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A new approach to determine strength of Perfobond rib shear connector in steel-concrete composite structures by employing neural network

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ABSTRACT

The main objective of this study is to introduce a novel numerical approach, based on Artificial Neural Network (ANN), to predict the shear strength of Perfobond rib shear connector (PRSC). For this purpose, 90 records were extracted from the literature and were used to develop a number of Bayesian neural network models for predicting the shear strength of PRSC. An accurate ANN model was attained with a high value of correlation coefficient for the train and test subsets. Having a reliable ANN, a parametric study on the shear strength of PRSC was carried out to establish the trend of main contributing factors. The majority of assumptions, considered by empirical equations, were predicted by the developed ANN. Moreover, a sensitivity analysis of input variables was conducted; the outcomes revealed that the area of concrete dowels had the strongest influence on the shear strength of PRSC. Eventually, using the validated ANN, an abundant number of curves (Master Curves) were generated to introduce a user-friendly equation. According to the results, both the ANN model and the proposed equation reflect a higher accuracy than other existing empirical equations.

1. Introduction

In recent decades, steel-concrete composite/hybrid systems have been extensively used in buildings and bridges. The shear connector is an essential element that assures the shear transfer between the steel profile and the concrete slab and also enables the composite action to develop [1–3]. Conventional shear connectors (i.e. Nelson stud) profit from a high degree of automation in workshops or construction sites; nonetheless, such connectors suffer from some limitations in the case of structures subjected to fatigue. [3–5]. Moreover, in comparison to other types of connectors, the resistance of Nelson stud is somewhat limited and leads to girders designed with partial interaction. Given this fact, many researchers have endeavoured to introduce an enhanced shear connector for composite and hybrid systems [6]. The pioneering research is traced back to 1980s. Perfobond, an alternative connector with higher resistance than a stud, was developed in 1987 by the German company Leonhardt, Andra and Partners for the design of the third bridge over the Caroni river, in Venezuela [3,6,7].

From the economic standpoint, Vianna et al. [8] conducted a study comparing the costs of manufacturing steel girders with several types of connectors. The authors reported that using Perfobond connectors in steel-concrete composite systems could result in an economy drive. Vianna et al. [3] also investigated the resistance, ductility and collapse modes of Perfobond and T-Perfobond rib shear connectors. They revealed that PRSC could provide both economical solution and structural efficiency to transfer the shear in composite and hybrid structures.

Oguejiofor & Hosain [2,9] conducted parametric and numerical studies of PRSC on 40 push-out test specimens. The evaluated PRSC was a simple perforated plate incorporating different numbers of holes and transverse rebars, as well as different compressive strength of concrete. The outcome was two expressions, based on regression analysis and finite element method, for predicting the shear capacity of PRSC.

Cândido-Martins et al. [4] experimentally studied the structural response of PRSC. They reported that an increase in the number of holes leads to a higher resistance of PRSC. According to the results, passing the reinforcement bars through the holes led to an increase in both the resistance and ductility of PRSC and a decrease in the uplift displacement. Moreover, Rodrigues and Laím [6] evaluated the effects of the number of holes, the transverse reinforcement bars in rib holes, and the doubled PRSC at the room and elevated temperatures. The results showed the adverse impact of elevated temperature on the load-carrying capacity of PRSC, particularly, on that of doubled PRSC. They

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Nomenclature

f_c	concrete cylinders compressive strength (MPa)
A_{tr}	total area of transverse reinforcement bars (mm^2)
$A_{tr,r}$	area of transverse reinforcement bars in rib holes (mm^2)
A_b	cross-section of the connector at the end-bearing zone (mm^2)
A_{cc}	longitudinal concrete shear area per connector (mm^2)
A_D	total area of concrete dowels (mm^2)
n	number of rib holes
A_F	contact area between the concrete and the connector (mm^2)
h_{sc}	connector height (mm)
h	slab length in the front of connector (mm)
b	concrete slab thickness (mm)
b_f	width of the steel section flange (mm)
L_c	contact length between the concrete and the flange of the steel section
D	connector hole diameter (mm)
D_s	the diameter of the transverse rebar (mm)
f_u	the tensile strength of the transverse rebar (MPa)
α	coefficient of end-bearing force (α = 1 and α = 0 includes and excludes the end-bearing force, respectively)
t_{sc}	connector thickness (mm)
$f_{y,r}$	yield stress of reinforcement bars in rib holes (MPa)
f_y	yield stress of the transverse rebars (MPa)
q_{exp}	Perfobond connector experimental shear strength (kN)
q_u	Perfobond connector nominal shear strength (kN)
ω_j	weights of network
e_i	errors of network
t_i	targets of network
α_i	outputs of network
γ	performance ratio
mse	the mean square error of the network
msw	the sum of squares of the network weights and biases
σ	standard deviation
COV	coefficient of variation
μ	mean value

List of acronyms

PRSC	Perfobond Rib Shear Connector
ANN	Artificial Neural Network
NMSE	Normalised Mean Square Error
BRB	Bayesian Regularisation Backpropagation

revealed that the presence of transverse reinforcement bars in rib holes reduces the load-carrying capacity of PRSC at elevated temperature. Furthermore, Al-Darzi et al. [10] conducted a parametric study on the shear strength of PRSC, using finite element method. The model was verified by experimental push-out test results, and the results of the parametric study were used to introduce a mathematical model to estimate the shear capacity of PRSC.

Ahn et al. [11] evaluated the shear behaviour of PRSC under the static and cyclic loadings. The results of static tests indicated that the shear capacity of specimens with the pure concrete dowels is about 65% of the shear capacity of specimens with both concrete dowels and concrete end-bearing zone. The shear capacity of specimens with transverse rebars in the holes was also about two times of the shear capacity of specimens with transverse rebars. According to cyclic tests, the residual shear capacity of specimens without transverse rebars was significantly lower than that of static shear capacity. Conversely, the residual shear capacity of specimens with transverse rebars was very close to their static shear capacity.

Zheng et al. [12] conducted a parametric study of circular-hole and long-hole PRSC. The results showed that the failure mode of both circular-hole and long-hole PRSC are associated with concrete failure. They also disclosed that the shear stiffness of PRSC increases with hole diameter and height.

Moreover, Allahyari et al. [13] investigated the dynamic characteristics of steel-concrete decks with PRSC, including normal-weight high-strength concrete and lightweight high-strength concrete. Some dynamic properties such as natural frequencies, damping ratio, and frequency response functions were evaluated through a non-destructive technique. They also compared the experimental results of natural frequencies with the finite element model. The results indicated that the most effective mode was the first mode with a damping ratio of almost 0.5% for both types of concrete.

According to the literature, there are many contributing factors in structural behaviour of PRSC, including the concrete compressive strength, the area and the yield strength of transverse rebars, the end-bearing force, rib arrangement, and rib spacing. Having taken different factors into account, some analytical models have been proposed to predict the resistance of PRSC, although the majority of them suffer from a low accuracy. Today, new models that are easier, convenient, and more accurate than the existing models could develop on account of the recent advances in data analysis techniques.

When coming to the data modelling of nonlinear problems, the traditional regression analysis is of hopeless inadequacy. By contrast, ANN is a powerful data modelling tool that is capable of coping with complex input-output problems. In other words, the power of ANNs lies in the capability to detect and learn nonlinear relations from the collected data. Recent studies have proved that ANN-based modelling is an alternative approach to modelling complex nonlinear problems. As a consequence, ANN-based modelling has rapidly developed in a variety of fields encompassing engineering, psychology, business, medicine, science, and many others. Take, as an illustration, in civil engineering, ANNs have been successfully used to model some behaviour of structures or some characteristics of materials [14–16].

From the literature, attempts to reach an accurate prediction for the shear strength of PRSC is an ongoing process. Therefore, the present study aims at (1) a test for feasibility of employing ANNs for modelling the PRSC, (2) a test for accuracy of other existing empirical equations, (3) a test for sensitivity of the designed ANN to input variables, (4) a parametric study of the PRSC and, eventually, (5) the presentation of a user-friendly equation with the assistance of ANNs.

2. Analytical models to predict the shear strength of PRSC

To evaluate the shear strength of a PRSC (Fig. 1), Oguejiofor and

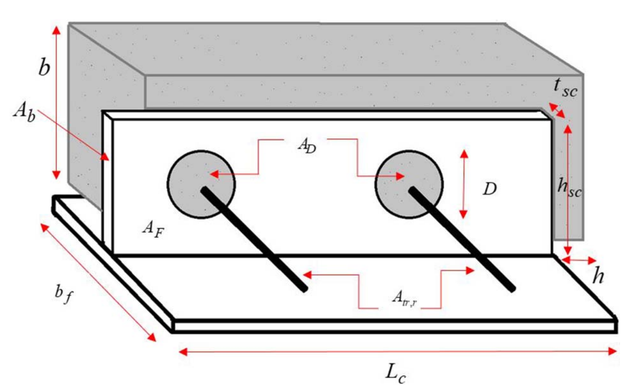

Fig. 1. A schematic of a PRSC.