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Statistical evaluation of the monotonic models for FRP confined concrete prisms

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Abstract. FRP confining is a widely used method for seismic retrofitting of concrete columns. Several studies investigated the stress-strain behavior of FRP confined concrete prisms with square and rectangular sections both experimentally and analytically. In some studies, the monotonic stress-strain behavior of confined concrete was investigated and compressive strength models were developed. To study the reliability of these models, thorough statistical tests are required. This paper aims to investigate the reliability of the presented models using statistical tests including t-test, wilcoxon rank sum test, wilcoxon signed rank test and sign test with a level of significance of 5%. Wilk Shapiro test was also employed to evaluate the normality of the data distribution. The results were compared for different cross section and confinement types. To see the accuracy of the models when there were no significant differences between the results, the coefficient of confidence was used.

Keywords: compressive strength; statistical tests; FRP confined concrete; square and rectangular sections

1. Introduction

One of the most widely used methods to increase both compressive strength and ductility of concrete columns is using FRP confining. Since the FRP confining changes the stress-strain behavior, it is necessary to understand the stress-strain behavior of the confined concrete. Several studies have been conducted to investigate the stress-strain behavior of FRP confined concrete specimens experimentally and theoretically. An important parameter affecting the performance of the confined concrete is the cross section shape. The effects of the cross section shape on the stress-strain behavior of FRP confined concrete prisms have been investigated in some studies.

Wang and Wu (2008) studied the effect of corner radius on the performance of square concrete columns confined with CFRP. They concluded that the confined concrete strength increases with the increase of corner radius. Abbasnia *et al*. (2012a), Abbasnia *et al*. (2013) investigated the stress-strain behavior of FRP confined concrete prisms with different corner radii and aspect ratios respectively. They indicated that the monotonic stress-strain curve is almost the same as the cyclic stress-strain envelope curve. They also showed that the failure area of the FRP jacket increases

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with the increase and decrease of the corner radius and aspect ratio respectively. Hosseinpour and Abbasnia (2014) examined the performance of 44 confined concrete prisms experimentally and observed an increase in the confinement effectiveness with the increase and decrease of the corner radius and aspect ratio respectively.

Some previous studies developed new models to predict the monotonic compressive strength of the square and rectangular concrete prisms confined with FRP. In most of these studies, the robustness of the models was simply evaluated either graphically by plotting the results of the predicted model along with the experimental data or analytically by performing simple statistical analyses, such as calculating the mean absolute error and standard deviation. This can be a good way for initial judgment but is not a reliable method to fully understand how accurate and reliable these models are. To evaluate the accuracy of a model, it is necessary to perform some statistical tests.

Skuturna and Valivonis (2015) investigated three design methods of the load-carrying capacity of flexural reinforced concrete elements strengthened with FRP and evaluated the accuracy of the design methods using t-test. Nisticò *et al*. (2014) assessed the predictive expressions for peak strength and ultimate strain of FRP confined circular and square concrete sections. They used the average absolute error (AAE) and average ratio (AR) to compare the existing models. Hosseinpour and Abdelnaby (2015) evaluated five strength models for FRP confined concrete prisms with square and rectangular sections using t-test and sign test.

In this paper, eight presented models for compressive strength of FRP confined concrete prisms are evaluated using experimental data. For this purpose, some statistical tests were employed. The statistical tests used in this study include t-test, wilcoxon rank sum test, wilcoxon signed rank test and sign test. T-test is used when the data distribution is normal. To check the normality of the data distribution, wilk shapiro test was utilized. Wilcoxon rank sum test, wilcoxon signed rank test and sign test are independent from the data distribution (nonparametric tests) and were mostly used to investigate the accuracy of the models when the data distribution was not normal and also to increase the accuracy of the findings. Since the results of nonparametric tests might be different in some cases, three tests were used. Depending on the cross section and FRP type, the experimental data divided into different groups. The models were evaluated for each set of data and in cases there were no significant difference between the results of the models, the accuracy of the models were compared using a coefficient of confidence.

2. Presented models

In recent years some models have been proposed to predict the monotonic stress-strain behavior and also the compressive strength of FRP confined concrete with square and rectangular sections. In many of these models, the strain softening behavior was not considered (see Fig. 1) and many others didn't consider the actual hoop rupture strain of FRP. Some models have been proposed to overcome previous problems. In a preliminary comparison, some models looked more accurate and selected for evaluating by statistical tests. These models are briefly explained in this section.

2.1 Wu et al. (2007)

Wu *et al*. (2007) proposed a stress-strain model including the first parabola and second linear parts. Despite most previous models, this model considers both strain hardening and strain softening behaviors. They developed their model using regression analysis of existing data

$$\begin{cases} \sigma_c = \sigma_{cp}[2\varepsilon_c / \varepsilon_{cp} - (\varepsilon_c / \varepsilon_{cp})^2] & \varepsilon_c \le \varepsilon_{cp} \\ \sigma_c = \sigma_{cp} + \dfrac{(f_{cu} - \sigma_{cp})(\varepsilon_c - \varepsilon_{cp})}{\varepsilon_{cu} - \varepsilon_{cp}} & \varepsilon_c > \varepsilon_{cp} \end{cases} \tag{1}$$

where σ_{cp} and ε_{cp} are the transitional stress and strain and f_{cu} and ε_{cu} are the ultimate stress and strain respectively (see Fig. 1), obtained according to the relationships provided in the Wu *et al*.'s paper (2007). The maximum stress of two parts ($\varepsilon_c \le \varepsilon_{cp}$ and $\varepsilon_c > \varepsilon_{cp}$) was considered as the compressive strength. When the confined concrete has a strain softening behavior, the ultimate stress is less than the compressive strength (see Fig. 1).

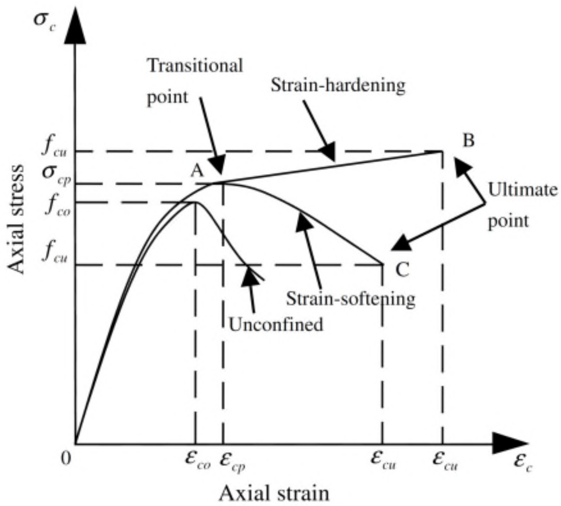

Fig. 1 Typical stress-strain curves of FRP-confined concrete prism (Wu *et al*. 2007)

2.2 ACI (2002)

ACI (2002) considers an effectively confined area and defines it as an area confined by 4 parabolas intersecting the edges at 45° (see Fig. 2) and provides a shape factor as follows

$$k_s = \frac{1 - ((b - 2R_c)^2 + (h - 2R_c)^2 / 3A_g) - \rho_{sc}}{1 - \rho_{sc}} \tag{2}$$

in which

$$A_g = bh - (4 - \pi)R_c^{\ 2} \tag{3}$$

where ρ_{se} is the ratio of the area of longitudinal steel reinforcement to the cross section area and A_g

is the gross area of the cross section.

Based on the shape factor, lateral confining pressure of FRP is obtained

$$f_l = \frac{2k_s E_{frp} \varepsilon_j t}{D} \tag{4}$$

where E_{frp} is the elasticity modulus of FRP, ε_j is the FRP nominal hoop rupture strain, t is the total thickness of FRP and D is the equivalent column diameter

$$D = \frac{2bh}{b+h} \tag{5}$$

Using lateral confining pressure, ACI (2002) predicted the compressive strength as follows

$$\frac{f_{cc}}{f_{co}} = 2.254\sqrt{1+7.94 f_l / f_{co}} - 2f_l / f_{co} - 1.254 \tag{6}$$

where f_{co} is the unconfined concrete strength.

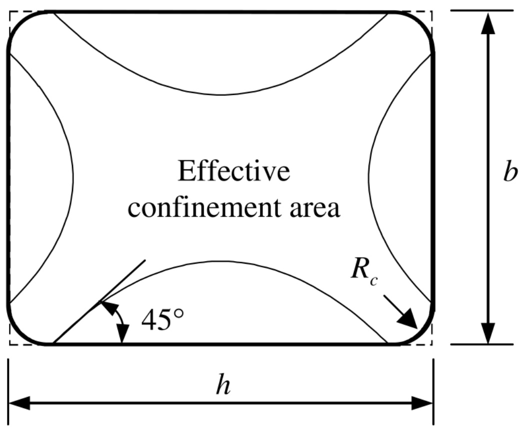

Fig. 2 Effectively confined concrete in a rectangular column (Lam and Teng 2003)

2.3 Wu and Wei (2010)

Wu and Wei's model (2010) is an extension of Wu and Wang's model (2009) for square prisms. They extended the model for rectangular prisms by adding an aspect ratio factor, k_a. They defined the aspect ratio factor as a function of *h/b* (k_a=$f(h/b)$) and predicted the compressive strength according to Eq. (7)

$$\frac{f_{cc}}{f_{co}} = 1 + 3.66\left(\frac{2r}{b}\right)^{0.72}\left(\frac{f_l}{f_{co}}\right)^{1.87}\left(\frac{h}{b}\right)^{-2.5} \tag{7}$$

in which

$$f_l = \frac{2E_{frp}\varepsilon_{frp}t}{b} \tag{8}$$

where b and h are the width and height of the cross section respectively.

Because there were some unusual experimental results, they also presented their model in another form after omitting the unusual data (Eq. (9)).

$$\frac{f_{cc}}{f_{co}} = 1 + 3.9\left(\frac{2r}{b}\right)^{0.72}\left(\frac{f_l}{f_{co}}\right)^{1.87}\left(\frac{h}{b}\right)^{-2.5} \tag{9}$$

As it can be seen the difference between two models is small. In the present study, the Eq. (9) was utilized.

2.4 Lam and Teng (2003b)

Lam and Teng (2003b) proposed a stress-strain model for FRP confined rectangular and square columns as an extension of their previous design oriented model developed for FRP confined circular columns (Lam and Teng 2003a). Based on their model, the compressive strength is predicted as follows

$$\frac{f_{cc}}{f_{co}} = 1 + k_1 k_{s1}\frac{f_l}{f_{co}} \tag{10}$$

in which

$$k_{s1} = \left(\frac{b}{h}\right)^{\alpha}\left(\frac{1-((\mathrm{b/h})(h-2\mathrm{R}_c)^2 + (\mathrm{h/b})(\mathrm{b}-2R_c)^2/3A_g) - \rho_{sc}}{1-\rho_{sc}}\right)$$
$$\alpha = 2 \tag{11}$$

$$f_l = \frac{2E_{frp}\varepsilon_j t}{b^2 + h^2} \tag{12}$$

where k_1=3.3 and k_{s1} is a shape factor.

2.5 ACI (2008)

ACI (2008) adopted the stress-strain model proposed by Lam and Teng (2003b). To predict the compressive strength, ACI (2008) employed Lam and Teng's equation (2003b), with inclusion of a reduction factor of ψ=0.95.

$$\frac{f_{cc}}{f_{co}} = 1 + \psi k_1 k_{s1}\frac{f_l}{f_{co}} \tag{13}$$

2.6 Al-Salloum (2007)

Al-Salloum (2007) proposed a modified analytical model predicting the compressive strength of FRP confined concrete prisms with square sections. The lateral confining pressure was defined as follows

$$f_l = \frac{2f_{FRP}}{D} k_e \tag{14}$$

where K_e is a shape factor, f_{FRP} is the tensile strength of FRP, t is the total thickness of FRP and D is the diagonal length of the square section with rounded corners (Al-Salloum 2007) (see Fig. 3). D and K_e are obtained according to Eq. (15) and Eq. (16) respectively.

$$D = \sqrt{2}b - 2r(\sqrt{2} - 1) \tag{15}$$

$$k_e = \frac{A_{confined}}{A_{gross}} = 1 - \frac{2}{3}\left[\frac{(1 - 2\frac{r}{b})^2}{1 - (4 - \pi)(\frac{r}{b})^2}\right] \tag{16}$$

where $A_{confined}$ is the confined area and A_{gross} is the gross area of the cross section (Al-Salloum 2007). Using above parameters and unconfined concrete strength, Al-Salloum (2007) presented a model for square prisms as follows

$$\frac{f_{cc}}{f_{co}} = 1 + 3.14 \frac{b}{D} \frac{f_l}{f_{co}} \tag{17}$$

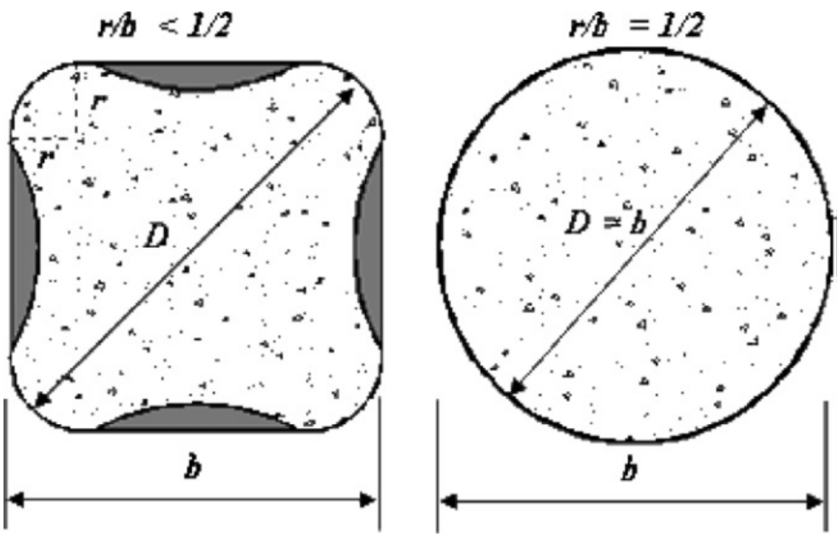

Fig. 3 Dimensions of confined sections (Al-Salloum 2007)

2.7 Wu and Wang (2009)

Wu and Wang (2009) developed a unified strength model for confined square and circular concrete columns as follows

$$\frac{f_{cc}}{f_{co}} = 1 + 2.2\rho^{0.72}(\frac{f_l}{f_{co}})^{0.94} \tag{18}$$

in which

$$f_l = \frac{2E_{frp}\varepsilon_{frp}t_f}{b} \tag{19}$$

The model defines the corner radius ratio, ρ as $2r/b$ (corner radius divided by half the width of the column), and thus when ρ=1 and 0, respectively, it represents the cases of circular and sharp-cornered square columns (Wu and Wei 2010).

2.8 Nisticò and Monti (2013)

Nisticò and Monti (2013) proposed an analytical strength model for FRP confined circular and square concrete sections. They evaluated the accuracy of their model using average absolute error and average ratio. They presented the model as follows

$$\frac{f_{cc}}{f_{co}} = 1 + 2.09\frac{f_l}{f_{co}}r \tag{20}$$

in which

$$f_l = 2\frac{t_f}{L}E_{frp}\varepsilon_{frp} \tag{21}$$

where r is the corner radius ratio and L is the side length of the square section.

3. Experimental data

Table 1 shows the experimental data used in this study (many of these data were obtained from Lam and Teng's paper (2003b)). For each model, the ratio of F_{exp} / F_{model} (compressive strength from the experiment to compressive strength from the model) was calculated (see Table 2) and evaluated using statistical tests. Because some studies mostly focused on square sections to present a model, they might not be reliable for rectangular sections. Furthermore, since some others mostly utilized carbon fiber reinforced polymer, they might not be suitable for the glass and aramid types. For this purpose, the data divided into five groups including square prisms confined with CFRP, square prisms confined with GFRP or AFRP, all square prisms (confined with CFRP, GFRP, and AFRP), rectangular prisms and all prisms.

4. Statistical tests

The reliability of the models was evaluated using four statistical tests. Since the t-test works

Table 1 Experimental data

No	b (mm)	h (mm)	f_{co} (Mpa)	FRP total thickness (mm)	Corner radius (mm)	FRP type	Tensile strength of FRP (Mpa)	E_{frp} (Mpa)
Abbasnia *et al*. (2012b) and Abbasnia and Ziaadiny (2010, 2015)								
1	150	150	32.00	0.352	13.60	CFRP	3943.5	241000
2	150	150	32.00	0.352	22.60	CFRP	3943.5	241000
3	150	150	34.00	0.352	34.50	CFRP	3943.5	241000
4	150	150	34.00	0.352	42.00	CFRP	3943.5	241000
5	120	180	35.00	0.352	18.10	CFRP	3943.5	241000
6	120	180	32.00	0.352	27.60	CFRP	3943.5	241000
7	120	180	32.00	0.352	34.50	CFRP	3943.5	241000
8	90	180	34.00	0.352	13.60	CFRP	3943.5	241000
9	90	180	32.00	0.352	22.60	CFRP	3943.5	241000
10	90	180	32.00	0.352	26.80	CFRP	3943.5	241000
11	90	152	30	0.528	17.5	CFRP	3943.5	241000
12	90	152	30	0.528	17.5	CFRP	3943.5	241000
13	152	152	30	0.528	29	CFRP	3943.5	241000
14	152	152	27	0.528	29	CFRP	3943.5	241000
Demers and Neale (1994)								
15	152	152	32.3	1.05	5	GFRP	220	10500
16	152	152	32.3	1.05	5	GFRP	220	10500
17	152	152	32.3	0.9	5	CFRP	380	25000
18	152	152	42.2	0.9	5	CFRP	380	25000
19	152	152	42.2	0.9	5	CFRP	380	25000
Rochette and Labossière (2000)								
20	152	152	42	0.9	5	CFRP	1265	82700
21	152	152	42	0.9	25	CFRP	1265	82700
22	152	152	42	0.9	25	CFRP	1265	82700
23	152	152	42	0.9	38	CFRP	1265	82700
24	152	152	42	0.9	38	CFRP	1265	82700
25	152	152	43.9	1.5	5	CFRP	1265	82700
26	152	152	43.9	1.2	25	CFRP	1265	82700
27	152	152	35.8	1.2	25	CFRP	1265	82700
28	152	152	35.8	2.5	25	CFRP	1265	82700
29	152	152	35.8	1.2	38	CFRP	1265	82700
30	152	152	35.8	1.5	38	CFRP	1265	82700
31	152	152	43	1.26	5	AFRP	230	13600
32	152	152	43	2.52	5	AFRP	230	13600
33	152	152	43	3.78	5	AFRP	230	13600
34	152	152	43	5.04	5	AFRP	230	13600
35	152	152	43	1.26	25	AFRP	230	13600

Table 1 Continued

No	b (mm)	h (mm)	f_{co} (Mpa)	FRP total thickness (mm)	Corner radius (mm)	FRP type	Tensile strength of FRP (Mpa)	E_{frp} (Mpa)
36	152	152	43	2.52	25	AFRP	230	13600
37	152	152	43	3.78	25	AFRP	230	13600
38	152	152	43	5.04	25	AFRP	230	13600
39	152	152	43	2.52	38	AFRP	230	13600
40	152	152	43	3.78	38	AFRP	230	13600
41	152	203	42	0.9	25	CFRP	1265	82700
42	152	203	42	0.9	38	CFRP	1265	82700
43	152	203	43.9	1.5	5	CFRP	1265	82700
44	152	203	43.9	1.2	25	CFRP	1265	82700
Suter and Pinzelli (2001)								
45	150	150	33.9	0.29	5	AFRP	2100	125000
46	150	150	33.9	0.58	5	AFRP	2100	125000
47	150	150	34.9	0.87	5	AFRP	2100	125000
48	150	150	35.9	1.16	5	AFRP	2100	125000
49	150	150	36.6	0.29	25	AFRP	2100	125000
50	150	150	36.6	0.58	25	AFRP	2100	125000
51	150	150	36.6	0.87	25	AFRP	2100	125000
52	150	150	36.6	1.16	25	AFRP	2100	125000
53	150	150	33.9	0.234	5	CFRP	3800	240000
54	150	150	36.6	0.234	25	CFRP	3800	240000
55	150	150	33.9	0.38	2	HM CFRP	2650	640000
56	150	150	36.6	0.38	25	HM CFRP	2650	640000
57	150	150	33.9	0.616	5	GFRP	2400	73000
58	150	150	33.9	1.232	5	GFRP	2400	73000
59	150	150	36.6	0.616	25	GFRP	2400	73000
60	150	150	36.66	1.232	25	GFRP	2400	73000
Shehata *et al*. (2002)								
61	150	150	23.7	0.165	10	CFRP	3550	235000
62	150	150	23.7	0.33	10	CFRP	3550	235000
63	150	150	29.5	0.165	10	CFRP	3550	235000
64	150	150	29.5	0.33	10	CFRP	3550	235000
65	94	188	23.7	0.165	10	CFRP	3550	235000
66	94	188	23.7	0.33	10	CFRP	3550	235000
67	94	188	29.5	0.165	10	CFRP	3550	235000
68	94	188	29.5	0.33	10	CFRP	3550	235000
Lam and Teng (2003b)								
69	150	150	33.7	0.165	15	CFRP	4519	257000
70	150	150	33.7	0.165	25	CFRP	4519	257000
71	150	150	33.7	0.33	15	CFRP	4519	257000

Table 1 Continued

No	*b* (mm)	*h* (mm)	f_{co} (Mpa)	FRP total thickness (mm)	Corner radius (mm)	FRP type	Tensile strength of FRP (Mpa)	E_{frp} (Mpa)
72	150	150	33.7	0.33	25	CFRP	4519	257000
73	150	150	24	0.495	15	CFRP	4519	257000
74	150	150	24	0.495	25	CFRP	4519	257000
75	150	150	24	0.66	15	CFRP	4519	257000
76	150	150	24	0.66	25	CFRP	4519	257000
77	150	150	41.5	0.825	15	CFRP	4519	257000
78	150	150	41.5	0.825	25	CFRP	4519	257000
79	150	225	41.5	0.66	15	CFRP	4519	257000
80	150	225	41.5	0.66	25	CFRP	4519	257000
Wang and Wu (2008)								
81	150	150	31.7	0.165	0	CFRP	4364	219000
82	150	150	31.9	0.165	15	CFRP	4364	219000
83	150	150	32.3	0.165	30	CFRP	4364	219000
84	150	150	30.7	0.165	45	CFRP	4364	219000
85	150	150	31.8	0.165	60	CFRP	4364	219000
86	150	150	31.7	0.33	0	CFRP	4364	219000
87	150	150	31.9	0.33	15	CFRP	4364	219000
88	150	150	32.3	0.33	30	CFRP	4364	219000
89	150	150	30.7	0.33	45	CFRP	4364	219000
90	150	150	31.8	0.33	60	CFRP	4364	219000
91	150	150	52.1	0.165	0	CFRP	3788	225700
92	150	150	54.1	0.165	15	CFRP	3788	225700
93	150	150	52	0.165	30	CFRP	3788	225700
94	150	150	52.7	0.165	45	CFRP	3788	225700
95	150	150	52.7	0.165	60	CFRP	3788	225700
96	150	150	52.1	0.33	0	CFRP	3788	225700
97	150	150	54.1	0.33	15	CFRP	3788	225700
98	150	150	52	0.33	30	CFRP	3788	225700
99	150	150	52.7	0.33	45	CFRP	3788	225700
100	150	150	52.7	0.33	60	CFRP	3788	225700
Harajli *et al*. (2006)								
101	131.5	131.5	18.3	0.13	15	CFRP	3500	230000
102	131.5	131.5	18.3	0.26	15	CFRP	3500	230000
103	131.5	131.5	18.3	0.39	15	CFRP	3500	230000
104	102	176	18.3	0.13	15	CFRP	3500	230000
105	102	176	18.3	0.26	15	CFRP	3500	230000
106	102	176	18.3	0.39	15	CFRP	3500	230000
107	79	214	18.3	0.13	15	CFRP	3500	230000

Table 1 Continued

No	b (mm)	h (mm)	f_{co} (Mpa)	FRP total thickness (mm)	Corner radius (mm)	FRP type	Tensile strength of FRP (Mpa)	E_{frp} (Mpa)
108	79	214	18.3	0.26	15	CFRP	3500	230000
109	79	214	18.3	0.39	15	CFRP	3500	230000
Ilki and Kumbaser (2003)								
110	250	250	32.8	0.165	40	CFRP	3430	230000
111	250	250	32.8	0.165	40	CFRP	3430	230000
112	250	250	32.8	0.495	40	CFRP	3430	230000
113	250	250	32.8	0.495	40	CFRP	3430	230000
114	250	250	32.8	0.825	40	CFRP	3430	230000
115	250	250	32.8	0.825	40	CFRP	3430	230000
116	150	300	34	0.165	40	CFRP	3430	230000
117	150	300	34	0.165	40	CFRP	3430	230000
118	150	300	34	0.495	40	CFRP	3430	230000
119	150	300	34	0.495	40	CFRP	3430	230000
120	150	300	34	0.825	40	CFRP	3430	230000
121	150	300	34	0.825	40	CFRP	3430	230000
Rousakis *et al.* (2007)								
122	200	200	33	0.117	30	CFRP	3720	240000
123	200	200	33	0.351	30	CFRP	3720	240000
124	200	200	33	0.585	30	CFRP	3720	240000
125	200	200	33	0.414	30	GFRP	1820	65000
126	200	200	33	0.828	30	GFRP	1820	65000
127	200	200	33	1.242	30	GFRP	1820	65000
128	200	200	34	0.117	30	CFRP	3720	240000
129	200	200	34	0.351	30	CFRP	3720	240000
130	200	200	34	0.585	30	CFRP	3720	240000
131	200	200	38	0.828	30	GFRP	1820	65000
132	200	200	38	1.242	30	GFRP	1820	65000
133	200	200	40	0.828	30	GFRP	1820	65000
134	200	200	40	1.242	30	GFRP	1820	65000

Table 2 F_{exp}/F_{model} for different models

No	F_{exp}	F_{exp}/F_{model}							
		Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	Nisticò and Monti (2013)
1	39.19	0.94	0.84	0.87	0.85	0.87	0.79	0.88	1.00
2	45.58	0.98	0.93	0.90	0.93	0.95	0.82	0.92	1.04
3	51.41	0.97	0.95	0.88	0.95	0.97	0.79	0.88	0.99
4	52.21	0.92	0.94	0.84	0.94	0.95	0.75	0.84	0.94
5	40.67	0.91	0.80	0.91	0.97	0.98	-	-	-
6	42.70	0.90	0.85	0.93	1.07	1.08	-	-	-

Table 2 Continued

No	F_{exp}	F_{exp}/F_{model}							
		Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	Nisticò and Monti (2013)
7	46.29	0.91	0.89	0.96	1.13	1.15	-	-	-
8	38.69	0.85	0.80	0.92	1.02	1.02	-	-	-
9	38.96	0.79	0.77	0.88	1.06	1.07	-	-	-
10	42.47	0.82	0.82	0.92	1.14	1.15	-	-	-
11	49.51	0.87	0.88	0.75	1.22	1.23	-	-	-
12	55.81	0.98	0.99	0.85	1.37	1.39	-	-	-
13	58.86	1.00	1.07	0.75	1.02	1.05	0.84	0.98	1.14
14	61.76	1.07	1.20	0.77	1.13	1.16	0.92	1.08	1.26
15	31.82	0.96	0.94	0.98	0.93	0.94	0.93	0.95	0.97
16	33.01	0.99	0.97	1.02	0.97	0.97	0.96	0.99	1.01
17	34.10	1.00	0.96	1.04	0.98	0.98	0.96	1.01	1.04
18	45.99	1.06	1.01	1.08	1.03	1.03	1.02	1.05	1.07
19	45.70	1.05	1.00	1.07	1.02	1.02	1.01	1.04	1.07
20	39.48	0.81	0.75	0.87	0.78	0.79	0.76	0.84	0.90
21	41.58	0.85	0.71	0.79	0.74	0.75	0.67	0.72	0.80
22	43.26	0.88	0.74	0.82	0.77	0.78	0.70	0.75	0.83
23	47.46	0.93	0.78	0.84	0.81	0.82	0.69	0.75	0.82
24	50.40	0.98	0.83	0.89	0.86	0.87	0.73	0.80	0.87
25	43.90	0.79	0.73	0.84	0.75	0.76	0.72	0.85	0.93
26	50.92	0.96	0.78	0.83	0.81	0.82	0.72	0.79	0.88
27	52.27	1.06	0.93	0.92	0.96	0.97	0.84	0.93	1.06
28	57.64	0.86	0.80	0.48	0.77	0.79	0.63	0.75	0.89
29	59.43	1.03	1.00	0.92	1.02	1.04	0.83	0.94	1.05
30	68.74	1.08	1.08	0.87	1.08	1.10	0.86	0.98	1.11
31	50.74	1.25	1.11	1.17	1.12	1.13	1.11	1.14	1.17
32	51.60	1.14	1.07	1.17	1.09	1.09	1.07	1.13	1.17
33	53.75	1.13	1.07	1.19	1.09	1.09	1.06	1.15	1.21
34	54.18	1.10	1.03	1.17	1.05	1.06	1.01	1.13	1.20
35	51.17	1.18	1.08	1.17	1.10	1.10	1.06	1.08	1.12
36	51.17	1.11	1.00	1.11	1.02	1.03	0.96	1.00	1.06
37	53.32	1.12	0.97	1.08	0.99	1.00	0.92	0.97	1.05
38	55.04	1.11	0.94	1.02	0.96	0.97	0.87	0.93	1.03
39	50.74	1.10	0.97	1.08	0.98	0.99	0.90	0.93	1.00
40	52.89	1.10	0.93	1.03	0.95	0.96	0.84	0.89	0.96
41	42.00	0.87	0.76	0.89	0.87	0.87	-	-	-
42	43.68	0.91	0.76	0.89	0.88	0.89	-	-	-
43	44.34	0.82	0.77	0.92	0.88	0.88	-	-	-
44	44.34	0.85	0.72	0.85	0.85	0.85	-	-	-
45	32.44	0.86	0.83	0.92	0.84	0.85	0.82	0.88	0.93

Table 2 Continued

No	F_{exp}	F_{exp}/F_{model}							
		Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	Nisticò and Monti (2013)
46	37.32	0.89	0.85	0.97	0.86	0.87	0.83	0.95	1.03
47	36.89	0.79	0.75	0.82	0.76	0.77	0.72	0.86	0.96
48	38.38	0.75	0.70	0.73	0.70	0.72	0.66	0.83	0.95
49	39.38	0.98	0.87	0.97	0.89	0.90	0.83	0.87	0.93
50	43.70	0.98	0.83	0.86	0.84	0.85	0.75	0.82	0.91
51	56.84	1.04	0.96	0.85	0.95	0.97	0.82	0.92	1.06
52	64.86	1.04	1.00	0.73	0.96	0.98	0.81	0.94	1.10
53	36.07	0.90	0.86	0.99	0.89	0.89	0.86	0.95	1.01
54	41.43	0.98	0.84	0.93	0.87	0.88	0.79	0.84	0.92
55	39.90	0.67	0.67	1.12	0.98	0.99	0.95	1.10	1.15
56	46.45	0.76	0.60	1.00	0.94	0.95	0.85	0.91	1.01
57	37.09	0.95	0.92	0.91	0.82	0.83	0.78	0.92	1.01
58	37.90	0.76	0.82	0.64	0.67	0.68	0.62	0.82	0.96
59	39.78	0.80	0.85	0.70	0.72	0.73	0.63	0.70	0.79
60	42.23	0.63	0.76	0.38	0.57	0.58	0.47	0.56	0.66
61	27.40	0.95	0.91	1.04	0.94	0.95	0.90	0.98	1.06
62	36.50	0.92	1.03	1.09	1.06	1.08	0.99	1.14	1.30
63	40.39	1.19	1.12	1.27	1.16	1.17	1.12	1.19	1.27
64	43.69	1.13	1.05	1.16	1.09	1.10	1.02	1.15	1.29
65	25.81	0.85	0.88	1.02	1.03	1.03	-	-	-
66	33.20	0.78	0.97	1.12	1.25	1.26	-	-	-
67	32.01	0.92	0.91	1.04	1.04	1.04	-	-	-
68	38.70	0.96	0.96	1.13	1.20	1.20	-	-	-
69	35.00	0.91	0.84	0.92	0.84	0.85	0.80	0.85	0.92
70	39.40	1.03	0.91	0.99	0.91	0.92	0.84	0.89	0.97
71	50.40	1.15	1.03	1.03	1.02	1.04	0.94	1.05	1.20
72	61.90	1.25	1.20	1.11	1.18	1.20	1.02	1.14	1.30
73	61.60	1.18	1.41	0.90	1.30	1.34	1.14	1.39	1.69
74	66.00	1.18	1.40	0.75	1.26	1.29	1.03	1.24	1.47
75	63.70	1.24	1.31	0.64	1.16	1.19	0.99	1.26	1.57
76	80.80	1.47	1.54	0.61	1.31	1.35	1.04	1.29	1.56
77	82.90	1.32	1.11	0.74	1.03	1.06	0.90	1.10	1.33
78	95.20	1.30	1.19	0.66	1.07	1.10	0.88	1.05	1.25
79	49.20	0.89	0.79	0.84	0.95	0.96	-	-	-
80	51.90	0.92	0.78	0.79	0.97	0.98	-	-	-
81	32.20	0.90	0.90	1.02	0.89	0.90	0.88	1.02	1.02
82	33.60	0.93	0.86	0.93	0.85	0.86	0.81	0.86	0.94
83	39.80	1.09	0.96	1.02	0.94	0.96	0.85	0.90	0.99
84	43.70	1.06	1.06	1.09	1.03	1.05	0.87	0.94	1.02

Table 2 Continued

No	F_{exp}	F_{exp}/F_{model}							
		Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	Nisticò and Monti (2013)
85	50.00	1.07	1.16	1.16	1.12	1.14	0.88	0.98	1.04
86	32.20	0.81	0.81	1.02	0.80	0.80	0.77	1.02	1.02
87	42.20	0.98	0.94	0.90	0.90	0.92	0.82	0.93	1.06
88	56.50	1.11	1.15	0.99	1.09	1.11	0.92	1.03	1.17
89	68.00	1.17	1.37	1.04	1.26	1.29	0.97	1.12	1.24
90	78.90	1.18	1.51	1.08	1.38	1.41	0.97	1.15	1.23
91	53.70	1.02	0.95	1.03	0.96	0.96	0.95	1.03	1.03
92	55.80	0.99	0.91	0.99	0.92	0.93	0.89	0.92	0.97
93	55.90	1.02	0.91	1.01	0.92	0.93	0.87	0.89	0.95
94	57.60	1.03	0.90	1.01	0.92	0.92	0.83	0.86	0.91
95	62.60	1.11	0.96	1.07	0.98	0.99	0.84	0.89	0.94
96	55.90	0.97	0.92	1.07	0.94	0.94	0.92	1.07	1.07
97	59.40	0.99	0.87	0.97	0.89	0.89	0.84	0.89	0.97
98	63.00	1.08	0.90	0.98	0.91	0.92	0.82	0.87	0.96
99	80.30	1.26	1.09	1.16	1.10	1.12	0.93	1.01	1.09
100	89.80	1.18	1.19	1.23	1.20	1.22	0.94	1.04	1.11
101	29.19	1.00	1.17	1.31	1.22	1.23	1.13	1.22	1.35
102	40.32	0.97	1.33	1.23	1.36	1.39	1.21	1.39	1.62
103	43.44	0.90	1.25	0.88	1.23	1.26	1.07	1.28	1.54
104	23.67	0.81	0.98	1.17	1.18	1.19	-	-	-
105	31.30	0.76	1.09	1.23	1.44	1.45	-	-	-
106	36.79	0.77	1.12	1.09	1.56	1.58	-	-	-
107	28.04	0.92	1.27	1.44	1.48	1.48	-	-	-
108	28.63	0.67	1.13	1.25	1.46	1.47	-	-	-
109	30.68	0.64	1.09	1.10	1.51	1.52	-	-	-
110	32.70	0.93	0.86	0.96	0.88	0.89	0.84	0.87	0.91
111	32.30	0.92	0.84	0.94	0.87	0.88	0.83	0.86	0.90
112	41.40	1.02	0.87	0.95	0.91	0.92	0.82	0.89	0.99
113	40.60	1.00	0.85	0.93	0.89	0.90	0.80	0.87	0.97
114	56.70	1.09	1.03	0.93	1.05	1.07	0.91	1.03	1.18
115	53.60	1.03	0.97	0.88	0.99	1.01	0.86	0.97	1.12
116	35.20	0.96	0.88	1.01	1.00	1.00	-	-	-
117	38.70	1.05	0.97	1.11	1.10	1.10	-	-	-
118	40.40	0.93	0.81	0.99	1.07	1.08	-	-	-
119	38.40	0.89	0.77	0.94	1.02	1.03	-	-	-
120	49.20	0.89	0.85	0.94	1.23	1.24	-	-	-
121	51.30	0.93	0.88	0.98	1.28	1.29	-	-	-
122	38.44	1.10	1.01	1.12	1.04	1.05	1.00	1.02	1.08
123	45.90	1.15	0.99	1.08	1.02	1.04	0.93	1.00	1.11

Table 2 Continued

No	F_{exp}	F_{exp}/F_{model}							
		Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	Nisticò and Monti (2013)
124	55.64	1.11	1.04	0.96	1.05	1.07	0.92	1.04	1.19
125	42.55	1.21	1.13	1.17	1.07	1.08	1.00	1.05	1.13
126	44.41	1.06	1.06	0.98	0.95	0.96	0.85	0.93	1.05
127	51.90	1.01	1.13	0.87	0.97	0.99	0.84	0.95	1.10
128	42.19	1.18	1.08	1.20	1.11	1.12	1.07	1.09	1.15
129	45.21	1.11	0.95	1.04	0.98	1.00	0.90	0.97	1.07
130	54.57	1.09	1.00	0.94	1.01	1.03	0.89	1.00	1.15
131	52.83	1.25	1.12	1.08	1.02	1.03	0.93	1.00	1.11
132	59.76	1.17	1.17	0.97	1.02	1.04	0.90	1.00	1.15
133	54.17	1.23	1.10	1.07	1.01	1.02	0.92	0.99	1.10
134	59.50	1.16	1.12	0.95	0.98	1.00	0.87	0.97	1.10

only when the data distribution is normal, nonparametric tests including wilcoxon rank sum test, wilcoxon signed rank test and sign test were also used. Because the results of nonparametric tests might be different in some cases, 3 tests were employed to enhance the accuracy of the results. In most cases, all tests indicated similar results (P-values were either above or below 0.05). Parametric tests (e.g., t-test) are more efficient than nonparametric tests. Therefore, when the data distribution was normal and there was a difference between the results, the result of the t-test was considered as the criterion in this study. In case the data distribution was not normal and there was a difference between the results, two similar results were considered as the criterion (because three nonparametric tests were employed, at least two of three results were similar in all cases). Brief descriptions of these tests are provided in this section.

4.1 Wilk shapiro test

Wilk Shapiro test is applied to check the normality of a population distribution. This test uses a null hypothesis assuming the population has a normal distribution. The null hypothesis is valid that the data has normal distribution when Eq. (22) is met.

$$W \geq W_a \tag{22}$$

Here W_a-critical value found in tables; W-Shapiro-Wilk test value calculated according to the Eq. (23) (Skuturna and Valivonis 2015).

$$W = \frac{\left(\sum_{i=1}^{k} a_{n-i+1}(x_{n-i+1} - x_i)\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{23}$$

In the above equation, x_i is F_{exp} / F_{model}, $\bar{x}$ is the average of F_{exp} / F_{model} for each model and group of data, n is the sample size, a_{n-i+1} is a constant obtained from statistical tables, and k is n / 2 and $(n-1)/2$ when n is an even and odd number respectively. Using n and W values, we can get a

P-value from statistical tables and test the null hypothesis according to this value. In the present study, the null hypothesis is tested using the *P*-value. All tests were performed with a level of significance of α=0.05. Therefore, the null hypothesis is valid (the data distribution is normal) when the *P*-value is more than 0.05.

4.2 T-test

T-test is carried out to see if the means of two normally distributed groups of data are significantly different from each other, or if the mean of a normally distributed group of data is significantly different from a constant value, μ_0. The statistical hypothesis used in the t-test is as follows

$$\begin{cases} H_0 : \mu_1 = \mu_2 \\ H_a : \mu_1 \neq \mu_2 \end{cases} \tag{24}$$

where μ_1 and μ_2 are the means of group 1 and 2 respectively. To evaluate the accuracy of the models, the mean of F_{exp} / F_{model} was compared with μ_0=1. So, the hypothesis was formulated as follows

$$\begin{cases} H_0 : \overline{F_{\text{exp}} / F_{\text{model}}} = 1 \\ H_a : \overline{F_{\text{exp}} / F_{\text{model}}} \neq 1 \end{cases} \tag{25}$$

In order to do the *t*-test, we need to determine a *t*-value according to the Eq. (26)

$$t = \frac{\overline{F_{\text{exp}} / F_{\text{model}}} - 1}{\sqrt{s^2_{\text{exp/model}} / n}} \tag{26}$$

where $s^2_{exp/model}$ and $\overline{F_{\text{exp}} / F_{\text{model}}}$ are the standard deviation and mean for each model and data set respectively and n is the size of the data set. The null hypothesis (H_0) will be valid when

$$t < t_{\alpha/2,(n-1)} \tag{27}$$

where $t_{\alpha/2,(n\text{-}1)}$ is the critical value of the student's distribution with $n-1$ degrees of freedom when the level of significance is α=0.05. The $t_{\alpha/2,(n\text{-}1)}$ is obtained from statistical tables.

Based on the t-value (Eq. (26)), degrees of freedom ($n-1$) and the level of significance (α), we can get a P-value from statistical tables and test the null hypothesis using this value. If the P-value is more than 0.05, we will conclude that the null hypothesis is valid and there is no significant difference between the means. The results of the *t*-test were checked by a 95% confidence interval (Eq. (28)). When there is no significant difference between the results, the interval should include the zero value.

$$\overline{F_{\text{exp}} / F_{\text{model}}} - t_{\alpha/2,n-1} . \frac{s_{\text{exp/model}}}{\sqrt{n}} \leq \overline{F_{\text{exp}} / F_{\text{model}}} \leq \overline{F_{\text{exp}} / F_{\text{model}}} + t_{\alpha/2,n-1} . \frac{s_{\text{exp/model}}}{\sqrt{n}} \tag{28}$$

$$\alpha = 0.05$$

4.3 Wilcoxon rank sum test

Wilcoxon rank sum test is a nonparametric test which is independent from the data distribution. It can be performed for two sets of data to see if there is any significant difference between their means. In order to do wilcoxon rank sum test, we need to (1) sort the data from the smallest to largest and devote a rank to each data based on its value and (2) get the summation of the ranks. For example for the groups A and B, we have

Group A	Group B
1	2
8	6
5	3
4	0

(1) Sorting the data from the smallest to largest:
0 (rank 1) 1 (rank 2) 2 (rank 3) 3(rank 4) 4(rank 5) 5(rank 6) 6(rank 7) 8 (rank 8)
(2) Summation of the ranks for each group:
The 2th, 5th, 6th and 8th ranks belong to group A and the 1th, 3th, 4th and 7th ranks belong to group B. So, the summations of the ranks are:
Group A: R_1= 2+5+6+8=21
Group B: R_2= 1+3+4+7=15

In case we have similar values in groups, we need to get the average of the ranks. For example

Group A	Group B
1	2
8	2
5	2
0	4

0 (rank 1) 1 (rank 2) 2 (rank 3) 2(rank 4) 2(rank 5) 4(rank 6) 5(rank 7) 8 (rank 8)
In this case, we need to get the average of the 3th, 4th and 5th ranks (similar values):
(3+4+5)/3=4
So we need to modify the ranking as follows:
0 (rank 1) 1 (rank 2) 2 (rank 4) 2(rank 4) 2(rank 4) 4(rank 6) 5(rank 7) 8 (rank 8). Therefore, the summations of the ranks are as follows:
Group A: R_1=1+2+7+8=18
Group B: R_2=4+4+4+6=18

The null hypothesis is valid (there is no significant difference between the means) if

$$R = (\min(R_1, R_2)) > R_{(\alpha, n_1, n_2)} \tag{29}$$

where $R_{(\alpha, n_1, n_2)}$ is the critical value determined from statistical tables for two groups of sizes n_1 and n_2 when the level of significance is α=0.05.When the sample sizes are large (usually more than 8), we can assume a normal distribution for R and use a z_0 value to test the null hypothesis

$$z_0 = \frac{R - \mu}{\sigma} \tag{30}$$

$$\mu = \frac{(n_1 + n_2)(n_1 + n_2 + 1)}{4} \tag{31}$$

$$\sigma = \frac{n_1 n_2 (n_1 + n_2 + 1)}{4} \tag{32}$$

where μ and σ are the mean and standard deviation of the normal distribution respectively. Therefore we can get a *P*-value as follows

$$P - value = 2 * p(z < z_0) \tag{33}$$

where $p(z<z_0)$ is determined from the z table (normal distribution table). If the $P{-}value>0.05$, we conclude that the null hypothesis is valid. To investigate the accuracy of the models using wilcoxon rank sum test, two groups of data with the same size, one including F_{exp} / F_{model} values and the other one including values equal to 1 were considered in this study.

4.4 Sign test

Sign test is a nonparametric test performed to determine whether there is any significant difference between the medians of two groups of data. The sign test is also used to see if the median of a data set is different from μ_0 (a constant value). In this case, the sign test is based on the number of observations more and less than μ_0 (which is 1 in this study). To test the null hypothesis, we need to get a S value according to Eq. (35)

$$S = Min(S^+, S^-) \tag{34}$$

where S^+ is the number of observations greater than μ_0 and S^- is the number of observations less than μ_0. The *P*-value can be obtained as follows

$$P - value = 2 * p(x < s) \tag{35}$$

where $p(x < s)$ is obtained from statistical tables. If $P\text{-}value > 0.05$, we will conclude that the null hypothesis is valid and there is no significant difference between the medians of two groups.

4.5 Wilcoxon signed rank test

Despite the sing test which considers only the sign of the differences, wilcoxon rank sum test considers magnitude of the differences as well. In wilcoxon signed rank test, the absolute magnitudes of differences between the observations in two groups of data or between a group of data and a constant value are sorted from the smallest to largest. Based on the summation of the positive and negative ranks, we get a *T* value

$$T = Min(T^+, T^-) \tag{36}$$

where T^+ is the absolute value of the summation of positive ranks and T^- is the absolute value of the summation of negative ranks. Based on the level of significance (α=0.05) and the number of nonzero deviations, we can get a critical T from statistical tables. If $T>T_{cr}$, we will conclude that there is no significant difference between the medians.

For a set of data, when the sample size is large, we can assume a normal distribution for T and use a z_0 value to test the null hypothesis as follows

$$z_0 = \frac{T - \mu}{\sigma} \tag{37}$$

$$\mu = \frac{n(n+1)}{4} \tag{38}$$

$$\sigma^2 = \frac{n(n+1)(2n+1)}{24} \tag{39}$$

where μ and σ are the mean and standard deviation respectively. Using z table, we can get a P-value as follows

$$P - value = 2 * p(z < z_0) \tag{40}$$

If $P-value$ > 0.05, we conclude that the null hypothesis is valid.

5. Results

The results of the wilk Shapiro test are presented in Table 3. In case the P-value is more than 0.05, we can conclude that the data distribution is normal and t-test is workable. To simplify the analysis, all statistical test results were presented using a P-value (see Table 4). When the P-value is more than 0.05, the null hypothesis is valid and there is no significant difference between the means or medians. Table 5 shows 95% confidence intervals. As it can be seen when the P-value

Table 3 P-values for wilk shapiro test

Models	Prisms				
	Square (CFRP)	Square (AFRP of GFRP)	Square (CFRP- AFRP- GFRP)	Rectangular	ALL
Wu *et al*. (2007)	0.743	0.085	0.814	0.164	0.907
ACI (2002)	0.019	0.199	0.013	0.01	0.001
Wu and Wei (2010)	0.546	0.017	0.025	0.097	0.077
Lam and Teng (2003b)	0.068	0.027	0.536	0.085	0.002
ACI (2008)	0.039	0.02	0.331	0.083	0.002
Al-Salloum (2007)	0.634	0.398	0.465	-	-
Wu and Wang (2009)	0.044	0.043	0.089	-	-
Nisticò *and Monti (2013)*	0	0.039	0	-	-

for the *t*-test is less than 0.05 (significant difference), the 95% confidence interval doesn't include the zero value.

Since there are less experimental investigations on the behavior of rectangular prisms compared with square prisms, many of existing studies mostly used square sections to present a model. Therefore, these models might not be able to show reliable results for rectangular prisms. The results of the statistical tests indicated that except the model by Wu and Wei (2010), the other models were not able to estimate the compressive strength of the rectangular prisms. In most proposed models, the employed prisms were confined with CFRP, so they might not show reliable results for other confinement types. Therefore, the present study evaluated the accuracy of the models for both CFRP and GFRP or AFRP confinements. As it can be seen in table 4, the models by ACI (2002) and ACI (2008) show the best prediction of the compressive strength for square prisms both confined with CFRP and GFRP or AFRP. Table 4 indicates that the models by Wu and Wang (2009) and Lam and Teng (2003b) work just for square specimens confined with CFRP. It

Table 4 Test results

		Models							
Prisms	Test	Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	*Nisticò and Monti (2013)*
Square (CFRP)	T[a]	0.05	-	0.03	1.00	-	0.00	-	-
	W-R-S[b]	0.13	0.13	0.03	0.36	0.54	0.00	0.36	0.00
	W-S-R[c]	0.06	0.39	0.05	0.63	0.82	0.00	0.30	0.00
	S[d]	0.30	0.30	0.13	0.56	0.73	0.00	0.56	0.01
SQUARE (AFRP or GFRP)	T	0.34	0.19	-	-	-	0.00	-	-
	W-R-S	0.10	0.48	0.48	0.01	0.04	0.00	0.00	0.04
	W-S-R	0.26	0.28	0.44	0.02	0.05	0.00	0.02	0.05
	S	0.28	0.72	0.72	0.07	0.15	0.00	0.01	0.15
Square (CFRP-AFRP-GFRP)	T	0.03	-	-	0.16	0.66	0.00	0.10	-
	W-R-S	0.03	0.10	0.03	0.03	0.10	0.00	0.01	0.00
	W-S-R	0.02	0.19	0.05	0.09	0.40	0.00	0.03	0.00
	S	0.12	0.24	0.12	0.12	0.24	0.00	0.05	0.00
Rectangular	T	0.00	-	0.85	0.00	0.00	-	-	-
	W-R-S	0.00	0.00	0.16	0.00	0.00	-	-	-
	W-S-R	0.00	0.00	0.60	0.00	0.00	-	-	-
	S	0.00	0.00	0.36	0.02	0.01	-	-	-
ALL	T	0.67	-	0.02	-	-	-	-	-
	W-R-S	0.22	0.00	0.01	0.74	0.74	-	-	-
	W-S-R	0.66	0.00	0.04	0.83	0.30	-	-	-
	S	0.39	0.01	0.06	0.86	0.86	-	-	-

[a]T-test
[b]Wilcoxon rank sum test
[c]Wilcoxon signed rank test
[d]Sign test

Table 5 95% confidence interval

Models	Prisms									
	Square (CFRP)		Square (AFRP of GFRP)		Square (CFRP- AFRP- GFRP)		Rectangular		ALL	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Wu *et al*. (2007)	0.000	0.064	-0.031	0.087	0.003	0.059	-0.166	-0.100	-0.031	0.020
ACI (2002)	-	-	-0.078	0.016	-	-	-	-	-	-
Wu and Wei (2010)	-0.074	-0.003	-	-	-	-	-0.061	0.051	-0.059	-0.004
Lam and Teng (2003b)	-0.034	0.034	-	-	-0.049	0.008	0.064	0.217	-	-
ACI (2008)	-	-	-	-	-0.036	0.023	0.072	0.225	-	-
Al-Salloum (2007)	-0.137	-0.084	-0.190	-0.085	-0.143	-0.095	-	-	-	-
Wu and Wang (2009)	-	-	-	-	-0.050	0.004	-	-	-	-
Nisticò and Monti (2013)	-	-	-	-	-	-	-	-	-	-

Table 6 Summary of the models' evaluations

Prisms	Models							
	Wu *et al.* (2007)	ACI (2002)	Wu and Wei (2010)	Lam and Teng (2003b)	ACI (2008)	Al-Salloum (2007)	Wu and Wang (2009)	Nisticò and Monti (2013)
Square (CFRP)	Accept	Accept	Reject	Accept	Accept	Reject	Accept	Reject
Square (AFRP or GFRP)	Accept	Accept	Accept	Reject	Accept	Reject	Reject	Accept
Square (CFRP-AFRP- GFRP)	Reject	Accept	Accept	Accept	Accept	Reject	Accept	Reject
Rectangular	Reject	Reject	Accept	Reject	Reject	-	-	-
All	Accept	Reject	Reject	Accept	Accept	-	-	-

can also be concluded that for square prisms, the models by Wu and Wei (2010) and Nisticò and Monti (2013) are reliable only for those confined with GFRP and AFRP. Test results also indicate that the model by Al-Sallum (2007) is not able to predict the compressive strength of any of data sets. Considering total prisms including square and rectangular prisms, the model by ACI (2008) look more reliable comparing with the other models but still it cannot predict the compressivestrength of rectangular prisms. Table 6 shows a summary of the models' evaluations.

To test the accuracy of a model, it is necessary to separate the prisms based on different specifications like cross section type (e.g., square and rectangular) and confinement type (e.g., CFRP, GFRP, and AFRP). In an initial judgment, a model may seem reliable for a series of data including square and rectangular prisms but considering the prisms separately and based on their shape or confinement, the model may not work. For example, if we have a series of data including 60 square prisms and 10 rectangular prisms, a model may predict the total behavior very good but may not be able to predict the behavior of rectangular prisms separately. This is because the number of square prisms (60 prisms) are more than the rectangular prisms (10 prisms).

The results of the models were also evaluated with each other using the statistical tests. To compare two models (e.g., *i* and *j*) for a data set, the same relationships explained in the section 4

Table 7 Comparison of the models for square (CFRP) prisms

Models	Tests					Results
	W-SH[a]	T	W-R-S	W-S-R	S	
ACI (2002)-Wu *et al.* (2007)	0.00	-	0.00	0.00	0.00	Reject
ACI (2002)-Lam and Teng (2003b)	0.00	-	0.00	0.13	0.01	Reject
ACI (2002)-ACI (2008)	0.00	-	0.00	0.00	0.00	Reject
ACI (2002)-Wu and Wang (2009)	0.00	-	0.36	0.69	0.56	Accept
Wu *et al.* (2007)-Lam and Teng (2003b)	0.00	-	0.00	0.00	0.00	Reject
Wu *et al.* (2007)-ACI (2008)	0.00	-	0.00	0.00	0.00	Reject
Wu *et al.* (2007)-Wu and Wang (2009)	0.00	-	0.00	0.00	0.00	Reject
Lam and Teng (2003b)-ACI (2008)	0.12	0.00	0.00	0.00	0.00	Reject
Lam and Teng (2003b)-Wu and Wang (2009)	0.08	0.17	0.01	0.09	0.05	Accept
ACI (2008)-Wu and Wang (2009)	0.15	0.00	0.00	0.00	0.00	Reject

[a] Wilk Shapiro test

Table 8 Comparison of the models for square (AFRP or GFRP) prisms

Models	Tests					Results
	W-SH	T	W-R-S	W-S-R	S	
ACI (2002)-Wu and Wei (2010)	0.000	-	0.102	0.891	0.281	Accept
ACI (2002)-Wu *et al.* (2007)	0.005	-	0.000	0.001	0.000	Reject
ACI (2002)-ACI (2008)	0.000	-	0.102	0.378	0.281	Accept
ACI (2002)-Nisticò and Monti (2013)	0.670	0.001	0.000	0.001	0.012	Reject
Wu and Wei (2010)-Wu *et al.* (2007)	0.033	-	0.000	0.003	0.012	Reject
Wu and Wei (2010)-ACI (2008)	0.000	-	0.000	0.081	0.012	Reject
Wu and Wei (2010)-Nisticò and Monti (2013)	0.003	-	0.036	0.009	0.151	Reject
Wu *et al.* (2007)-ACI (2008)	0.100	0.000	0.000	0.000	0.000	Reject
Wu *et al.* (2007)-Nisticò and Monti (2013)	0.152	0.790	0.816	0.891	1.000	Accept
ACI (2008)-Nisticò and Monti (2013)	0.001	-	0.000	0.000	0.000	Reject

were employed (except using F_{exp} / F_{model}, $F_{model(i)}$ / $F_{model(j)}$ was used). The results are provided using P-values in the Tables 7-10. As it can be seen except in very limited cases, the models show different results.

To see which model is more accurate when there is no significant different between the results, a coefficient of confidence according to the Eq. (41) was obtained for each model (see Table 11).

$$CoC = \frac{1}{\overline{F_{\exp} / F_{\text{model}}}(1 - 2CV_{F_{\exp}/F_{\text{model}}})} \tag{41}$$

where CV $_{F\exp/Fmodel}$ is the coefficient of variation.

The closer this coefficient is to 1, the more accurate are the results and the closer they are to the experimentally received ones (Skutuma and Valivonis 2015). As it can be seen in Table 11, all

Table 9 Comparison of the models for square (CFRP- AFRP- GFRP) prisms

Models	Tests					Results
	W-SH	T	W- R-S	W- S-R	S	
ACI (2002)-Wu and Wei (2010)	0.000	-	0.001	0.581	0.019	Reject
ACI (2002)-Lam and Teng (2003b)	0.000	-	0.003	0.780	0.032	Reject
ACI (2002)-ACI (2008)	0.000	-	0.000	0.024	0.000	Reject
ACI (2002)-Wu and Wang (2009)	0.000	-	0.702	0.256	0.845	Accept
Wu and Wei (2010)-Lam and Teng (2003b)	0.000	-	0.000	0.205	0.001	Reject
Wu and Wei (2010)-ACI (2008)	0.000	-	0.000	0.705	0.002	Reject
Wu and Wei (2010)-Wu and Wang (2009)	0.000	-	0.003	0.141	0.029	Reject
Lam and Teng (2003b)-ACI (2008)	0.053	0.000	0.000	0.000	0.000	Reject
Lam and Teng (2003b)-Wu and Wang (2009)	0.001	-	0.001	0.234	0.019	Reject
ACI (2008)-Wu and Wang (2009)	0.005	-	0.000	0.002	0.001	Reject

Table 10 Comparison of the models for all prisms

Models	Tests					Results
	W-SH	T	W- R-S	W-S-R	S	
Wu *et al*. (2007)-Lam and Teng (2003b)	0.000	-	0.000	0.088	0.000	Reject
Wu *et al*. (2007)-ACI (2008)	0.000	-	0.000	0.321	0.002	Reject
Lam and Teng (2003b)-ACI (2008)	0.001	-	0.000	0.000	0.000	Reject

Table 11 Coefficient of confidence

Models	Prisms				
	Square (CFRP)	Square (AFRP of GFRP)	Square (CFRP- AFRP- GFRP)	Rectangular	All
Wu *et al.* (2007)	1.3	1.4	-	-	1.4
ACI (2002)	1.6	1.4	1.6	-	-
Wu and Wei (2010)	-	1.7	1.6	1.4	-
Lam and Teng (2003b)	1.4	-	1.5	-	1.5
ACI (2008)	1.4	1.5	1.5	-	1.5
Al-Salloum (2007)	-	-	-	-	-
Wu and Wang (2009)	1.4	-	1.4	-	-
Nisticò and Monti *(2013)*	-	1.3	-	-	-

coefficients of variations are close to each other and this means that all models are almost as accurate as each other in case there is no significant difference between them.

5. Conclusions

In the present study the accuracy of eight presented models predicting the monotonic compressive strength of FRP confined concrete prisms with square and rectangular sections was investigated. The models were evaluated using statistical tests including t-test, wilcoxon rank sum test, wilcoxon signed ranked test and sign test. The results indicated that in most cases the workability of the models depends severely on the cross section and confinement type. For example, considering square prisms, the models by Wu and Wang (2009) and Lam and Teng (2003b) worked just for prisms confined with CFRP and the models by Wu and Wei (2010) and Nisticò and Monti (2013) showed good results only for square prisms confined with GFRP and AFRP. The findings showed that except the model by Wu and Wei (2010), the other models couldn't predict the compressive strength of the rectangular prisms. However the model by ACI (2008) showed totally good results for most prisms but it was not able to model the compressive strength of rectangular prisms. Based on the results none of the models could predict the compressive strength of FRP confined concrete for all confinement types and cross section shapes. Therefore a new reliable model should be proposed to predict the compressive strength considering all confinement types and cross section shapes. Test's results also indicated that except in limited cases, the results of the models were different from each other and in cases there were no significant difference between the results, the models' predictions were almost as accurate as each other.

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