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Neural network modeling of strength enhancement for CFRP confined concrete cylinders

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Abstract

This study presents the application of neural networks (NN) for the modeling of strength enhancement of CFRP (carbon fiber-reinforced plastic) confined concrete cylinders. The proposed NN model is based on experimental results collected from literature. It represents the ultimate strength of concrete cylinders after CFRP confinement which is also given in explicit form in terms of diameter, unconfined concrete strength, tensile strength CFRP laminate and total thickness of CFRP layer used. The accuracy of the proposed NN model is quite satisfactory as compared to experimental results. Moreover the results of proposed NN model are compared with 10 different theoretical models proposed by researchers so far and are found to be by far more accurate.

Keywords: Neural network; CFRP confinement; Concrete cylinder; Strength enhancement

1. Introduction

With over 50 years of excellent performance records in the aerospace industry, fiber-reinforced-polymer (FRP) composites have been introduced with confidence to the construction industry. These high-performance materials have been accepted by civil engineers and have been utilized in different construction applications such as repair and rehabilitation of existing structures as well as in new construction applications. One of the successful and most popular structural applications of FRP composites is the external strengthening, repair and ductility enhancement of reinforced concrete (RC) columns in both seismic and corrosive environments [1]. Main types of FRP composites used in external strengthening and repair of RC columns are: glass-fiber-reinforced polymers (GFRP), carbon-fiber-reinforced polymers (CFRP), and aramid-fiber-reinforced polymers (AFRP). Types of FRP confinement can be spiral, wrapped and tube. FRP composites offer several advantages due to extremely high strength-to-weight ratio, good corrosion behavior, electromagnetic neutrality. Thus, the effect of FRP confinement on the strength and deformation capacity of concrete columns has been extensively studied and several empirical and theoretical models have been proposed [2]. This study proposes a new approach for the modeling of strength enhancement of CFRP wrapped concrete cylinders using NNs. The proposed NN model for the compressive strength of the confined concrete cylinder is presented in explicit form.

2. Behavior of FRP confined concrete

Being a frictional material, concrete is sensitive to hydrostatic pressure. The beneficial effect of lateral stresses on the concrete strength and deformation has been recognized nearly for a century. In other words when uniaxially loaded, concrete is restrained from dilating laterally, it exhibits increased strength and axial deformation capacity indicated as confinement which has been generally applied to compression members through steel transverse reinforcement in the form of spirals, circular hoops or rectangular ties, or by encasing the concrete columns into steel tubes that act as permanent formwork

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Nomenclature

f'_{co}	compressive strength of the unconfined concrete cylinder
f'_{cc}	compressive strength of the confined concrete cylinder
p_u	ultimate confinement pressure
E_l	confinement modulus or lateral modulus
E_f	modulus of elasticity of the FRP laminate
nt	total thickness of FRP layer
D	diameter of the concrete cylinder
L	Length of the concrete cylinder

[2]. Besides steel reinforcement FRPs are also for confinement of concrete columns and offers several advantages as compared to steel [3] such as continuous confining action to the entire cross-section, easiness and speed of application, no change in the shape and size of the strengthened elements, corrosive resistance [2].

Typical response of FRP-confined concrete is shown in Fig. 1, where normalized axial stress is plotted against axial, lateral, and volumetric strains. The stress is normalized with respect to the unconfined strength of concrete core. The figure shows that both axial and lateral responses are bi-linear with a transition zone at or near the peak strength of unconfined concrete core. The volumetric response shows a similar transition toward volume expansion. However, as soon as the jacket takes over, volumetric response undergoes another transition which reverses the dilation trend and results in volume compaction. This behavior is shown to be markedly different from plain concrete and steel-confined concrete [4].

The characteristic response of confined concrete includes three distinct regions of un-cracked elastic deformations, crack formation and propagation, and plastic deformations. It is generally assumed that concrete behaves like an elastic-perfectly plastic material after reaching its maximum capacity, and that the failure surface is fixed in the stress space. Constitutive models for concrete should be concerned with pressure sensitivity, path dependence, stiffness degradation and cyclic response. The existing plasticity models range from nonlinear elasticity, endochronic plasticity, classical plasticity, and multi-laminate or micro-plane plasticity to bounding surface plasticity. Many of these models, however, are only suitable in a specific application and loading system for which they are devised and may give unrealistic results in other cases. Also, some of these models require several parameters to be calibrated based on experimental results [4]. Considerable experimental research has been performed on the behavior of CFRP confined concrete columns [5–11]. Several models are proposed in literature for the strength enhancement of FRP confinement effect of concrete columns given in Table 1.

This study aims to propose an alternative approach and a new formulation by means of NNs for the prediction of strength enhancement of CFRP confined concrete cylinders.

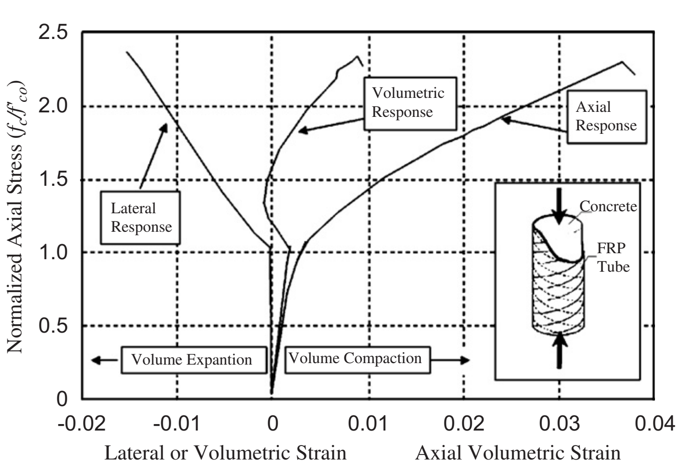

Fig. 1. Typical response of FRP-confined concrete [4].

Table 1
Models for strength enhancement of FRP confined concrete cylinders

Model	Expression (f'_{cc}/f'_{co})	
Fardis and Khalili [12]	$\frac{f'_{cc}}{f'_{co}} = 1 + 4.1\frac{p_u}{f'_{co}}$	(1)
	$\frac{f'_{cc}}{f'_{co}} = 1 + 3.7\left(\frac{p_u}{f'_{co}}\right)^{0.86}$	(2)
Saadatmanesh et al. [13]	$\frac{f'_{cc}}{f'_{co}} = 2.254\sqrt{1 + 7.94\frac{p_u}{f'_{co}}} - 2\frac{p_u}{f'_{co}} - 1.254$	(3)
Miyauchi et al. [5]	$\frac{f'_{cc}}{f'_{co}} = 1 + 3.485\frac{p_u}{f'_{co}}$	(4)
Kono et al. [6]	$\frac{f'_{cc}}{f'_{co}} = 1 + 0.0572p_u$	(5)
Samaan et al. [14]	$\frac{f'_{cc}}{f'_{co}} = 1 + 6.0\frac{p_u^{0.7}}{f'_{co}}$	(6)
Toutanji [15]	$\frac{f'_{cc}}{f'_{co}} = 1 + 3.5\left(\frac{p_u}{f'_{co}}\right)^{0.85}$	(7)
Saafi et al. [16]	$\frac{f'_{cc}}{f'_{co}} = 1 + 2.2\left(\frac{p_u}{f'_{co}}\right)^{0.84}$	(8)
Spoelstra and Monti [17]	$\frac{f'_{cc}}{f'_{co}} = 0.2 + 3\left(\frac{p_u}{f'_{co}}\right)^{0.5}$	(9)
Xiao and Wu [18]	$\frac{f'_{cc}}{f'_{co}} = 1.1 + \left(4.1 - 0.75\frac{f'^{2}_{co}}{E_l}\right)\frac{p_u}{f'_{co}}$	(10)