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Estimation of flexural capacity of quadrilateral FRP-confined RC columns using combined artificial neural network

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ABSTRACT

This study presents the application of combined artificial neural networks (CANNs) for the flexural capacity estimation of quadrilateral fiber-reinforced polymer (FRP) confined reinforced concrete (RC) columns. A database on quadrilateral FRP confined RC columns subjected to axial load and moment was obtained from experimental studies in the literature; CANN models were built, trained and tested. Then the flexural capacities of quadrilateral FRP confined RC columns were determined using the developed CANN model. Single and combined ANN was used for the first time in the literature for the estimation of flexural capacities of non-circular fiber-reinforced polymer (FRP) confined reinforced concrete (RC) columns. The accuracies of the proposed ANN and CANN models were more satisfactory as compared to the existing conventional approaches in the literature. Moreover, the proposed CANN models' results had lower prediction error than those of the single ANN model.

1. Introduction

The use of fiber-reinforced polymers (FRPs) has started as the confining materials in newly encased columns and for the repairing, retrofitting, strengthening, rebuilding processes in engineering structures nowadays [1–3]. One of the most important applications of FRP-composites is a thin layer of FRP jacket for the repairing, retrofitting, and strengthening processes of concrete columns, and the other is a tubular FRP case used for new constructions and rebuilding [4]. The results of several studies showed that the FRP jacket can greatly enhance the strength and ductility of concrete columns by providing confinement to the concrete core, and the strain gradient reduces the retrofit efficiency of the FRP jacket for concrete columns.

The FRP composites are excellent materials in terms of their extremely high strength to weight ratio, corrosion resistance and electromagnetic neutrality characteristics [5]. As a result, many researchers have shown deep interest for circular concrete columns wrapped with FRP sheets that have a significant increase in strength and ductility. However, the square and rectangular columns were found to experience less increase in strength and ductility than their circular counterparts. This is because the distribution of lateral confining pressure in square and rectangular x-sections is nonuniform, in contrast to circular sections for which the confining pressure is uniform. Thus, the existing analytical models for predicting the stress–strain behavior of FRP-confined concrete have been mostly derived for circular plain concrete columns [6]. Therefore, the analytical models derived for circular specimens under uniform confining pressure generally predict the stress–strain behavior quite well for circular sections. However, because of the complicated nature of the interaction between FRP and concrete at the outer concrete shell, the ultimate compressive strength of FRP-confined concrete and corresponding strain capacity cannot be precisely predicted for square and rectangular columns [7,8] using the models originally proposed for circular columns.

Many experimental and analytical investigations have been conducted to assess the behavior of FRP confined concrete that most of these studies were about the stress–strain relationship of FRP-confined concrete columns [9–14]. Some theoretical and experimental studies have been also conducted on the behavior of FRP-confined concrete columns subjected to axial force and flexure to obtain axial force–moment interaction diagrams [15,16]. Fam et al. [17] tested ten CFFT (concrete-filled fiber reinforced polymer) tubes and used the test results to propose a new (*P*–*M*) interaction diagram. The predicted values well-matched with the experimental results and the shape of the interaction curves of

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Table 1
Data set for CANN testing and training.

Reference	Specimen name	Fiber type	b (mm)	h (mm)	h/b	H (m)	r (mm)	ρ_g (%)	ρ_t (%)	ρ_f (%)	f_c (MPa)	f_y (MPa)	E_f (MPa)	f_{fu} (MPa)	ε_{fu} (%)	t_f (mm)	P/P_u	$M_{r\ EXP}$ (kN m)	$M_{r\ CANN}$ (kN m)
Nosho	NOl	0	280	280	1.00	2.36	13	1.02	0.25	0.00	40.6	407	NA	NA	NA	NA	0.39	140	139
	N02	1	280	280	1.00	2.36	13	1.02	0.25	0.94	41.6	407	261.484	4165	1.60	0.17	0.35	147	148
	N03	1	280	280	1.00	2.36	13	1.02	0.25	0.16	41.6	407	267.358	4206	1.57	0.11	0.36	137	136
	N04	1	280	280	1.00	2.36	13	1.02	0.25	0.08	42.7	407	267.358	4206	1.57	0.11	0.36	140	141
Walkup	WA1	0	458	458	1.00	3.05	51	1.48	0.21	0.00	24.6	460	NA	NA	NA	NA	0.29	559	556
	WA2	1	458	458	1.00	3.05	51	1.48	0.21	0.86	*22.7*	460	230.303	3515	1.50	0.17	0.29	581	584
	WA3	1	458	458	1.00	3.05	51	1.48	0.21	0.58	*24.1*	460	230.303	3515	1.50	0.17	0.27	537	534
	WA4	1	458	458	1.00	3.05	51	1.48	0.21	0.29	24.1	460	230.303	3515	1.50	0.17	0.27	556	559
Chaallal and Shahawy	CSl-b	0	200	350	1.75	2.10	25	1.62	1.57	0.00	25.5	414	NA	NA	NA	NA	0.79	105	104
	CS2-b	1	200	350	1.75	2.10	25	1.62	1.57	1.57	25.5	414	45.000	540	1.20	0.50	0.81	145	146
	CSl-c	0	200	350	1.75	2.10	25	1.62	1.57	0.00	25.5	414	NA	NA	NA	NA	0.46	139	138
	CS2-c	1	200	350	1.75	2.10	25	1.62	1.57	1.57	25.5	414	45.000	540	1.20	0.50	0.50	159	160
	CSl-d	0	200	350	1.75	2.10	25	1.62	1.57	0.00	25.5	414	NA	NA	NA	NA	0.20	114	115
	CS2-d	1	200	350	1.75	2.10	25	1.62	1.57	1.57	25.5	414	45.000	540	1.20	0.50	0.27	158	159
	CSl-e	0	200	350	1.75	2.10	25	1.62	1.57	0.00	25.5	414	NA	NA	NA	NA	0.15	119	118
	CS2-e	1	200	350	1.75	2.10	25	1.62	1.57	1.57	25.5	414	45.000	540	1.20	0.50	0.21	179	178
Iacobucci et al.	IAl-a	0	305	305	1.00	1.47	16	2.58	0.61	0.00	31.4	465	NA	NA	NA	NA	0.45	180	182
	IA2-a	1	305	305	1.00	1.47	16	2.58	0.61	1.31	36.5	465	76.350	962	1.26	1.00	0.37	229	230
	IA3-a	1	305	305	1.00	1.47	16	2.58	0.61	2.62	36.9	465	76.350	962	1.26	1.00	0.63	233	232
	IA4-a	1	305	305	1.00	1.47	16	2.58	0.61	1.31	36.9	465	76.350	962	1.26	1.00	0.63	218	217
	IA5-a	1	305	305	1.00	1.47	16	2.58	0.61	3.93	37.0	465	76.350	962	1.26	1.00	0.63	260	261
	IA6-a	1	305	305	1.00	1.47	16	2.58	0.61	2.62	37.0	465	76.350	962	1.26	1.00	0.37	246	247
Bousias et al.	BOl-a	0	250	500	2.00	1.60	13	0.83	0.51	0.00	18.3	560	NA	NA	NA	NA	0.43	304	303
	B02-a	1	250	500	2.00	1.60	13	0.83	0.51	0.31	18.1	560	230.000	3450	1.50	0.13	0.40	358	356
	B03-a	1	250	500	2.00	1.60	13	0.83	0.51	0.78	17.9	560	230.000	3450	1.50	0.13	0.42	379	381
	B04-a	2	250	500	2.00	1.60	13	0.83	0.51	1.02	18.7	560	70.000	2170	3.10	0.17	0.39	326	328
	BOl-b	0	500	250	2.00	1.60	13	0.83	0.51	0.00	17.9	560	NA	NA	NA	NA	0.43	110	109
	B02-b	1	500	250	2.00	1.60	13	0.83	0.51	0.31	18.1	560	230.000	3450	1.50	0.13	0.38	112	111
	B03-b	1	500	250	2.00	1.60	13	0.83	0.51	0.78	17.9	560	230.000	3450	1.50	0.13	0.40	122	121
	B04-b	2	500	250	2.00	1.60	13	0.83	0.51	1.02	18.7	560	70.000	2170	3.10	0.17	0.36	120	121
Elnabelsy and Saatcioglu	ES1-S	1	500	500	1.00	1.73	13	1.44	0.33	2.16	33.0	400	60.000	700	1.17	0.90	0.13	640	643
	ES2-S	1	500	500	1.00	1.73	13	1.44	0.33	3.60	38.0	400	60.000	700	1.17	0.90	0.13	640	640
Harajli and Rteil	HRl-a	0	150	300	2.00	1.12	13	1.50	0.80	0.00	20.3	534	NA	NA	NA	NA	0.24	59	59
	HR2-a	1	150	300	2.00	1.12	13	1.50	0.80	0.26	21.1	534	230.000	3500	1.50	0.13	0.21	65	65
	HR3-a	1	150	300	2.00	1.12	13	1.50	0.80	0.39	21.7	534	230.000	3500	1.50	0.13	0.21	70	70
	HRl-b	0	150	300	2.00	1.12	13	3.00	0.80	0.00	20.3	565	NA	NA	NA	NA	0.27	88	88
	HR2-b	1	150	300	2.00	1.12	13	3.00	0.80	0.26	21.1	565	230.000	3500	1.50	0.13	0.24	94	94
	HR3-b	1	150	300	2.00	1.12	13	3.00	0.80	0.39	21.7	565	230.000	3500	1.50	0.13	0.23	94	95
Memon and Sheikh	MSI	0	305	305	1.00	1.48	16	2.58	0.61	0.00	42.4	465	NA	NA	NA	NA	0.71	195	196
	MS2	2	305	305	1.00	1.48	16	2.58	0.61	3.28	42.5	465	19.754	450	2.28	1.25	0.36	250	249
	MS3	2	305	305	1.00	1.48	16	2.58	0.61	6.56	42.7	465	19.754	450	2.28	1.25	0.61	252	253
	MS4	2	305	305	1.00	1.48	16	2.58	0.61	3.28	43.3	465	19.754	450	2.28	1.25	0.60	232	233
	MS5	2	305	305	1.00	1.48	16	2.58	0.61	1.64	43.7	465	19.754	450	2.28	1.25	0.36	235	234
	MS6	2	305	305	1.00	1.48	16	2.58	0.61	4.92	44.2	465	19.754	450	2.28	1.25	0.60	286	285