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Analytical model for Axial Strength of FRP-Reinforced Short Columns Confined with Sheets and Tubes

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ABSTRACT

Reinforcement of concrete structures using (FRPs) fiber-reinforced polymers as an alternative to conventional steel is on the rise. In this study, the effects of axial cyclic and concentric stresses on the durability of (CFFT) columns constructed from concrete reinforced FRP tubes are investigated. The axial durability of 587 FRP-confined concrete collapse pieces was included in our massive dataset compiled from previous studies. The database (excel file) is submitted along this paper. This database is used to develop an analytical model of a CFFT column reinforced by FRP bars which is used to find the axial strength of that column accurately. This information was used to generate an analytical model that successfully predicts the axial power of a CFFT column that has been internally reinforced with FRP bars. The proposed model's remarkable agreement with observed outcomes demonstrates its success in predicting the axial lifespan of FRP-RC components housed in FRP tubes.

KEYWORDS: Analytical model; FRP-tube; FRP bars; Axial strength; Short column.

1 INTRODUCTION

Engineering structures have been used FRPs in many type of works [1], [2], [3] Fiber Reinforced Polymers because of their superior qualities, fibres employed as reinforcement are replacing conventional steel in many applications. Some examples include improved fire resistance, a more aesthetically pleasing appearance, and a longer lifespan in addition to their already impressive corrosion resistance. Outward local buckles in cylinders limit axial capacities for sustaining load and ductility. Negating the benefits of lateral steel confinement, which increases concrete strength. Fiber-reinforced polymers (FRPs) offer further confinement to stop local buckling from spreading [4]. Greater stiffness, corrosion resistance, higher strength, decreased weight, and extended service life are just some of the benefits of composite constructions over those produced from more traditional materials [2]. Following this, rockets have found uses in numerous industries, including construction, cooking, transportation, and recreation [5, 6]. Increased strength and ductility from lateral confinement account for the widespread adoption of confined concrete [7].

There have been several research studies conducted on the composition and performance of concrete compression structures limited by both conventional steel tubes and steel tubes with enhanced resistance to corrosion, with and without the use of FRP reinforcements [8], [9] [10-18].

Compression members built of composite concrete have been found to gain strength and strain adaptability through confinement. In terms of strength and durability, laminated composite concrete is superior to both steel and regular concrete. To achieve this superiority, concrete works in unison with FRP and/or metallic tubes, which play a critical function in restricting the strength of the concrete core and minimizing local buckling. To be more precise, CFSST columns save more energy than their steel-tube counterparts. Outward regional buckling, which reduces ductility and strength, has been identified as the failure mechanism for CFSST columns [19]. The consequences of local buckling must be mitigated, and the load-bearing capacity must be increased, through the use of FRP wood laminates and other hardening techniques. FRP wraps improve the ductility and axial durability of the concrete core because they enclose the core [20]. Even though CFSST columns have various desirable structural features, there are currently no internationally accepted standards for their design. More research is required to provide guidelines for the study and development of FRP-confined concrete pressure members. All 587 observations in the database were carefully chosen from credible sources in the existing literature on FRP-reinforced concrete columns. These sources included an extensive collection of published studies and research articles. The data collection method included a detailed assessment and extraction of experimental results related to the axial strength of FRP-reinforced short columns constrained with sheets and tubes. This stringent approach secured the dataset's integrity and quality, allowing for more robust analysis and modelling in our research. In this research, the authors have developed a sophisticated analytical simulation of FRP-reinforced structures constrained in a range of FRP tubes. To accurately predict the axial strength of an FRP-reinforced CFFT column, the information was used to develop a new analytical model. This research will focus on developing optimized design and algorithms and applying the model to real world projects. This comprehensive approach enables significant performance in improving the design and engineering works related to FRP-reinforced columns. Our objective is to create a reliable analytical model capable of reliably estimating the axial strength of FRP-reinforced short columns restricted with sheets and tubes. In addition, we want to investigate the nonlinear behaviour of FRP-reinforced columns. To assist the building industry and establish new guidelines for concrete columns reinforced with FRP model for axial strength.

1.1 Database

The authors found a significant gap in the existing literature when looking at the possibility of predicting the axial loading of FRP-tube structures supplemented by FRP bars through the interior. This study proposes an analytical model built on a strong experimental database that can estimate the ultimate axial ability of compounding FRP confined cylinders with a high degree of precision. To reduce the number of outliers that inflated the RMSE index, researchers painstakingly compiled a massive dataset of limited concrete strength through regression analysis with established strength models. After eliminating the most extreme data points (those with errors of 20% or more), the authors were kept with 587 reliable observations. Comprehensive regression study was done on this data to generate the new FRP-confined a concrete strength model.

A parametric study showed the proposed empiric model to be correct when compared to the findings of a finite-element prediction. The newly constructed database is summarised in Table 1.

1.2 Proposed Model

As long as the beginning stress and the final dimensions of the FRP tube are known, the axial strain of plastic bars in reinforcements in concrete columns contained in FRP tubes can be anticipated. Many models of constrained concrete's strength were initially evaluated by the analytical ability model. In this study, the authors analysed the work of Lam and Teng [21], Fardis and Khalili [22], Newman and Newman [23], Karbhari and Gao [24], Toutanji [25], Teng et al.[26], Mander et al. [27], Richart et al. [28], Samaan et al.[29], Saafi et al.[30], Miyauchi et al. [31] and Matthys et al. Mean square error, sum of squared errors, and coefficient of predictability were a few of the statistical measures that were applied to the dataset. Lam and Teng, Fardis and Khalili, and Miyauchi's models improve understanding and performance of reinforced concrete structures. They look at FRP-reinforced concrete behaviour, FRP-encased concrete as a structural material, and the usefulness of carbon fiber sheets in increasing concrete column strength. Leveraging these models enables breakthroughs in structural engineering procedures, resulting in more durable and efficient concrete structures. These models provide significant contributions to the fields of concrete reinforcing and structural engineering. Leveraging them increases the research base, broadens the context, and promotes innovation in building engineering techniques. It may encourage further research into design guidelines, new building techniques, and novel applications of FRP materials in concrete construction. The suggested analytical model was developed using a methodology that included curve fitting techniques and the use of MATLAB to improve the accuracy of the model and refine constants. Crucially, our methodology was fully based on experimental data there are no assumptions.

Table 1. Statistical details of the constructed database

Parameter	*D* (mm)	*H* (mm)	*nt* (mm)	*Es* (GPa)	*f'co* (MPa)	*f'cc* (MPa)	ε_{co} (%)	ε_{cc} (%)
MIN	51.0	102.0	0.09	10.0	12.41	18.50	0.17	0.33
MAX	406.0	812.0	5.90	663.0	188.20	302.20	1.53	4.62
Mean	153.7	307.57	0.92	174.59	43.520	78.08	0.27	1.60
St. Dev	43.91	87.83	1.06	120.06	22.31	34.60	0.14	0.82
COV	0.29	0.29	1.16	0.69	0.52	0.45	0.52	0.52
MIN	51.0	102.0	0.09	10.0	12.41	18.50	0.17	0.33
MAX	406.0	812.0	5.90	663.0	188.20	302.2	1.53	4.62

The RMSE for the tested version of the Lam and Pang model [21] was 0.244, and the R^2 was 0.903%. The resulting constrained concrete strength equation has been incorporated into the more comprehensive analytic model. Figure 1 is an illustration of the effectiveness of many strength models studied in the literature.

RC columns enclosed by FRP tubes have a maximum allowable load (P_n) calculated as:

$$P_n = P_{confinement} + P_{FRP\ tube} \quad (9)$$

In this context, $P_{confinement}$, This is the maximum load allowed on the support structure because of the concrete confinement, $P_{FRP\ tube}$ implies the maximum load capacity due to the GFRP tube. The formula for the safe working load limit due to enclosure is as follows:

$$P_{confinement} = A_{cc} f'_{cc} \quad (10)$$

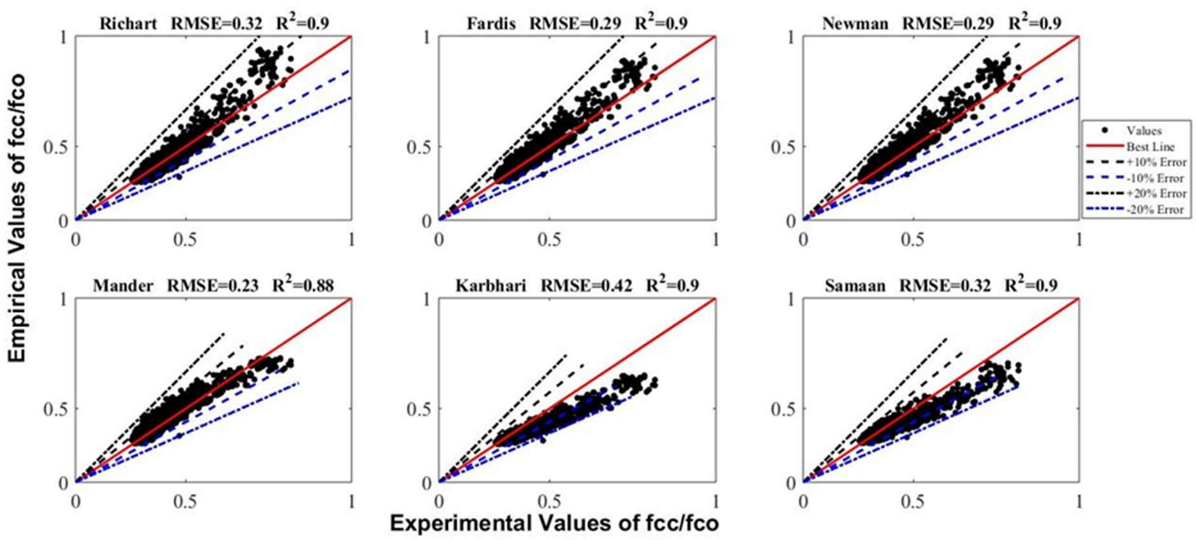
Here, A_{cc} is a tube made of fiberglass-reinforced plastic that encloses a core of Concrete with reinforcement, and f'_{cc} is the limit to how strong concrete can be when compressed. The equation takes the form shown here as a whole. of f'_{cc} was as described in Eq. (11) below, is an adaptation of the model by Lam and Teng [21].

$$\frac{f'_{cc}}{f_{co}} = 1 + k\left(\frac{f_l}{f_{co}}\right)^n \quad (11)$$

Variables *k* and *n* are not given in the equation and f_l is ultimate confinement stress given by FRPs-tube together Eq. (12) will give you f_l given below [32, 33]:

$$f_l = \frac{2E_f \varepsilon_{h,rup} t_{FRP}}{D_c} + \frac{2t_{FRP} f_y}{D_c - 2t_{FRP}} \quad (12)$$

In this context, the diameter of the reinforced concrete core within a column is denoted by D_c represents the diameter of the concrete core within the column, E_f denotes the modulus of elasticity for Fiber-reinforced bars, GFRP-tube which is used for confinement its total thickness is given by t_{FRP} , and $\varepsilon_{h,rup}$ signifies the rupture strain of FRPs in the hoop direction. The relationship for $\varepsilon_{h,rup}$ was constructed by Lim et al. [34] utilizing genetic programming.



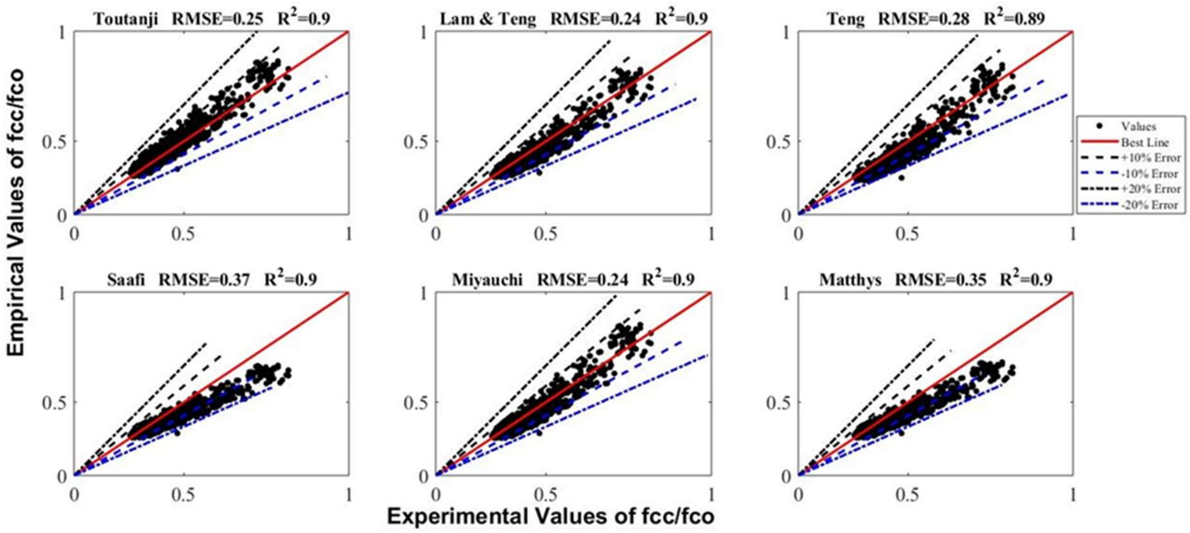


Figure. 1. This data set was used to evaluate the efficiency of proposed strength models for constrained concrete.

$$\varepsilon_{h,rup} = \frac{\varepsilon_f}{f_{co}'^{0.125}} \tag{13}$$

Following initial assessments employing statistical parameters (such as R^2, SSE, and RMSE) through the curve fitting technique in MATLAB, the unknown coefficients *k* and *n* were determined to be 2.9 and 3/4, respectively. Consequently, the axial strength of FRP-reinforced confined concrete is formulated and represented in Eq. (15) by using analytical modeling.

$$\frac{f_{cc}'}{f_{co}'} = 1 + 2.9\left(\frac{f_l}{f_{co}'}\right)^{3/4} \tag{14}$$

$$f_{cc}' = f_{co}' + 2.9 f_{co}'^{1/4} f_l^{3/4} \tag{15}$$

The effectiveness of the recently developed analytical strength model in predicting the axial strength of confined concrete is illustrated in Figure 2. Notably, this proposed model exhibited a lower error, with an R^2 value of 0.91 and an RMSE of 0.19, in comparison to previously suggested strength models. Consequently, it was chosen for utilization in the current study.

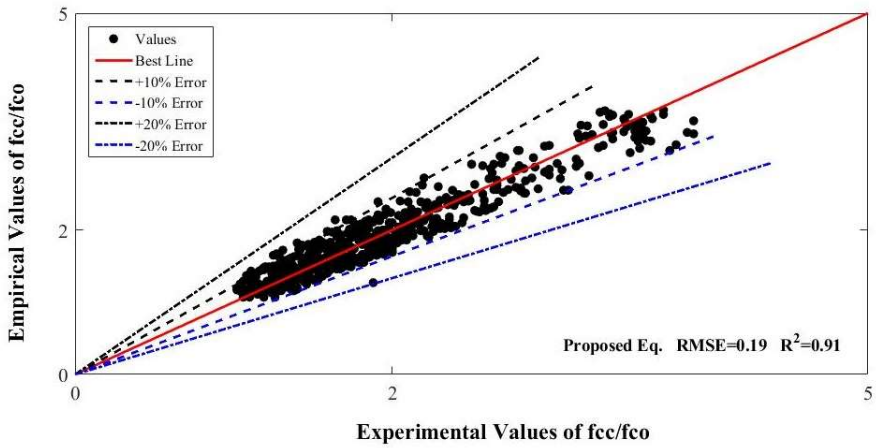


Figure. 2. The response of constrained concrete according to the compiled database by deduced empirical strength model

we can express Eq. (10) in the following form:

$$P_{confinement} = A_{cc}\left[f'_{co} + 2.9{f'_{co}}^{1/4}{f_l}^{3/4}\right] \tag{16}$$

Continuous strength approach is used to determine the ultimate capacity of the FRP-tube ($P_{FRP\ tube}$) which was developed to take advantage of strain hardening for determining the stiffness of fiber-reinforced polymer-tube sections in order [18, 35, 36]. Bilinear behavior was assumed for the FRP tube.

$$P_{FRP\ tube} = A_{FRP\ tube}\sigma_{LB} \tag{17}$$

In this context, $A_{FRP\ tube}$ represents the total area of the section perpendicular to the direction of load of the FRP tube, and the strain at a certain location along the tube that causes buckling is σ_{LB}. Buchanan and Gardner [36] suggest utilizing Eq. (18) and Eq. (19) to calculate this stress. To maximize the FRP-tube's commitment to the ultimate capacity to load and suppleness of the FRP-tube constrained composite columns [37], it is important to understand how the FRP-tube's strain hardening properties work.

$$\sigma_{LB} = E\varepsilon_{LB}\frac{\varepsilon_{LB}}{\varepsilon_{0.2}} < 1.0 \tag{18}$$

$$\sigma_{LB} = \varepsilon_{0.2} + E_{sh}\varepsilon_{0.2}(\frac{\varepsilon_{LB}}{\varepsilon_{0.2}} - 1)\frac{\varepsilon_{LB}}{\varepsilon_{0.2}} \geq 1.0 \tag{19}$$

In this equation, ε_{LB} represents the local buckling strain, represents the elasticity for the FRP-tube is given by $\varepsilon_{0.2}$, which means the FRP-tube's verification strain at 2%, and E_{sh} is FRP-tube bilinear capability Young's modulus while strain hardening. Since this is the case, the equation to determine the ultimate capacity for loading of the FRP-tube confined column of concrete is as follows.

$$P_n = A_{cc}\left[f'_{co} + 2.9 {f'_{co}}^{1/4} {f_l}^{3/4}\right] + A_{FRP\ tube}\sigma_{LB} \qquad (20)$$

A suggested formula for calculating the ultimate load-bearing ability of CFFT columns strengthened with FRP bars subjected to axial loads is represented by the above equations.

2 CONCLUSION

To forecast the height of sophistication axial pulling capacity for FRP-tube confined columns and by using regression analysis analytical model and findings showed a good level of concurrence with experimental findings (coefficient of determination = 0.95). As a result, the structural behaviour of CFFT columns may be accurately predicted using this analytical model. It is a reliable tool for analyzing and designing CFFT columns with FRP bars within a variety of essential parameters. The analytical model for CFFT columns with FRP bars takes into account the following key parameters: the size of the column, the concrete and FRP bar material properties, the confinement circumstances and the loading configurations. Thorough validation against experimental data from many investigations proved the model's reliability in a variety of circumstances, showing strong agreement across a range of column geometries, loading types, and FRP reinforcement layouts. A high degree of accuracy and predictive power is indicated by the coefficient of determination (R-squared value) of 0.95, which shows a good correlation between the model's predictions and experimental outcomes. This information improves comprehension of the model's usefulness in real-world applications.

3 ACKNOWLEDGMENTS

None

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