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Fuzzy Neural Modelling with Parametric Study in Structural Engineering

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Abstract*: A new predictive design method is presented in this study. This is an hybrid method for modelling, called neuro-fuzzy, it's based on neural networks with fuzzy learning.*
A total of 170 experimental datasets obtained from the literature concerning concentric punching shear tests of reinforced concrete slab-column connections without shear reinforcement were used to test the model (113 for experimentation and 57 for validation) , and were endorsed by statistical validation criteria. The punching shear strength predicted by the neuro-fuzzy model was compared with those predicted by current punching shear strength models widely used in the design practice, such as ACI 318-08, SIA262 and CBA93. The neuro-fuzzy model showed high predictive accuracy of resistance to punching according to all of the relevant codes.
A parametric study on the main interaction parameters of the phenomenon shows that the model met the mechanism's fundamental failure by punching as described by several researchers.

Keywords: *Punching shear strength, slab-column connection, neuro-fuzzy system , size effect, ,meta-heuristics method.*

1. Introduction

In the field of civil engineering many phenomena are studied in an analytical way and in some cases empirical, because the elements of constructions used such as reinforced concrete, are heterogeneous nature with unpredictable behavior. In what follows it is proposed to study a controversial phenomenon that failure by punching of a slab-column connection without shear reinforcement. Flat plates consist of slabs directly supported on columns without beams. Because of this simplicity, flat plate systems have various economic and functional advantages over other floor systems.

From a structural mechanics viewpoint, however, flat plates are complex structures. Moreover, flat plates usually fail in a brittle manner by punching at the slab-column connections within the discontinuity region.

Investigations have been conducted to study this complex phenomenon of concentric punching shear in reinforced-concrete flat plates by trying to estimate the strength of shear failure using mechanical or purely empirical models [1][2][3][4][5][6][7][8].

Despite the importance of these models to understand the mechanism of failure by punching, the complexity of their use is not justified by their precision. To compensate for this problem, most design codes developed simple equations in which a nominal shear stress is calculated on a section critical to some distance from the column Fig.[1] Predictive modelling in structural engineering and compared to a known value [9][10][11]. The classical empirical techniques used by many design codes show limited accuracy, so a more robust empirical modelling technique is needed that can resolve the uncertainties encountered in determining punching shear failure mechanisms.

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This study introduces a new approach for predicting the punching shear strength of concentrically loaded interior slab-column connections using a hybrid method called the Neuro-adaptive model. The proposed approach incorporates the concept of critical contours and various geometric and material parameters.

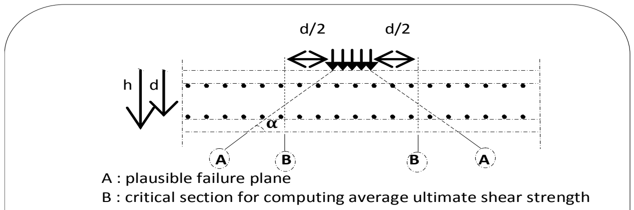

Figure 1: *Cross section of slab-column connection showing critical section at distance d/2 from column face to intersect most plausible failure planes (angle* ***α*** *ranges between 30 and 45 degrees).*

Fig. 1: Cross section of slab-column connection showing critical section

2. Models Used by Standard Codes

In codes and standards, the nominal shear stress caused by gravity loads is determined at an assumed vertical critical section around the column and, generally, compared to the resistance determined empirically based on several parameters [9][10][11]:

2.1. Swiss Code SIA 262 (2003)

This code recommends that the punching shear resistance, V_{rd}, be expressed:

$$V_{rd}=K_r*\tau_c*d*u \tag{1}$$

2.2. American Code ACI 318-08 (2008)

A simple equation, developed based on the classical shear strength equation, is expressed:

$$\phi*V_n\geq Vc \tag{2}$$

2.3. Algerian Code CBA 93 (1993-2004)

A simple equation is applied in which the critical perimeter **U** is equal to **d/2** of the loading area:

$$V_u\leq[0.045*U*h*F_c]/\gamma \tag{3}$$

3. Fuzzy Neural Optimiser and Punching

Neuro-adaptive networks are hybrid systems that combine the learning capacity of neural networks with the very powerful theory of fuzzy logic. Together, they have the power to obtain conclusions and generate responses from vague, imprecise and incomplete information when mathematical models are unknown or difficult to retrieve**.** In this study, the architecture and learning procedure exploited in the program is *ANFIS type 3* (Adaptive-Network-based Fuzzy Inference System) [12] which employ to model the punching shear of concentrically loaded interior slab-column connections and predict the ultimate rupture load by punching. **.** It is composed of a 5-layer adaptive network and a system of inference type3 (SIF). The weight and parameters are optimised by the algorithm of retro-propagation based on gradient descent. We developed a fuzzy neural controller in the form of a program with different souboutines that determines the parameters of the input layer by identifying the most relevant physical and geometric variables in the behaviour of the rupture of slabs by punching. *Table [1]*

TABLE I: The most relevant physical and geometric variables in the behaviour of punching slabs**.**

THE PARAMETERS OF THE INPUT LAYERS		***OUTPUT LAYER***
d [mm]	Effective thickness of the slab	
b/2 [mm]	Side of the square column or diameter of the circular column	
B	Side of the slab of test	
F_c [MPa]	Concrete compressive stress	***V_r [KN]***
U [mm]	Perimeter of critical section, measured at distance *d*/2 from column	the ultimate rupture load
ρ [%]	Reinforcement as a percentage of slab area	due to punching
D_{max}[mm]	Maximum diameter of aggregate	

4. Database for Punching Trials

All samples are cases of punching slabs without shear reinforcement. A total of 170 experimental datasets were collected through specialised literature [3][4][5][13][14][15][16][17][18][19][20], a summary of which is shown in the T***able [2].*** The learning process is conducted on a set of data named <Terndada>, equivalent to 2/3 of the sample size, and the validation process is performed on 1/3 of the sample size in a file named <Chekdata>.

TABLE II: Geometric and material properties of the studied specimens and Limit validity program

N^bre de spécimens		**Margin of variable parameters**					
Training	Validation	Fc [MPA]	.d [mm]	.b, [mm	B [mm	Dmax [mm]	***ρ***%
113	**57**	9.2/118.72	70/275	4/38.1	100/520	750/3221	0.21/3.92

After the input data were standardised, we compared between the observed testing data and created a simulation using the fuzzy neural method. There is a great convergence between the values of the observed and simulated failure effort (R = 0. 97), shown in ***Fig.***[2].

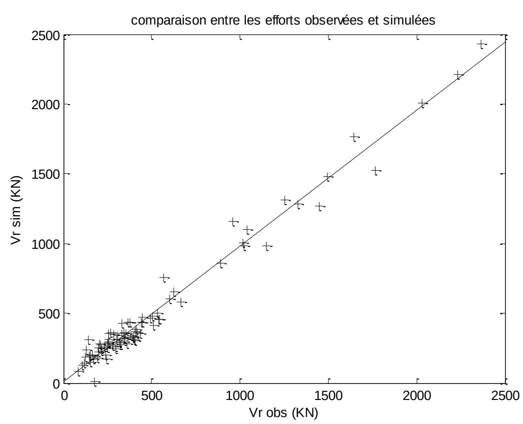

Fig. 2: comparison between observed and simulated test data

5. Parametric Study

In this component of the study, we performed a parametric comparison of the results obtained from using different design codes with the test values observed and simulated by the neuro-fuzzy method. This approach aims to see the capacity of this method to represent the fundamental mechanism of failure.

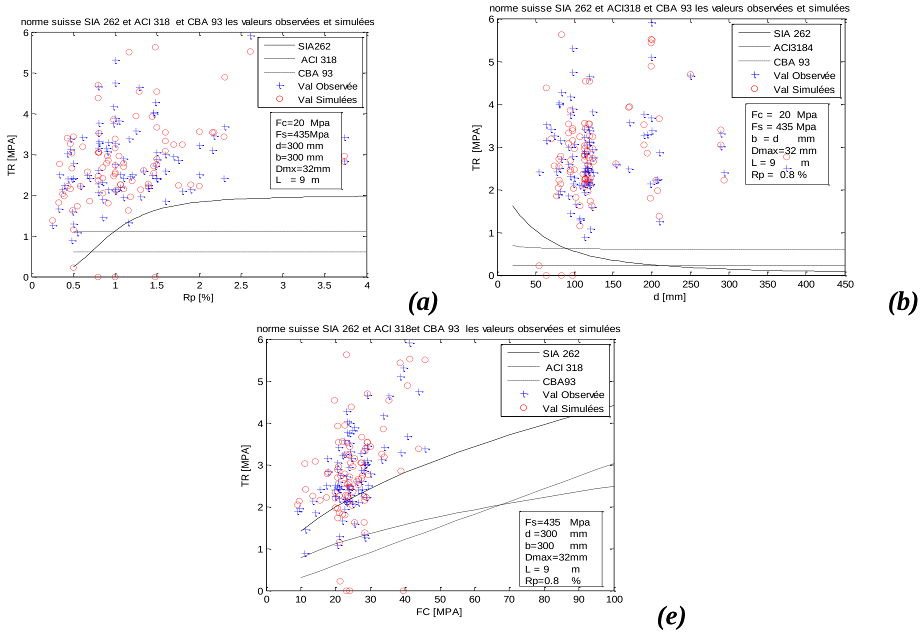

Fig. 3: Variation of study parameters based on standard design codes SIA 262, CBA 93, and ACI 318 and proposed model

6. Statistical Analysis and Validation Criteria

In addition to subjective analysis, such as a parametric study, objective statistical criteria are used to broadly characterise the quality of the simulation. :

6.1. Error on the Balance Sheet

This criterion expresses the error between the observed and simulated values as a percentage:

$$Er=\frac{\sum_{i=1}^{n}(Vi_{obs}-Vi_{sim})}{\sum_{i=1}^{n}(Vi_{obs})} \quad (8)$$

The total results of comparison are shown in table [4**]**

TABLE IV: Comparison of the simulated and observed values of <chekdata=86 tests>

Tests [86]	SIA-262 Suisse [%]	ACI-318 american [%]	CBA- 93 algerian [%]	Neuro-fuzzy simulé [%]
Err	**34.7**	**62.3**	**62.3**	**12.25**

7. Conclusion

At the beginning of this study, we as designers were not convinced of the usefulness of a method that we had found to be unstable and, by its nature, random and subjective. Our objective was to better understand this approach through the experimental and simulated results obtained during our research.

One new predictive design methods are explored this is a hybrid method based on neural networks with fuzzy learning called neuro-fuzzy. A total of 170 experimental datasets obtained from concentric punching shear tests of reinforced concrete slab-column connections from the literature have been exploited by the model (113 for learning and 57 for validation) and confirmed by statistical validation criteria. Very satisfactory results were obtained from this assessment, and the results were compared to representative design codes from around the world. The neuro-fuzzy model accurately predicted punching resistance with an average error of 12%, unlike all the design codes studied (ACI 318, SIA 262, CBA 93) where the error varied from 30 to 60%. A parametric study of the main parameters affecting punching shows that the model adequately approximates the fundamental failure mechanism of punching as described by several researchers.

In conclusion, the neuro-fuzzy model can be taken as an alternative method, within limits, to simple empirical approaches used by different design codes.

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