International Journal of GEOMATE, July, 2017, Vol.13, Issue 35, pp.40 - 47
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.35.6648

EVALUATION OF DIFFERENT FIBER REINFORCED MORTAR AS RETROFITTING MATERIALS FOR RC COLUMNS

* Bernardo A. Lejano [1]

[1] Faculty, De La Salle University, Philippines

*Corresponding Author, Received: 10 June 2016, Revised: 20 July 2016, Accepted: 24 Nov. 2016

ABSTRACT: This study is about the use of fiber reinforced mortar (FRM) as a jacketing material for reinforced concrete (RC) columns. Presented in this paper are analyses of the test results of destructive-loading that were conducted to explore the applicability of different jacketing materials as retrofit to RC columns. The jackets used to wrap RC columns were built of mortar mixed with different fibers. The fibers considered were steel fibers and polymer fibers. A simple model based on material properties was used to simulate the axial strength of the columns. The numerical model calculation results as well as the experimental test results were used to assess the performance of the jacketing materials used. The experimental part consisted of testing two sets of column specimens. The first set is wrapped with mortar jackets reinforced with steel fibers and the second set is wrapped with mortar jackets reinforced with polymer fibers with and without fly ash. The efficacy of the different FRM jackets as retrofitting materials was assessed by calculating the effect of confinement. The calculation was accomplished by measuring the maximum load of the retrofitted columns with jackets and then subtracting the load that can be carried by the control specimens, that is, the column with the original cross section. The confining effect was used as the basis in determining the confined compressive strength of concrete and then used to establish a model that can simulate the axial strength of the columns. The results indicate that the FRM jackets are effective as retrofitting material for RC column.

Keywords: Fiber Reinforced Mortar, RC Column, Retrofitting, Confining Effect, Axial Strength, Jacketing

1. INTRODUCTION

Columns are primarily structural members of a building that should not fail because failure of even one of these columns could result to the collapse of the whole structure. When columns show some sign of weakness, retrofitting is needed. Example to this are aged reinforced concrete (RC) columns, which usually are in need of retrofitting so as to compensate for the lost strength due to various environmental factors. Other reasons why RC columns need rehabilitation are concrete deterioration, unexpected increase in load, or physical damage. Retrofitting may be done by encasing the column with certain material. This retrofitting technique is termed as jacketing. This is the usual solution to fix deteriorated or damaged columns caused by environmental hazards like fire, seismic event, or differential upheaval of the foundation because of expansive clay soil [1].

Jacketing using steel plates is the usual method of retrofitting columns. While it is popular because of its simplicity, efficiency, and effectiveness, it also has its criticisms. Aside from being expensive, another disadvantage is that it may produce larger earthquake forces because it is heavy. Studies [2], [3] have shown that fiber reinforced polymer (FRP) sheet is a good alternative to steel plates. This material is very light, does not corrode and very easy to install. However, it is still very expensive.

As another option to steel plates and FRP sheets, jackets made of fiber reinforced mortar (FRM) are investigated in this study. This idea complements other studies [4]-[6] that fiber reinforcement can increase the strength, ductility and toughness of concrete. Even the use of recycled carpet fibers have been used as fiber reinforcement to concrete [7].

The study of Valerio *et al*. [8] recommended Steel Fiber Reinforced Mortar (SFRM) as another option of retrofitting material for RC columns. Their study showed improvement in the load that can be carried by the RC column after it is retrofitted with SFRM. However, they reported that using steel fibers has a down side. Since the fibers were stiff and cannot bend, it is difficult to place and distribute them in the column corners. This resulted to failure of the retrofitted columns initiated by the propagation of cracks at the column corners.

Considering the problem stated above, an alternative to steel fibers was proposed by Oropel *et al*. [9]. Polymer Fiber Reinforced Mortar (PFRM) was used as jacketing material instead of steel fibers because they are more flexible and can be easily placed at the column corners. Moreover, aside from being light, these fibers are resistant to corrosion. Two types of polymer fibers were used, synthetic and cellulose fibers.

This paper focuses on the simulation of the load-carrying capacity of RC columns with the above-mentioned jacketing materials (SFRM and PFRM). Previous work of the author [10] reported test results on the use of similar retrofitting materials but lacks the model to simulate the behavior of RC columns retrofitted with jackets. This paper attempts to provide a simple model that can predict the axial strength of RC columns retrofitted with FRM jackets once the confinement effect is determined.

2. RETROFITTING USING FRM

The usual repair of RC column is done by removing the damaged or deteriorated concrete and substituting it with new concrete. To improve its strength, it may be encased with layer (or jacket) of mortar or shotcrete [10]. The effect of the jacket is two-fold, it enlarges the cross-section of the column and it provides confinement to the original core concrete. In this study, the load is applied only to the original section such that the effect of the enlargement of the section may not apply. Hence, only the confinement effect will be emphasized in this study. However, it may not be denied that the section enlargement may have an effect because of the redistribution of stresses.

2.1 Confinement Effect

When a material is subjected to axial compression, it would be accompanied by transverse tensile deformation. If this transverse deformation is restrained, it would result to higher axial resistance of the material. This phenomenon is the same for concrete and is termed as the confinement effect. In RC columns, the steel ties or hoops usually provide the partial restrain of the transverse deformation resulting to the confinement of the core concrete. This usually results to an increase in the axial strength of the column. In addition, the hoops avert the concrete expansion and prevent tensile cracking in concrete. Hence, considerable improvement in ductility is usually observed [3].

In retrofitted RC columns, the jackets provide the same confinement effect as mentioned above. To provide adequate confinement the jacket must have enough tensile strength. For this reason, the mortar jacket is reinforced with fibers.

2.2 Material Selection

The choice of suitable material is an important factor in deciding the retrofitting technique to be used. The material must match with the RC column and must be easy to install. Prospective clients for retrofitting jobs would usually want something that is economical and that would not drastically impair the use or occupancy of the structure. Reinforced mortar jacket is an ideal material for this job.

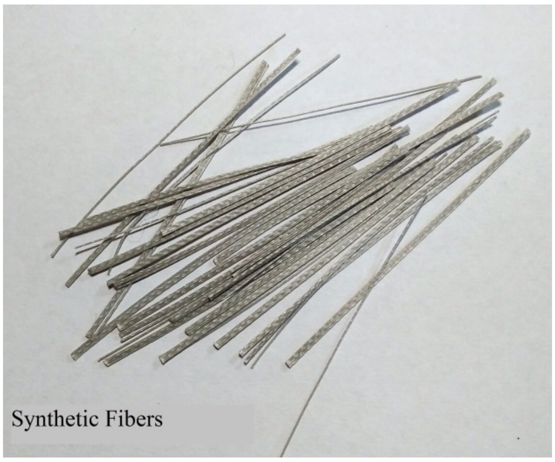
To make the mortar jacket suitable as retrofitting material, it must possess the following qualities: low drying shrinkage, fast strength development, and excellent crack resistance. These qualities of mortar may be attained by reinforcing it with fibers. Moreover, shorter fiber reinforcement may be desirable because it can be made into a thinner layer of repair [6]. However, the above mentioned qualities of mortar jacket must be maintained and longer fiber may be needed to ensure this.

One of the materials examined in this study is the Steel Fiber Reinforced Mortar (SFRM) jacket. Mortar was mixed with steel fibers to increase its tensile strength. The steel fibers used in this study have the following properties: unit weight is 19 g, length is 50 mm and diameter is 0.75 mm. Photo of the steel fibers is shown in Fig. 1. Notice the curls at the ends of each fiber. They provide better bond between the steel fibers and concrete.

Fig.1 Photo of steel fibers

The other material examined in this study is the Polymer Fiber Reinforced Mortar (PFRM). The two polymer fibers used were the synthetic fibers and the cellulose fibers. These fibers were expected to provide the same increase in tensile strength of concrete as steel fibers provided, but more flexible.

The synthetic fibers are especially engineered copolymer fibers designed as substitute to the steel reinforcement in concrete floors on grade and pavements. They are also used as reinforcement in precast concrete products with strength up to 35 MPa. As can be seen in Fig. 2, the size and shape of synthetic fibers are almost similar to the steel fiber suggesting that it can be used as direct substitute for steel fibers. The dosage used is 2.5 kg per cubic meter of mortar [9].



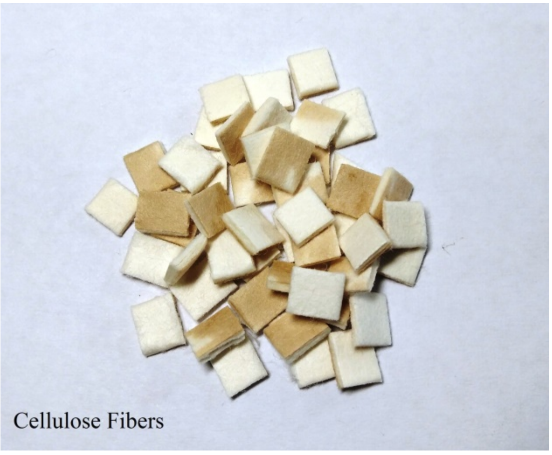


Fig.2 Pictures of synthetic fibers (top) and cellulose fibers (bottom)

As shown in Fig. 2, the cellulose fibers appear first as blocks but disperse evenly into concrete as micro fibers after contact with water. Approximately 1500 million crack-fighting micro fibers are produced per kg of concrete on a dosage of 2 bags per cubic meter of concrete. These cellulose fibers have excellent bond with cement resulting to decrease in plastic shrinkage cracking. They also tend to make the concrete denser. The same effects are expected in mortar, hence improving the strength of mortar jacket [9]. In addition, the cellulose fiber is alkali resistant and allows better surface finishing.

3. EXPERIMENTAL PROGRAM

Several RC column specimens were made and subjected to destructive testing to evaluate their efficacy as retrofitting materials. In this study, 4 cases were studied for the columns with SFRM jacket (referred to as SFRM series). This includes the control specimens (without jacket), and specimens with mortar jackets containing 1%, 2%, and 3% steel fibers by volume. This resulted to 3 control column specimens and 9 column specimens with SFRM jacket. (Refer to Table 1). Sakthivel *et al*. [4] investigated concrete with almost the same steel fiber volume range.

Table 1 Construction details of specimens

	SFRM Series	PFRM Series
Retrofitting material	Mortar w/ Steel Fiber	Mortar w/ Polymer Fiber
Original column size	120x120x300 Ac=14400mm^2	180x180x400 Ac=32400mm^2
Concrete cover	20 mm	40 mm
Main rebars	4 – 10 mmϕ	4 – 10 mmϕ
Tie diameter	8 mm	8 mm
Tie spacing	160 mm	160 mm
Mortar jacket thickness	20mm	10mm
Different cases (Each case has 3 column specimens)	1) control 2) 1% SFRM 3) 2% SFRM 4) 3% SFRM	1) control 2) mortar 3) Synthetic 4) Cellulose 5) Syn. w/ FA 6) Cel. w/ FA

There were 6 cases that were studied for columns with polymer FRM jackets (referred to as PFRM series). The 1st case is the control specimens without jacket, the 2nd is with mortar jacket, the 3rd is with synthetic FRM jacket, the 4th case is with cellulose FRM jacket, 5th is with synthetic FRM jacket mixed with fly ash (FA), and the 6th case is with cellulose FRM jacket mixed with fly ash. This resulted to 12 column specimens with PFRM jacket, 3 column specimens with mortar jacket, and 3 control specimen (without jacket). (Refer to Table 1)

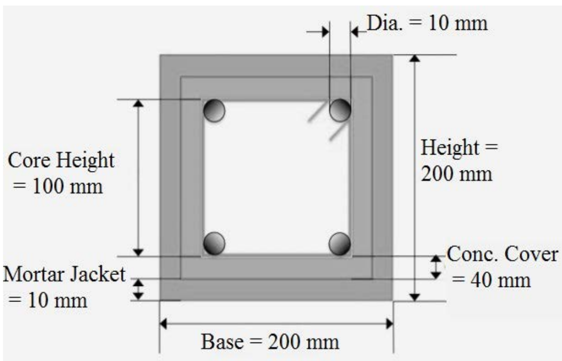


Fig.3 Typical cross-section of column specimen with PFRM jacket

Shown in Table 1 are the construction details of the RC column specimens. All columns were tied RC columns with square cross-section. The details of the dimension and reinforcement are shown in Fig. 3 and Fig. 4. Although the details shown are for column specimens of PFRM series, the other series were constructed in similar manner with slight variation only in the size of the cross section and the jacket thickness. Furthermore, the ties are the same for all column specimens justifying the assumption that the magnitude of its confinement effect (if there is any) is the same for all column specimens.

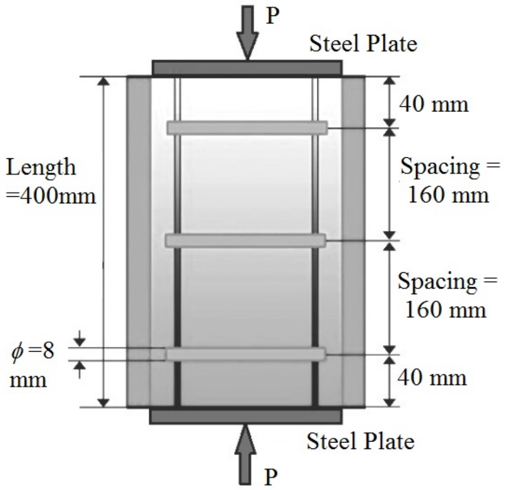


Fig.4 Typical side-section of column specimens with PFRM jacket

Axial load was applied through steel plates, as shown in Fig. 4, to ensure that the force is applied only to the original cross-section of the column specimen. This is done to simulate the possible actual condition at the ends of the columns. Due to difficulties in application of the mortar at the column ends, the jacket cannot be ensured to be in full contact with the other connected members of the structure at the column ends resulting to ineffective transmission of the axial load through the jacket cross-section.

4. TEST RESULTS

The results of strength tests of concrete, mortar with fibers, and steel reinforcing bars are tabulated in Table 2. It can be seen that the compressive strength of mortar increased with the addition of fiber. However, the introduction of fly ash in the PFRM series resulted to the decrease in strength. Fly ash was introduced because it was thought to improve the performance of mortar. However, the result was contrary as indicated in the mortar strength test results shown in Table 2. It is not clear why the fly ash did not perform as expected, but it may have something to do with its proportion to the mix. In this study, fly ash was used as 30% replacement to cement.

Table 2 Strength of concrete, mortar, and steel

Material	SFRM series	PFRM series
Concrete, fc'	21.0 MPa	21.5 MPa
Mortar fc' (MPa)	15.2 (0%SF) 19.2 (1%SF) 18.6 (2%SF) 17.6 (3%SF)	18.2 (No Fiber) 23.7 (Synthetic) 21.8 (Cellulose) 20.8 (Syn. w/ FA) 16.4 (Cel. w/ FA)
Steel, fy	388 MPa	378 MPa

The average maximum recorded axial force (P_{max}) is used as the basis of comparison of these retrofitting materials. It was observed that when the strain reached 0.003, the maximum load was already attained. Tabulated in Table 3 are average maximum loads (P_{max}) for each case investigated.

Table 3 Average maximum load of the columns

Series	Case	P_{max} (kN)	% Increase in P_{max}
SFRM	Control	369.5	0.0
	1% SFRM	401.5	8.7
	2% SFRM	437.9	18.5
	3% SFRM	390.4	5.7
PFRM	Control	697.8	0.0
	Plain Mortar	673.7	-3.5
	Synthetic	894.7	28.2
	Syn. w/ FA	853.2	22.3
	Cellulose	794.3	13.8
	Cel. w/ FA	730.2	4.6

The increase in P_{max} (expressed in %) of each retrofitted column is obtained with respect to the P_{max} of the control specimens of the series. The largest increase in strength is 28.2%. This is for the case of synthetic PFRM jacket. For SFRM series, the maximum increase is 18.5%, which was obtained at 2% steel fiber reinforcement.

It is interesting to note that there is no significant increase in P_{max} when plain mortar jacket was used. This means that enlargement of the section due to mortar jacket did not contribute to the strength increase of the column. Also, it seems that the ties did not provide significant confinement. This was also observed by other research [11] when the tie spacing is medium to large. Furthermore, the introduction of fly ash to the mortar mix did not result to a better jacket.

Shown in Fig.5 are pictures showing the difference in the crack patterns between column with PFRM jacket and column with SFRM jacket, at the final failure. It can be seen that cracks are more scattered in the PFRM series while cracks are concentrated in the corner of the column with SFRM jacket. Since it is difficult to place the steel fibers in the corners of the SFRM jacket, the corners may be considered as zone of weakness.

Fig.5 Comparison of cracks of column with PFRM jacket (top picture) and with SFRM jacket (bottom picture)

5. ANALYSIS OF DATA

The load that can be carried by control specimens (columns without jacket) may be expressed as Eq. (1). Considering the nominal or maximum loads obtained from tests, the load-carrying efficacy of concrete (represented by α) may be calculated. The results are shown in Table 4. It can be seen that the values obtain for α is very close to the 0.85 value that is commonly used in design formulas.

$$P\max = \alpha \;\; fc' \;\; Ac + fy \;\; As \qquad (1)$$

Table 4 Efficacy of concrete, α

Type	P_{max} (kN)	α fc'Ac (kN)	fy As (kN)	α
SFRM	369.5	302.4	121.9	0.82
PFRM	697.8	696.6	118.8	0.83

5.1 Simulation Using a Simple Model

To simulate the behavior of columns a simple model is developed based on the stress-strain relationships of the materials. Shown in Fig. 6 is the stress-strain curve of concrete and steel.

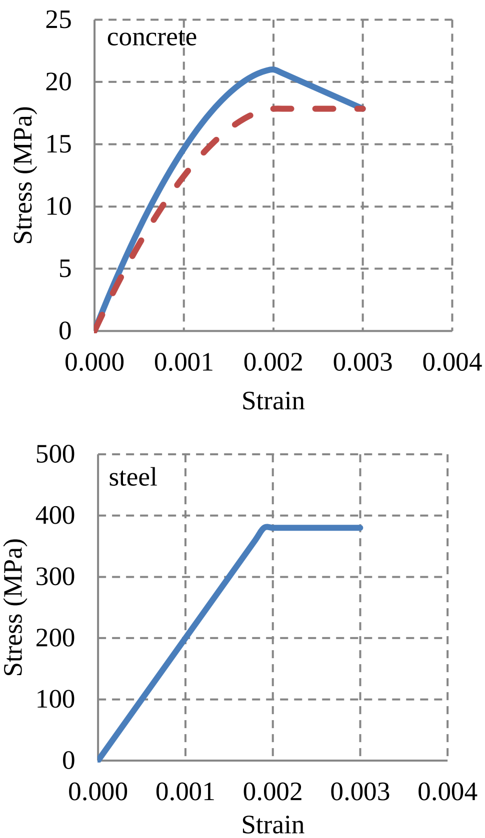


Fig.6 Stress-strain curve of concrete (top graph) and steel rebar (bottom graph)

For concrete (shown as solid line in Fig. 6), the exponential stress-strain curve developed by

Lejano [12] was used as a constitutive model for concrete. The equation for the ascending branch of the stress-strain curve of this model is shown in Eq. (2). The descending branch is linear from peak stress up to the ultimate strain of 0.003.

$$fc = fc'\left[1 - \left(\frac{\varepsilon_p - \varepsilon}{\varepsilon_p}\right)^b\right] \tag{2}$$

where fc = stress of concrete at strain (ε), fc' = compressive strength of concrete, ε_p = strain at peak stress = 0.0018 + 0.00001 fc', and b = 2 - 0.0125 fc'.

For steel, the relationship is simply elastic-plastic model. The steel stress (fs) is linear and proportional to the strain at the ascending branch, and become fully plastic after the yield point, that is, fs=fy.

Using these stress-strain relationships, the axial force (P) at any particular strain of the control column specimens may be calculated by changing Eq. (1) into Eq. (3). Note that α is multiplied to fc up to the peak stress and afterwards the stress is maintained constant, as shown in the dashed curve in the stress-strain curve of concrete in Fig. 6.

$$P = \alpha \ fc \ Ac + fs \ As \tag{3}$$

The calculation results using this model are compared to the experiment results and are shown in Fig. 7 and Fig. 8 for the control specimens of SFRM and PFRM series, respectively. It can be seen that relatively good agreement is obtained between the calculation and the experiment results.

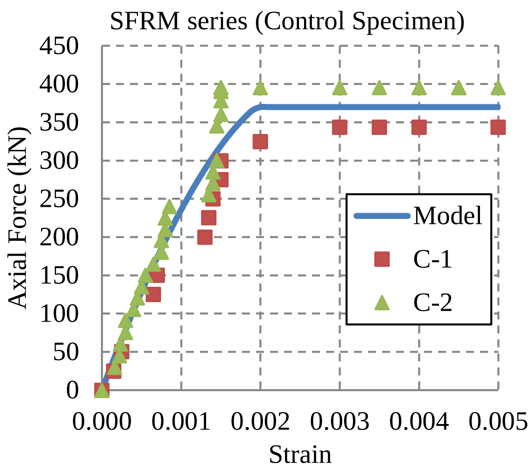


Fig.7 Comparison of model with test data of control column specimen (SFRM series)

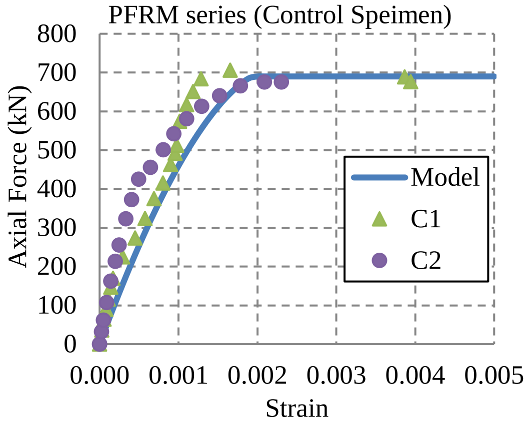


Fig.8 Comparison of model with test data of control column specimen (PFRM series)

Using this model, the calculated P_{max} are 369.9 kN and 690.0 kN for the control specimens of SFRM series and PFRM series, respectively. These are very close to the test results.

5.2 Calculation of Confinement Effect

As indicated by test results, there is no significant increase in axial force because of the enlargement of the section due to the jacket. In fact, if one tries to include the axial force carried by the jacket, the result would be very much greater than the experimentally obtained P_{max}. Hence, the increase in axial force may be concluded to be due to the confinement effect only of the jackets. The axial force due to confinement (which is termed as confinement effect) may be obtained by subtracting the calculated strength of the control column specimen from the experimentally observed P_{max}. This results to Eq. (4), where C_f is the confinement effect.

$$C_f = P_{max} - \left(\alpha \ fc' \ Ac + fy \ As\right) \tag{4}$$

Table 5 Confinement effect and increase in compressive strength of concrete

Case	C_f (kN)	λ = Inc. in fc' (%)
Control	-0.4	-0.2
1% SFRM	31.6	12.8
2% SFRM	68.0	27.4
3% SFRM	20.5	8.3
Control	7.8	1.4
Mortar	-16.3	-2.9
Synthetic	204.8	35.8
Syn. w/ FA	163.3	28.6
Cellulose	104.3	18.3
Cel. w/ FA	40.2	7.0

The confinement effect is evaluated for all column specimens. The results are shown in Table 5. By dividing Cf by the force resisted by the concrete, that is, αfc'Ac, then the increase in fc' may be determined. This increase in fc' is denoted as λ and is shown also in Table 5.

It can be seen that the FRM provided significant confinement. Among all cases, the synthetic PFRM jacket provided the largest confinement effect. For the SFRM series, the highest increase seems to be obtained in the 2% steel fiber. But when the jacket is made of plain mortar, negligible confinement effect was observed. Furthermore, the incorporation of fly ash resulted to less confinement effect.

Lastly, a model for predicting the load-strain relationship of the column considering the confinement effect is proposed by simply increasing the concrete stress by the factor λ. This is expressed in Eq. (5).

$$P = (1+\lambda)\ 0.85\, fc\ \ Ac + fs\ \ As \qquad (5)$$

The plot of the results of the simulation using the model as compared to the experiment results is shown in Fig. 9.

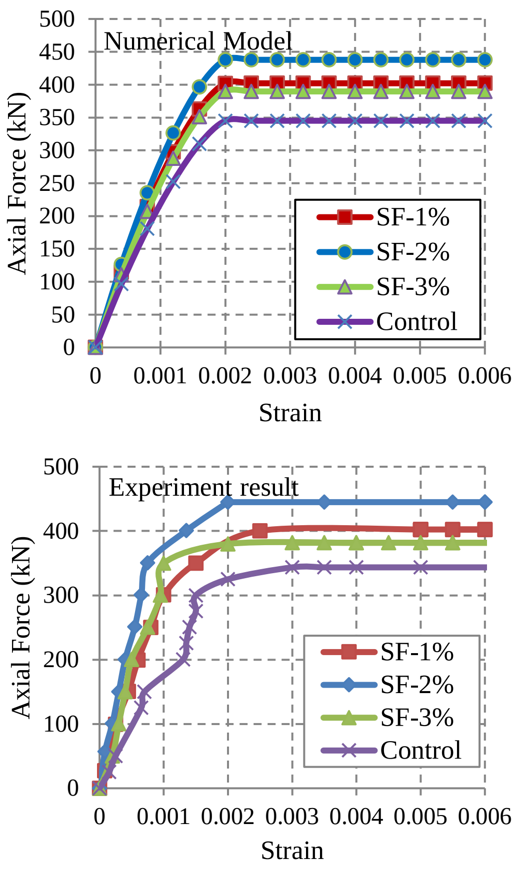


Fig.9 Comparison of model with test data

It can be seen that relatively good agreement is obtained. The practical application of this model is in the analysis of RC structure. Columns retrofitted with FRM jacket may be simulated using this model.

6. CONCLUSION

It had been shown that the FRM jackets were effective as retrofitting material for RC columns. Among all cases investigated, the results indicate that the largest increase in strength is obtained in the column with synthetic FRM jacket. The axial load was increased by as much as 28.2%. The corresponding increase in the confined concrete strength was evaluated as 35.8%. Both occurred for the column with synthetic PFRM jacket. Furthermore, it was shown that the confined concrete strength may be determined through the calculation of the confinement effect by evaluating the contribution of the different materials. A simple model was presented that can simulate the behavior of column as affected by confinement.

7. ACKNOWLEDGEMENTS

The author acknowledges J.C. Oropel, G.C. Panaligan, J.C. Sy, D.N. Valerio, K.K. Galicia, and J.V. Sia for their vital roles in the conduct of the experimental tests. The author is also grateful to the faculty and staff of the Civil Engineering Department of De La Salle University for their encouragement.

8. REFERENCES

[1] Daoud OM, “Damage assessment and strengthening of R/C building constructed on expansive soils”, Int. J. of GEOMATE, Vol. 4, No. 2 (Sl. No. 8), June, 2013, pp. 516-521.

[2] Berthet JF, Ferrier E and Hamelin P, “Compressive behavior of concrete externally confined by composite jackets. Part A: Experimental study”, Construction and Building Materials, Vol. 19, Issue 3, 2005, pp. 223–232.

[3] Binici B, “An analytical model for stress–strain behavior of confined concrete”, Engineering Structures, Volume 27, 2005, pp. 1040–1051.

[4] Sakthivel PB, Ravichandran A and Alagumurthi N, “Experimental and predictive mechanical strength of fiber reinforced cementitious matrix”, Int. J. of GEOMATE, Vol. 7, No. 1 (Sl. No. 13), Sept. 2014, pp.993-1002.

[5] Cominoli L, Failla, C and Plizzari GA, “Steel and synthetic fibres for enhancing concrete

toughness and shrinkage behavior", Proc. Int. Conf: Sustainable Construction Materials and Technologies, 2007, pp.231-240.

[6] Sorelli L, Banthia N and Plizzari GA. "Crack growth resistance of thin mortar layers with hybrid fiber reinforcement", Special Publication 224, Paper N. 12, ACI, 2004, pp. 161-178.

[7] Abdul Awal ASM, Mohammadhosseini H, Hossain MZ, "Strength, modulus of elasticity and shrinkage behavior of concrete containing waste carpet fiber", Int. J. of GEOMATE, Vol. 9, No. 1 (Sl. No. 17), Sept., 2015, pp. 1441-1446.

[8] Valerio DN, Galicia KK, Sia JV and Lejano B, "Retrofitting of RC columns with steel fiber reinforced mortar", 15th ASEP International Convention (15AIC), Manila, Philippines, Sep. 28-29, 2011.

[9] Oropel JC, Panaligan GC and Sy JC, "A study on the confinement effects of fiber reinforced mortar (FRM) on RC columns", Thesis, De La Salle University, 2013.

[10] Lejano B, "Confinement effects of different retrofitting materials on the axial strength of reinforced concrete columns", 7th HNICEM Conference, Palawan, Phil., Nov. 13-14, 2014.

[11] Demers M and Neale KW, "Confinement of reinforced concrete columns with fibre-reinforced composite sheets - an experimental study", Can J Civil Eng, Vol 26, 1999, pp. 226–241.

[12] Lejano B, "Modeling the stress-strain relationship of high strength concrete made of local aggregates", 1st ASEAN Civil Engineering Conference (ACEC), Pattaya, Thailand, March 12-13, 2009.