Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Analytical Model for CFRP Strengthened RC Columns in Humid Conditions

R. Rashid[1] and R.S. Aboutaha[2]

[1]*Univeristi Putra Malaysia,Serdang, Malaysia*
rsrashid@syr.edu

[2]*Syracuse University, Syracuse, USA*
rsabouta@syr.edu
L.C. Smith College of Engineering and Computer Science
151 Link Hall, Syracuse NY 13244

ABSTRACT

Replacement of functionally obsolete structural members is not the answer in sustainable construction market. Sustainable methods should be adopted to increase the load carrying capacity structures/members to increase their service life. In order to increase the load carrying capacity and/or increase the service life of existing reinforced concrete columns, Carbon Fibre Reinforced Polymer (CFRP) composites could be utilized. It provides good confinement to the concrete column core, which enhances the bending and compression strength as well as ductility.

This paper presents an analytical concrete confinement model that reflects the effects of humidity on the mechanical properties of CFRP composites, and consequently, the humidity effects on the efficiency of CFRP in strengthening concrete columns. Tensile strength and modulus in humidity, and their effects on the concrete confinement are the two primary parameters that will be investigated. A modified concrete confinement model is developed and presented.

Keywords. CFRP, Circular concrete columns, Confinement, Humidity and temperature

INTRODUCTION

Replacement of functionally obsolete structural members is not the answer in sustainable construction market. Sustainable methods should be adopted to increase the load carrying capacity structures/members to increase their service life. It is now widely acceptable that the compressive strength and ductility of concrete can be significantly enhanced by fiber-reinforced polymer (FRP) wrappings. These easy to manage and install FRP wraps can be utilized to extend the service life of structural damage columns, increase load capacity of buildings and bridges that are prone to earthquake forces.

Several models are available to estimate the strength of CFRP confined concrete. In south-east Asia, a hot-humid region, it is important to develop models that take these two critical environmental factors into account. In developing an equation to be considered as practically accepted, the need to add the humidity and elevated temperature effects to the existing confined model is indeed significant.

The existing strength and well known model equation for FRP confined concrete is given in Equation 1 (Lam & Teng, 2002):

$$\frac{f'_{cc}}{f'_{co}} = 1 + 2\frac{f_l}{f'_{co}} \tag{1}$$

where f'_{cc} is the compressive strengths of the confined concrete, f'_{co} is the compressive strengths of the unconfined concrete, meanwhile f_l is the lateral confining pressure and 2 is the confinement effectiveness coefficient. The detailed explanation regarding this equation can be found in reference by Lam and Teng (Lam & Teng, 2002). It is also stated in that reference that the tensile strength of the CFRP should be determined according to ASTM D 3039 or similar method using flat coupons where it is clearly giving lower standard deviation compared to splitting tests for ring specimen and manufacturers and others sources. Also in the same reference, it is clearly stated that axial compression strength for steel confined concrete are conservative and unsuitable for FRP confined concrete.

In the development of Equation 1, data were collected from three different set of data to determine the mechanical properties of the FRP with set no. 1 is with flat coupon test, set no. 2 is with ring splitting test and set no. 3 is from the manufacturer specification. The data was with various type of FRP which is the Carbon Sheets, Carbon Filament, E Glass Sheets, Glass Sheets, Glass and Carbon sheets, Aramid Sheets, S Glass Sheets, E Glass Filament, Glass Strands, E Glass Strands and Glass Filament. However, this paper will only focus on Carbon Fiber Sheets or CFRP sheets and with flat coupon test according to (ASTM., 1995) knowing that this is the most common material and test opted.

EFFECTS OF ELEVATED TEMPERATURE ON CFRP PROPERTIES

Most of the research associated with the effect of elevated temperature on properties of CFRP was found typically by investigating the exposure of the CFRP confined concrete to fire. The temperature of exposure ranges between 100^{o}C to 700^{o}C (Bisby, Chen, Li, Stratford, Cueva, & Crossling, 2011; A. Al-Salloum, M. Elsanadedy, & A. Abadel, 2011). This extreme heat exposure has several other effects, such as the phase where the CFRP would start to ignite and combustion effect of the polymer matrix which is definitely very complicated scenario to simulate.

In this paper, CFRP confined circular concrete column exposed to temperature ranging between room temperature (25^{o}C ± 2) and 100^{o}C are considered in developing a modified analytical model based on Equation 1. Reason of the selection of the criteria is to simulate the temperature exposure during summer in southern United States of America and some countries in Asia. Having this type of temperature variation exposure causes the CFRP to expand, which may result in decreased confining effect and consequently, reduced overall column strength.

EFFECTS OF HUMIDITY ON CFRP PROPERTIES

There seem to be very limited data on the effect of humidity variation on the CFRP properties. Most of the humidity effects were investigated under the freeze and thaw research

(Toutanji & Balaguru, 1998; Bae & Belarbi, 2010; El-Hacha, Green, & Wight, 2010; Micelli, Myers, & Murthy, 2002). It is known, that the effect of humidity itself is disturbed when the temperature drops and vice versa. In the effort to included humidity effect in Equation 1, National Climatic Data Center (NCDC) data was referred (National Climatic Data Center, 2008). NCDC data was based from observation station located at 48 states monitoring the temperature, wind, snowfall, rainfall and humidity which was last updated January 16th 2008. From the information provided, the hottest temperature recorded was from Key West, Florida Station meanwhile the highest humidity reading recorded was from Quillayute, Washington State Station.
However, NOAA does not provide the data for these two stations. The data were found available from Weather Underground beginning June 2012 to November 2012 consist of day to day temperature and humidity monitoring record (Weather Underground, 2012). All the data were then plotted as shown in Figure 1. Relationship between relative humidity and temperature is represented by:

$$\boldsymbol{RH}(\%) = \mathbf{88.22} - \mathbf{0.55}(\boldsymbol{T}°\boldsymbol{C}) \qquad (2)$$

where T^oC is temperature in Celsius. Equation (2) later was used in Table 1 to obtain the missing data for Relative Humidity for each temperature.

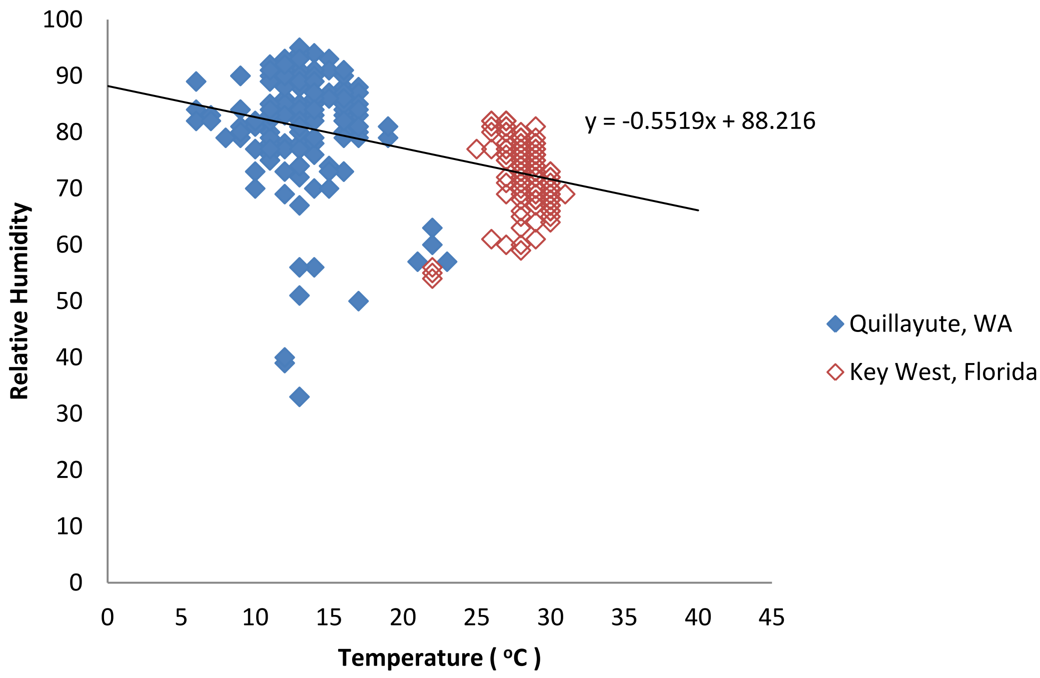

Figure 1: Relationship between Temperature (°C) and Relative Humidity (%).

TEST DATA

In Table 1, test data from (Harmon & Slattery, 1992; Demers & Neale, 1994; Picher, Rochette, & Labossiere, 1996; Watanable, et al., 1997; Miyauchi, Nishibayashi, & Inoue, 1997; Harries, Kestner, Pessiki, Sause, & Ricles, 1998; Toutanji & Balaguru, 1998; Toutanji H. , 1999; Matthys, Taerwe, & Auddenaert, 1999; Xiao & Wu, 2000 and Zhang, Ye, & Mai, 2000) was complied based on (Lam & Teng, 2002) paper. All 61 data was considered to have temperature exposure equal to room temperature of 25^{o}C ± 2. Meanwhile the other 23 data based on (Micelli, Myers, & Murthy, 2002; El-Hacha, Green, & Wight, 2010; Bae & Belarbi, 2010; A. Al-Salloum, M. Elsanadedy, & A. Abadel, 2011; Bisby, Chen, Li, Stratford, Cueva, & Crossling, 2011; Hadi & Louk Fanggi, 2012) was for various temperature exposure recorded in test. In total, 84 data were considered in this analysis. In this set of data, all the circular concrete is without any steel reinforcement, with L/d, and concrete compressive strength is not exceeding 4.0 and 60 MPa respectively. It is also worth noting here that only the first 4 data for f'cc in Table 1 was calculated from stress-strain curves while the others were from compression test done in the lab.

Table 1: Experiment Data (CFRP sheets only)

Number	**Data**	**d (mm)**	**L (mm)**	**f'_{co} (MPa)**	**t (mm)**	**f_{frp} (MPa)**	**E_{frp} (MPa)**	**f'_{cc} (MPa)**	**^{o}C**	**Relative Humidity (%)**
1	Harmon and Slattery 1992*	51	102	41.0	0.09	3500	235000	86.0	25	74
2	Harmon and Slattery 1992*	51	102	41.0	0.18	3500	235000	117.0	25	74
3	Harmon and Slattery 1992*	51	102	41.0	0.34	3500	235000	158.0	25	74
4	Harmon and Slattery 1992*	51	102	41.0	0.69	3500	235000	241.0	25	74
5	Demers and Neale 1994	152	305	32.2	0.30	380	25000	41.1	25	74
6	Demers and Neale 1994	152	305	43.7	0.30	380	25000	48.4	25	74

Number	Data	d (mm)	L (mm)	f'$_{co}$ (MPa)	t (mm)	f_{frp} (MPa)	E_{frp} (MPa)	f'$_{cc}$ (MPa)	^{o}C	Relative Humidity (%)
7	Demers and Neale 1994	152	305	43.7	0.90	380	25000	75.2	25	74
8	Demers and Neale 1994	152	305	43.7	0.90	380	25000	73.4	25	74
9	Picher et al 1994	152	304	39.7	0.90	1266	83000	56.0	25	74
10	Watanabe et al 1994	100	200	30.2	0.17	2716	224600	46.6	25	74
11	Watanabe et al 1994	100	200	30.2	0.50	2873	224600	87.2	25	74
12	Watanabe et al 1994	100	200	30.2	0.67	2658	224600	104.6	25	74
13	Watanabe et al 1994	100	200	30.2	0.14	1579	628600	41.7	25	74
14	Watanabe et al 1994	100	200	30.2	0.28	1824	628600	56.0	25	74
15	Watanabe et al 1994	100	200	30.2	0.42	1285	576600	63.3	25	74
16	Miyauchi et al 1997	150	300	45.2	0.11	3481	230500	59.4	25	74
17	Miyauchi et al 1997	150	300	45.2	0.22	3481	230500	79.4	25	74
18	Miyauchi et al 1997	150	300	31.2	0.11	3481	230500	52.4	25	74
19	Miyauchi et al 1997	150	300	31.2	0.22	3481	230500	67.4	25	74
20	Miyauchi et al 1997	150	300	31.2	0.33	3481	230500	81.7	25	74
21	Miyauchi et al 1997	150	300	51.9	0.11	3481	230500	75.2	25	74
22	Miyauchi et al 1997	150	300	51.9	0.22	3481	230500	104.6	25	74
23	Miyauchi et al 1997	150	300	33.7	0.11	3481	230500	69.6	25	74
24	Miyauchi et al 1997	150	300	33.7	0.22	3481	230500	88.0	25	74
25	Miyauchi et al 1997	150	300	33.7	0.33	3481	230500	109.9	25	74

Number	**Data**	**d (mm)**	**L (mm)**	**f'$_{co}$ (MPa)**	**t (mm)**	***f$_{frp}$* (MPa)**	**E$_{frp}$ (MPa)**	**f'$_{cc}$ (MPa)**	**^{o}C**	**Relative Humidity (%)**
26	Harries et al 1998	152	610	26.2	1.00	580	38100	50.6	25	74
27	Harries et al 1998	152	610	26.2	2.00	580	38100	64.0	25	74
28	Toutanji and Balaguru 1998	76	305	31.8	0.22	1518	228000	98.7	25	74
29	Toutanji and Balaguru 1998	76	305	31.8	0.33	3485	373000	96.0	25	74
30	Toutanji 1999	76	305	31.0	0.24	2940	372800	60.8	25	74
31	Matthys et al. 1999	150	300	34.9	0.12	2600	200000	44.3	25	74
32	Matthys et al. 1999	150	300	34.9	0.24	1100	420000	41.3	25	74
33	Xiao and Wu 2000	152	305	33.7	0.38	1577	105000	47.9	25	74
34	Xiao and Wu 2000	152	305	33.7	0.38	1577	105000	49.7	25	74
35	Xiao and Wu 2000	152	305	33.7	0.38	1577	105000	49.4	25	74
36	Xiao and Wu 2000	152	305	33.7	0.76	1577	105000	64.6	25	74
37	Xiao and Wu 2000	152	305	33.7	0.76	1577	105000	75.2	25	74
38	Xiao and Wu 2000	152	305	33.7	0.76	1577	105000	71.8	25	74
39	Xiao and Wu 2000	152	305	33.7	1.14	1577	105000	82.9	25	74
40	Xiao and Wu 2000	152	305	33.7	1.14	1577	105000	86.2	25	74
41	Xiao and Wu 2000	152	305	33.7	1.14	1577	105000	95.4	25	74
42	Xiao and Wu 2000	152	305	43.8	0.38	1577	105000	54.7	25	74
43	Xiao and Wu 2000	152	305	43.8	0.38	1577	105000	52.1	25	74

Number	Data	d (mm)	L (mm)	f'_{co} (MPa)	t (mm)	f_{frp} (MPa)	E_{frp} (MPa)	f'_{cc} (MPa)	°C	Relative Humidity (%)
44	Xiao and Wu 2000	152	305	43.8	0.38	1577	105000	48.7	25	74
45	Xiao and Wu 2000	152	305	43.8	0.76	1577	105000	84.0	25	74
46	Xiao and Wu 2000	152	305	43.8	0.76	1577	105000	79.2	25	74
47	Xiao and Wu 2000	152	305	43.8	0.76	1577	105000	85.0	25	74
48	Xiao and Wu 2000	152	305	43.8	1.14	1577	105000	96.5	25	74
49	Xiao and Wu 2000	152	305	43.8	1.14	1577	105000	92.6	25	74
50	Xiao and Wu 2000	152	305	43.8	1.14	1577	105000	94.0	25	74
51	Xiao and Wu 2000	152	305	55.2	0.38	1577	105000	57.9	25	74
52	Xiao and Wu 2000	152	305	55.2	0.38	1577	105000	62.9	25	74
53	Xiao and Wu 2000	152	305	55.2	0.38	1577	105000	58.1	25	74
54	Xiao and Wu 2000	152	305	55.2	0.76	1577	105000	74.6	25	74
55	Xiao and Wu 2000	152	305	55.2	0.76	1577	105000	77.6	25	74
56	Xiao and Wu 2000	152	305	55.2	0.76	1577	105000	77.0	25	74
57	Xiao and Wu 2000	152	305	55.2	1.14	1577	105000	106.5	25	74
58	Xiao and Wu 2000	152	305	55.2	1.14	1577	105000	108.0	25	74
59	Xiao and Wu 2000	152	305	55.2	1.14	1577	105000	103.3	25	74
60	Zhang et al 2000	150	300	34.3	1.00	423	37000	44.2	25	74
61	Zhang et al 2000	150	300	34.3	1.00	753	91000	59.4	25	74
62	F. Micelli et al 2002	102	204	37.0	0.16	3793	227000	60.0	22	76
63	El-Hacha et al 2010	150	300	52.7	0.16	3400	230000	66.1	20	77
64	El-Hacha et al 2010	150	300	52.7	0.16	3400	230000	75.4	45	63

Number	Data	d (mm)	L (mm)	f'_{co} (MPa)	t (mm)	f_{frp} (MPa)	E_{frp} (MPa)	f'_{cc} (MPa)	^{o}C	Relative Humidity (%)
65	Bae and Belarbi 2010	203	914	28.3	0.16	3790	227000	30.2	25	74
66	Bae and Belarbi 2010	203	914	28.3	0.16	3790	227000	29.9	25	74
67	Al-Salloum et al 2011	100	200	38.8	1.00	846	77280	95.4	25	74
68	Al-Salloum et al 2011	100	200	38.8	1.00	846	77280	95.4	25	74
69	Al-Salloum et al 2011	100	200	38.8	1.00	846	77280	95.4	25	74
70	Al-Salloum et al 2011	100	200	38.2	1.00	846	77280	94.7	100	33
71	Al-Salloum et al 2011	100	200	38.1	1.00	846	77280	94.5	100	33
72	Al-Salloum et al 2011	100	200	37.0	1.00	846	77280	90.5	100	33
73	Bisby et al 2011	100	200	30.0	0.16	4100	231000	32.0	22	76
74	Bisby et al 2011	100	200	30.0	0.16	4100	231000	63.0	22	76
75	Bisby et al 2011	100	200	30.0	0.16	4100	231000	61.0	22	76
76	Bisby et al 2011	100	200	30.0	0.16	4100	231000	53.0	22	76
77	Bisby et al 2011	100	200	30.0	0.16	4100	231000	55.0	22	76
78	Bisby et al 2011	100	200	30.0	0.16	4100	231000	59.0	22	76
79	Hadi and Fanggi 2012	100	200	60.2	1.00	621.67	628076	107.7	20	77
80	Hadi and Fanggi 2012	100	200	60.2	1.00	621.67	628076	105.2	70	50

Number	Data	d (mm)	L (mm)	f'_{co} (MPa)	t (mm)	f_{frp} (MPa)	E_{frp} (MPa)	f'_{cc} (MPa)	°C	Relative Humidity (%)
81	Hadi and Fanggi 2012	100	200	60.2	1.00	621.67	628076	108.1	70	50
82	Hadi and Fanggi 2012	100	200	60.2	1.32	952.11	628076	168.7	20	70
83	Hadi and Fanggi 2012	100	200	60.2	1.32	952.11	628076	172.4	70	50
84	Hadi and Fanggi 2012	100	200	60.2	1.32	952.11	628076	176.5	70	50

* = f'cc calculated from stress-strain curves

CONFINEMENT RATIO AND STRENGTHENING RATIO

All 84 data from Table 1 were first plotted in Figure 2 to show the relationship between confinement and strengthening ratio for the confined concrete. This is to identify whether the effect of elevated temperature exposure will have any contribution in reducing the confinement strength of the circular concrete. It appears from Figure 2 that without considering temperature and humidity effect, an increase in compressive strength is observed with the increase of the confining pressure.

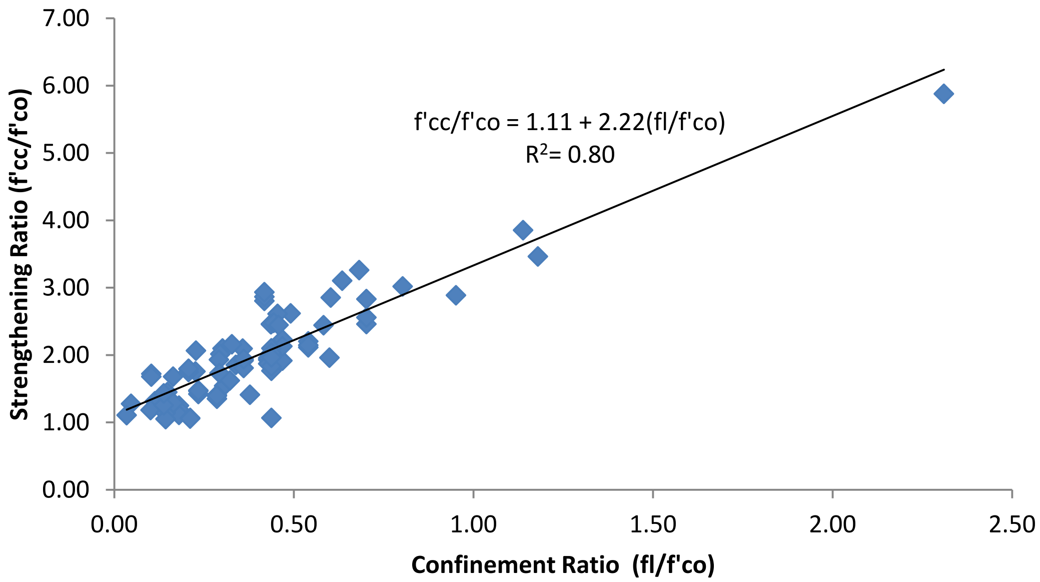

Figure 2: Relationship between Confinement Ratio and Strengthening Ratio.

TEMPERATURE EFFECT TO CONFINEMENT RATIO

In Figure 3, a direct comparison between confinement ratio with temperature effect and strength increase ratio is plotted. As the temperature increases to 100°C the compression strength of confine concrete was observed to have an increase. The increase in strength is represented with Equation 3 below.

$$\frac{f'cc}{f'co} = 1.33 + \left(0.05\left(\frac{fl}{f'co}\right) * (T^{o}C)\right) \quad (3)$$

In addition, from Figure 3 by including temperature effect to the confinement ratio, it seems the results are much more scattered compared to Figure 2. This is probably because only 8 data from Table 1 is with temperature higher than the room temperature; 45°C (1 data), 70°C (4 data) and 100°C (3 data). This small amount of data with temperature exposure may be the reason for this shown relation.

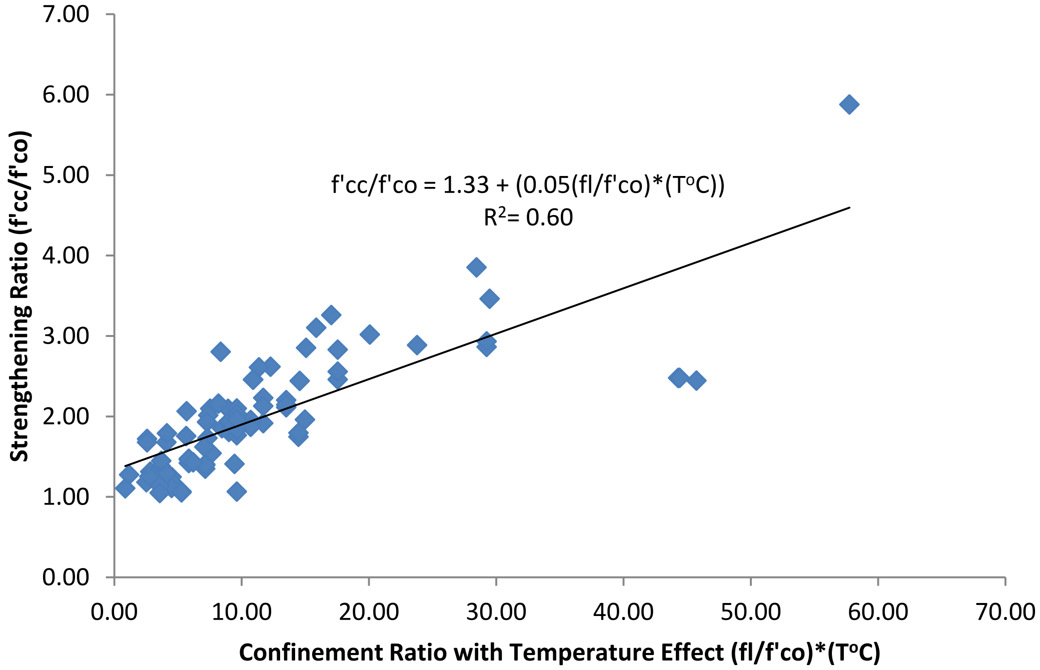

Figure 3 : Effect of Confinement Ratio with Temperature (ToC) on Strengthening Ratio.

RELATIVE HUMIDITY EFFECT TO CONFINEMENT RATIO

Humidity is another exposure to be considered. As explained earlier, there is no data available that directly tested the exposure of humidity to a CFRP confined circular concrete column. The relative humidity data were calculated using Equation 2 and included in Table 1. In Figure 4, with relative humidity effect is added to the confinement ratio, a similar distribution of data is observed. However, the data here is less scattered compared with the effect of temperature. Equation 4 represents the relationship of humidity effect with confinement ratio and strengthening ratio.

$$\frac{f'cc}{f'co} = 1.2 + (0.03\left(\frac{fl}{f'co}\right) * (RH(\%)) \quad (4)$$

Although, it is shown in Table 1 that the relative humidity drops as the temperature increases, the equation for both effects are showing not much of difference with both equation having more or less the same multiplying factor as shown in Equation (3) and (4).

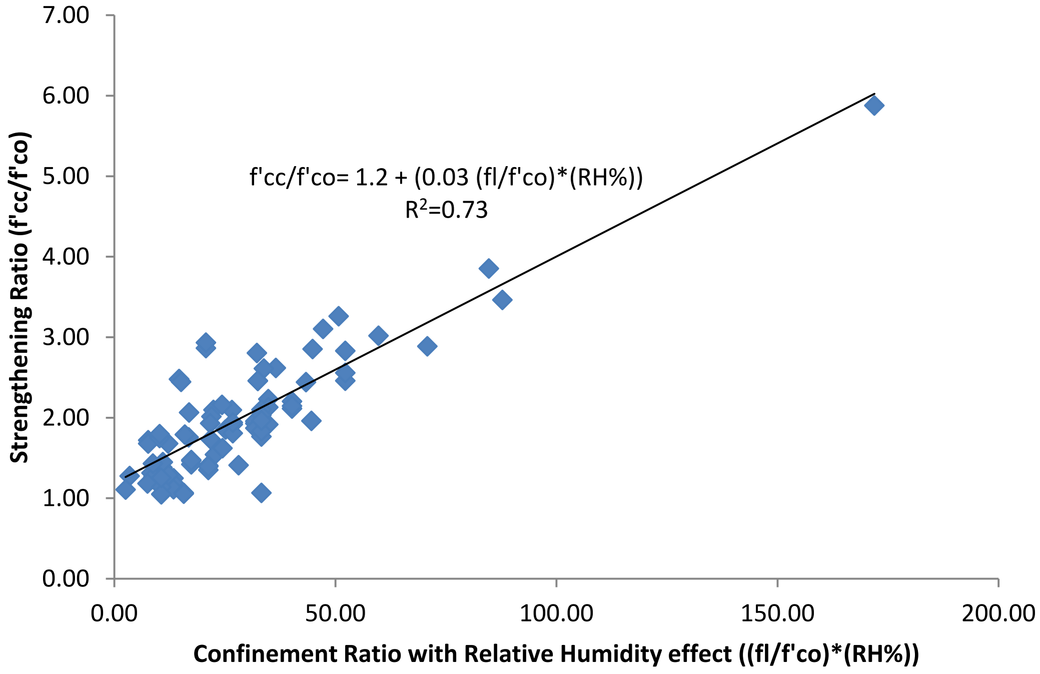

Figure 4: Effect of Confinement Ratio with Humidity (RH%) on Strengthening Ratio.

RELATIVE HUMIDITY AND TEMPERATURE RATIO EFFECT TO CONFINEMENT RATIO

With both effects independently considered earlier, the combination of these two was considered in developing a new analytical model, which is known to have direct correlation, not only between temperature and humidity but also with the confinement ratio. The proposed equation, based on Figure 5, is shown in Equation 5, below.

$$\frac{f'cc}{f'co} = 1.17 + (0.64\left(\frac{fl}{f'co}\right) * (RH(\%)/T^{o}C) \quad (5)$$

The data plotted in Figure 5 is with R^2= 0.64 which is much more scattered compare to Figure 4 but slightly less scattered data compare to Figure 3.

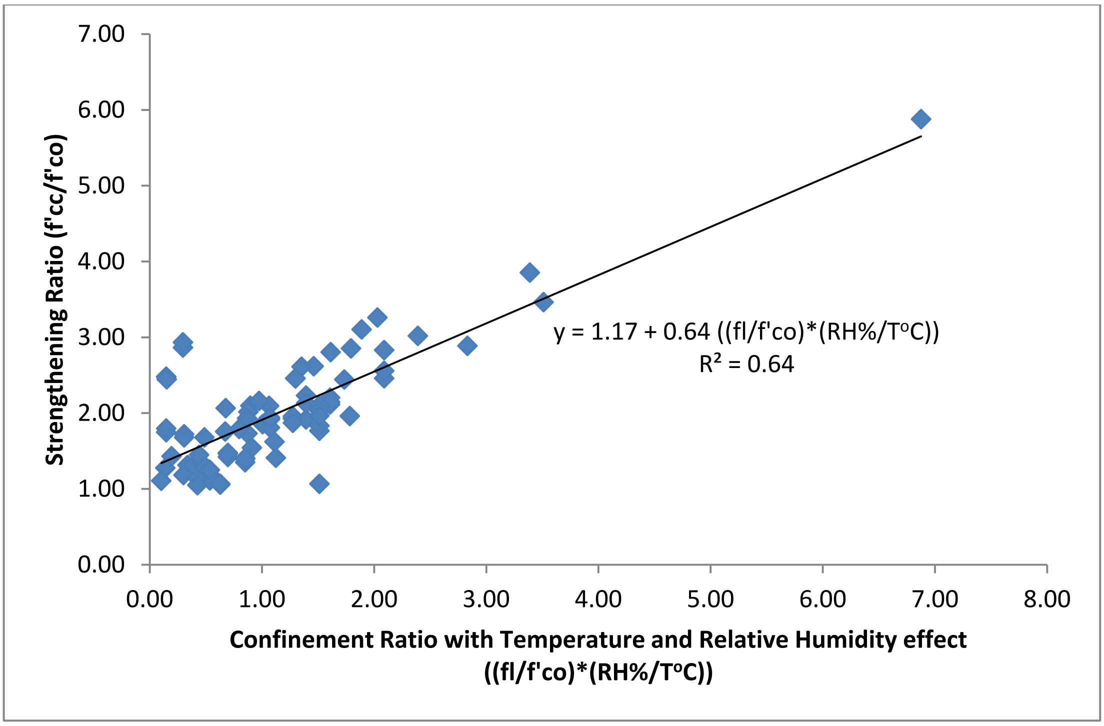

Figure 5: Effect of Confinement Ratio with Temperature ($T^{o}C$) and Humidity (RH%) on Strengthening Ratio.

PROPOSED NEW ANALYTICAL MODEL

The original confinement model given in Equation 1 provides a good strength prediction of CFRP wrapped concrete circular section, at room temperature. However, most structures, particularly transportation civil infrastructure, experience wide range of temperatures and level of humidity. Such lack of practical application asks for a new model that reflects the effects of the two critical parameters; temperature and humidity.

Based on Equation 5 a simple statistical analysis was performed by comparing calculated compression strength with experimental results. From Table 2, it was found that Equation 5 provides a much better average prediction of the experimental results.

Table 2: Improved Equation.

	f'cc (cal)/f'cc (exp)		
Equation	Average	Standard Deviation	Coefficient of Variation (%)
1	0.93	0.18	0.19
5	1.00	0.28	28.0

Without any modification, the original Equation 1 is also being compared to Equation 5 and from Table 2 it shows that although Equation 5 gives a better average, Equation 1 gives much better distribution of calculated value when it is compared to experimental data. This scatter distribution of prediction can be overcome by having more data along with an exact temperature and humidity contribution in deriving Equation 5.

SUMMARY AND CONCLUSIONS

Replacement of functionally obsolete structural members is not the answer in a sustainable construction market. Sustainable retrofit methods should be adopted to increase the load carrying capacity of structures/members, consequently, increase their service life. This paper presented a modified model for CFRP strengthened circular concrete column section. The modified model takes into account the effects of various temperatures and humidity levels. The existing model by Lam and Teng gives a good prediction of a confine circular concrete at room temperature. The new confinement model incorporates additional effects, such as temperature and humidity for better prediction no matter where the installation of CFRP sheet is carry out, whether it is at a very high humidity or high temperature area. However, despite the large amount of data collected, and a best fit equation is proposed, the analysis still give large scatter of results. This may be caused by the limited data for combined effect of both types of exposures. More work is needed to fully understand these two effects, especially related to the humidity exposure that eventually will lead to extend and prolonged service life of CFRP wrapped circular concrete columns.

REFERENCES

A. Al-Salloum, Y., M. Elsanadedy, H., & A. Abadel, A. (2011). Behavior of FRP confined concrete after high temperature exposure. *Construction and Building Materials , 25* (2), 838-850.

ASTM. (1995). Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. *14* (02).

Bae, S. W., & Belarbi, A. (2010). Effects of Various Environmental Conditions on RC Columns Wrapped with FRP Sheets. *Journal of Reinforced Plastics and Composites , 29* (2), 290-308.

Bisby, L., Chen, J., Li, S., Stratford, T., Cueva, N., & Crossling, K. (2011). Strengthening fire damage concrete by confinement with fibre reinforced polymer wraps. *Engineering Structures , 33* (12), 3381-3391.

Demers, M., & Neale, K. W. (1994). Strengthening of Concrete Columns with Unidirectional Composite Sheets. In A. Mufti, B. Bakht, & L. Jaeger (Ed.), *Developments in Short and Medium Span Bridge Engineering '94 4th International Conference on Short and Medium Bridges* (pp. 895-905). Montreal: Canadian Society for Civil Engineering.

El-Hacha, R., Green, M. F., & Wight, G. R. (2010). Effect of Severe Environmental Exposures on CFRP Wrapped Concrete Columns. *Journal of Composites for Construction , 14* (1), 83-93.

Hadi, M., & Louk Fanggi, B. (2012). Behaviour of FRP Confined Concrete Cylinders Under Different Temperature Exposure. *6th International Conference on Bridge Maintenance, Safety and Management, IABMAS 2012.*, (pp. 1187-1192). Lake Maggiore.

Harmon, T., & Slattery, K. (1992). Advanced composite confinement of concrete. In K. Neale, & L. P. (Ed.), *1st International Conference on Advanced Composite Materials in Bridges and Structures.* (pp. 299-306). Sheerbrooke, Canada: Canadian Society for Civil Engineering.

Harries, K., Kestner, J., Pessiki, S., Sause, R., & Ricles, J. (1998). Axial behavior of reinforced concrete column retro with FRPC jackets. *2nd International Conference on Composite in Infrastructures (ICCI)*, (pp. 411-425). Tuscon.

Lam, L., & Teng, J. G. (2002). Strength Models for Fiber Reinforced Plastic Confined Concrete. *Journal of Structural Engineering , 128* (5), 612-623.

Matthys, S., Taerwe, L., & Auddenaert, K. (1999). Test on axially loaded concrete columns confined by fiber reinforced polymer sheet wrapping. *4th International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures*, (pp. 217-229). Farmington.

Micelli, F., Myers, J. J., & Murthy, S. S. (2002). Performance of FRP Confined Concrete Subjected to Accelerated Enviromental Conditioning. *Durability of Fibre Reinforced Polymer (FRP) Composite for Construction.* , (pp. 87-98). Montreal.

Miyauchi, K., Nishibayashi, S., & Inoue, S. (1997). Estimation of Strengthening effects with carbon fiber sheets for concrete columns. *Non-Metallic (FRP) Reinforcement for Concrete Structures Proceeding 3rd International* , (pp. 217-224). Sapporo.

National Climatic Data Center. (2008, January 16). Retrieved from http://www.ncdc.noaa.gov/extremes/extreme-us-climates.html#MHUMID-LHUMID

Picher, F., Rochette, P., & Labossiere, P. (1996). Confinement of concrete cylinders with CFRP. *1st International Conference on Composite for Infra-Structures*, (pp. 829-841). Tuscon.

Toutanji, H. (1999). Stress-Strain Characteristics of Concrete Columns Externally Confined with Advanced Fiber Composite Sheets. *Materials Journal , 96* (3), 397-404.

Toutanji, H., & Balaguru, P. (1998). Durability Characteristics of Concrete Columns Wrapped with Fiber Tow Sheets. *Journal of Materials in Civil Engineering , 10* (1), 52-57.

Watanable, K., Nakamura, H., Honda, T., Toyoshima, M., Iso, M., Fujimaki, T., et al. (1997). Confinement effect of FRP sheet on strength and ductility of concrete cylinders under uniaxial compression. *Non-Metallic (FRP) Reinforcement for Concrete Structures, Proceeding, 3rd International Symposium. 1*, pp. 233-240. Sapporo Japan: Japan Concrete Institute.

Weather Underground. (2012). Retrieved from http://www.wunderground.com/history/airport/KUIL/2012/6/4/MonthlyHistory.html?req_city=NA&req_state=NA&req_statename=NA

Xiao, Y., & Wu, H. (2000). Compressive Behavior of Concrete Confined by Carbon Fiber Composite Jackets. *Journal of Materials in Civil Engineering , 12* (2), 139-146.

Zhang, S., Ye, L., & Mai, Y.-W. (2000). A study on polymer composites strengthening systems for concrete columns. *Applied Composite Materials , 7* (2-3), 125-138.