d	ρ_t	ρ_w	ρ_f
	-	m	-	%	%	%
SP5	PET	1150	3.1	2.87	0.16	0.19
SP6	PET	1500	4	2.87	0.16	0.12
SP7	PET	1150	4	2.87	0.16	0.06
SP8	PET	1150	4	2.87	0.16	-
SP9	PET	1150	4	3.59	0.16	0.12
SP10	PET	1150	4	2.15	0.16	0.06

(2) Comparison of Analytical and Experimental Results

It was observed that for all specimens the ultimate deformation was mainly reached due to concrete crushing and buckling of longitudinal reinforcement. The experimental results have shown that there was no breakage of the high fracturing strain PET fibers. Thus, the performance of the structure was improved by FRP-retrofitting in terms of greater ductility. For the specimen in which shear was dominant, SP5, with a small shear span, the ultimate deformation was due to the extensive shear cracking and eventually lead to flexure-shear failure. SP8 without FRP-retrofitting showed a sudden drop after buckling of longitudinal reinforcement, while SP6 which was jacketed by FRP shows a flexural failure and more ductility than that of SP8. This is great evidence to support that application of PET fibers improves ductility. In addition, the degradation of load-carrying capacity of FRP-jacketed specimens was prevented by the confinement provided by the PET fibers. Verification of the proposed model with combination of fiber model and truss mechanism model [1] was conducted. The analytical results can predict well and shows good agreement with the experimental results as shown in Figure 2.

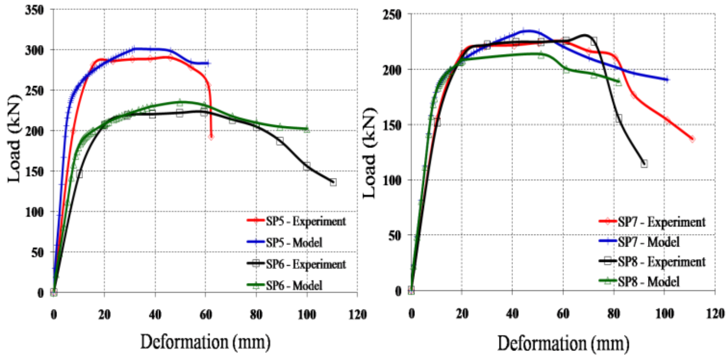

Figure 2 Analytical and experimental results of SP5-SP10

4. CONCLUSIONS

The analytical model for the ultimate of deformation of column, which consists of the potential flexure and shear model, is presented and its reliability is verified using an experimental program of square columns strengthened with PET sheet jacketing tested under reversed cyclic loading. The deformation from the experimental program well agrees with the analytical predictions. The proposed model shows that the fiber with high rupture strain can provide good ultimate ductility as the experimental fact indicates

REFERENCES

1) Anggawidjaja, D.: "Shear and Ductility of Reinforced Concrete Pier with High Fracturing Strain Fiber Material". *Master's Thesis, Hokkaido University*, 2006.

2) Nakamura, H. & Higai, T.: "Compressive Fracture Energy and Frascture Zone Length of Concrete". *JCI-C51E Seminar on Post-Peak Behavior of RC Structures Subjected to Seismic Loads, October 1999*, Vol.2, pp.2590-272, 1999.

3) Ueda, T. et al.: "Shear Deformation of Reinforced Concrete Beam". *JSCE Journal of Materials, Concrete Structures, Pavements*, Vol.56 No. 711, pp.205-215, 2002.