Load Capacity Prediction of Elliptical Tube Column (ETC) Filled with Concrete using Artificial Neural Networks

Munir Mahgub Altamami[1*], Mahmoud A. T. Khatab[2], Abdalla Ali Agwila[3]

[1] Gulf of Sidra University, Ben Jouad, Libya
[2] Omar Al-Mukhtar University, Al-Baida, Libya
[3] Alasmarya Islamic University, Zileten, Libya
Munir.altamami@gsu.edu.ly*

Abstract. Elliptical hollow sections have been recently presented to civil engineering industry and its application is becoming popular in contemporary building design due to its pleasing appearance, however, there are no equation in Eurocode to forecast the load capacity of elliptical tube columns (ETC). The present study was conducted to develop an Artificial Neural Network (ANN) model to forecast the load capacity of elliptical tube column filled with concrete. The proposed model was developed using a group of ETC samples collected from different sources of earlier research. The collected data was used to train and examine the proposed ANN model. Moreover, a series of parametric studies are conducted to find out about the main parameters that have the most influence on the ultimate load of ETC filled with concrete. The results showed that the regression value (R) obtained by the proposed model for individual plot, which quantifies the relation among output and target data, was close to 1, which show strong relationship. The results obtained by the proposed ANN model were compared to those predicted using the simple analytical model suggested by Euro Code 4 for concrete-filled steel rectangular tube column. The comparisons displayed a practical agreement. Overall, the results showed that ANN can reasonably estimate ultimate load of ETC filled with concrete.

Keywords: Artificial neural network; Load capacity; elliptical; Eurocode 4

1 Introduction

Steel hollow section (SHS) occupied with concrete have become popular structural element used in construction since 21st century. It has high performance such as ductility, high load capacity, great energy absorption capacity, fire and high safety against earthquakes [1]. SHS is made from composite material, steel and concrete. Due to the steel-concrete interaction, local buckling of steel can be postponed because of the restraint effect on concrete. Moreover, the concrete compressive strength can be enhanced by the steel confinement [2]. Composite behavior can also help to gain weighty savings in resources and an increase the span between columns. Square, rectangular and circular section have more attention than ETC. However, ETC have been recently presented to civil engineering industry and its application is becoming popular in contemporary building design due to its pleasing appearance [1]. Many studies have focused on SHS to find out about its behaviors under different circumstances such as fire conditions and cold form. The concrete compressive strength and the cross-sectional area of column were discovered to be the most dominant parameters on fire resistance. The result showed that, the overall capacity strength affected by concrete. [3, 4-5]. A high number of research showed that the strength of concrete is increased by the confining effect obtained from the steel tube and the local and global buckling of steel wall was delayed by the restraining effect of concrete [7, 8]. The positioning of the concrete and steel in the merged column cross section has an important role in terms of improving the strength and stiffness of a structure. Furthermore, the composite columns have greater moment of inertia than the concrete ones because the steel part is positioned furthermost from the centroid of the composite section [8]. Most research has focused on circular and rectangular SHS occupied by different types of concrete. The ultimate load was figured out to be very close when normal concrete was used [6]. On the other hand, a small number of research have investigated the behaviors of ETC occupied by concrete. Apparently, ETC sections can offer greater efficiency than circular

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ones, particularly when subjected to eccentric loading (in this case, a bending moment is created about a certain axis) or when differing end restraints or bracings exist about the two principal axes [9]. Unfilled elliptical columns have been employed recently in several constructions such as a coach station at Heathrow terminal three in the UK, Ireland's Sword Airside scheme, Bern main railway station in Switzerland and some airports around the world. Nevertheless, the ETC is not at present taking into account by any code of practice.

Up to date, there is limited understanding of structural behavior of ETC. The finding about the performance of ETC are at this time inadequate, and very limited experimental data can be built regarding ETC filled with concrete. However, studies still carried on ETC filled with concrete. Most of the research on elliptical columns focused on short columns and limited number were focused on long columns. The confinement effect is an important issue which needs to be addressed, particularly in consideration of how it affects the steel section. The interaction between local and global buckling also needs to be investigated, especially for slender columns. Some studies used analytical models (finite elements) to predict axial load capacity of elliptical columns. The results showed reasonable agreement when comparisons were made with experimental work [2, 9-13]. Nowadays, some researchers presented a new model to forecast the lateral stress of CFT occupied by concrete. This model was considered in the computational fiber-based model of nonlinear simulation of short ETC subjected to axial load [14]. The study concluded that, the proposed confinement model for ETC provide further precise outcomes than those improved for tube circular columns. Additionally, the model showed reasonable results when validated against experimental result. ANN has been used by researchers in many aspects and close results were obtained when compared with experimental ones [15-19]. Load capacity of simple support deep beam was reasonably predicted by ANN when compared to other models and code [20]. Some studies employed ANN to predict the total load of circular and rectangular sections filled with concrete based on data from literature. The overall results showed the ANN models can effectively predict the load capacity of columns when compared to experimental results [21, 22]. Other than load capacity, ANN can be adapted to predict different properties such as buckling capacity, elastic shear and ultimate shear capacity, a reasonable prediction was obtained [23]. Experimental investigations on fall-size long columns are difficult to be conducted due to the high cost which limit the number of specimens available in literature. As a result, it is important to find another way to study and analyses the behavior of elliptical columns in order to save time and cost. There is lack of experimental and numerical results in the literature. Consequently, the behavior cannot not be completely understood.

The aim of this research is to present artificial neural network simulation to estimate the axial load capacity of ETC filled with concrete in order to economies on computational time and effort. The artificial neural network was developed under Matlab software to predict the load capacity. The precision and trustworthiness of the proposed model were confirmed by comparing the result with Eurocode 4. Parametric research was also carried out to investigate the importance of various parameters when considering the load capacity of ETC filled with concrete.

2 Artificial Neural network

An artificial neural network (ANN) can be defined as a computational model proposed to simulate the structure and function of the biological neural networks in the human brain. Typically, an ANN is a flexible technique that can adjust its model based on applicable information flowing through the network throughout the learning phase. ANN consists of five main parts. Two of these parts, the input and output, can be controlled by users. However, the other three parts, which include the operations inside the ANN toolbox, remain hidden from users. These hidden operations are weights, the sum function and activation function. Inputs are fed into the network using data from previous studies. The values that indicate the effect of input data or other process elements on the pervious layer, are called Weights. The operation responsible for calculating the effect of input and weights on the elements is called the sum function. The cell output is determined by activation of functions [24]. Any complicated correlation between inputs and outputs in data can be easily simulated using ANN technique [25, 26]. The main strategy to perform a neural-based model of materials behavior is to train a neural network on the results of many experimental studies on those materials [27-28].

The input data is divided into three parts. 75%for the training process, 20% for testing process and 5% for validation phase. The main job of the test phase is verifying the network using the database not used throughout the training process. The validation phase is used to halt training when the improvement in generalization ceases. ANN simulation with two hidden layers was constructed and developed under MATLAB technique. Training, testing and validation of the model stages were conducted utilizing 205 samples of ETC filled with concrete collected from previous research investigations. However, a number of these samples have been omitted due to consistency issues. As a result, a total of 165 samples were the actual data feeding the ANN [2,

10, 12, 2935]. The input was column's length, cross-sectional area, thickness, concrete compressive strength and steel yield strength. The load capacity of ETC was the output or target. Table 1 shows the limitation of the input and output that collected from previous research. Figure (1) shows the results obtained from training, testing and validation which were predicted by the proposed ANN model. It presents the relation between output and target for training, testing, validation and overall. It can be clearly noticed that the regression value for each plot (R), which defines the relation linking the output and target data, is close to 1, which means the best correlation is achieved. It can also be noticed that the relation between the predicted load capacity and target is extremely acceptable. From the results, ANN can be utilized to forecast the load capacity of ETC filled with concrete. For more accuracy, ANN was compared with result obtained from the EC4 for validation purposes [36].

Table 1. Limitation of input and output data

Parameters	L (mm)	A (mm^2)	t (mm)	$F_c^{'}$ (Mpa)	F_y (Mpa)	P (KN)
Max	3600	38878	6.89	102.66	612	2607
Min	160	3825	1.88	18	201	326.6
Mean	1880	21351.5	4.38	60.3	406.5	1466.8

L: length, A: area, t: thickness, F': concrete strength, F: steel yield strength and P: load capacity

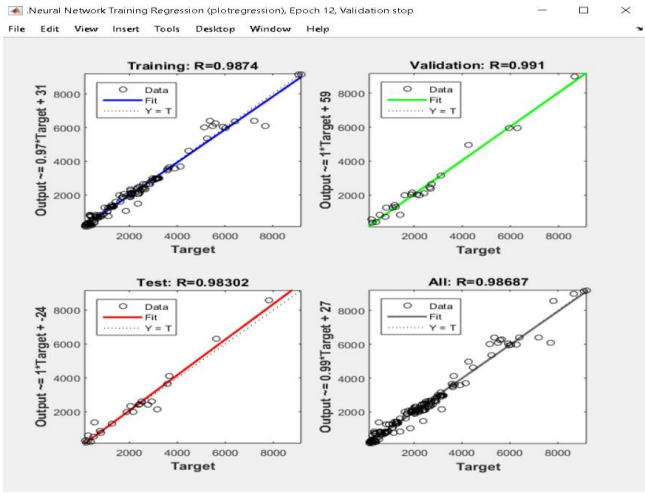

Figure 1. Training, validation and testing Results

3 Comparison with Eurocode 4

The load capacity of concrete filled ETC has not been taken into account by Eurocode 4 yet. The calculation provided in EC 4 covers the design rules for square, rectangular and circular sections. Moreover, it is assessed in the current paper to evaluate how far it can be applicable to expect the capacity of composite ETC. The buckling curves provided by EC3 for columns made of steel is also examined [37]. Two assumptions were used in the calculation: fully plastic behavior and a uniform distribution for the load between concrete core and steel tube.

The resistance of the concrete core filling the steel columns can be calculated from equation (6.3) in section 6.7.3.2 in EN 1994-1-1:2004

$$N_{ed} = \chi N_{Pl,Rd} \tag{1}$$

More details are presented in EN 1994-1-1:2004 section 6.7.3.2-5. The predicted load-carrying capacities ($PEC4$) calculated using the method provided in Eurocode, as mentioned above, are compared with load

capacity predicted by the proposed ANN model (PU) as shown in table 2. Table 2 compares the load capacity of column specimens obtained ANN model against those predicted using the method provided in EC4. It can be seen that the proposed model showed accurate prediction with an average of 1.03, standard deviation of 2.97% and a coefficient of variation of %2888. For all specimens, the load capacities predicted by EC4 are lower than those obtained from artificial neural network

Table 2. Comparison between ANN and EC4

SpecimenID	F_c' (Mpa)	t mm	L m	P_{ANN} KN	P_{EC4} KN	$\frac{P_{ANN}}{P_{EC4}}$
150*75	35	5	185	991	983	1.01
250*125	50	6	185	2105	2015	1.04
150*75	35	5	1875	842	802	1.05
250*125	50	6	1875	1917	1874	1.02
150*75	35	5	2	776	740	1.05
250*125	50	6	2	1878	1866	1.01
150*75	35	5	285	558	557	1.00
250*125	50	6	285	1018	937	1.09
				Average		1.03
				SD (%)		2.97
				COV (%)		2.88

4 Parametric study

The quality of a predictive simulation depends on the weight of each parameter conducting the phenomena. The purpose of the parametric study is to quantify the effect of one parameter while all the others are fixed. This can help to find out what are the main parameters that can significantly affect the load capacity of ETC. Two parameters will be considered in the parametric study, namely, the compressive strength of concrete core and the length of the column.

4.1 Compressive strength of concrete

The effect of compressive strength of concrete on the load capacity of elliptical tube column was predicted for five specimens with different values of concrete compressive strength. It should be noticed that all the other parameters were kept constant. Eurocode 4 was used to obtain the relationship, and the results were compared with those predicted by the proposed ANN model. It can be clearly noticed from figure 3 that compressive strength has a high influence on the load capacity of elliptical tube columns. As the compressive strength increased, the load capacity increased. Therefore, compressive strength is one of the most notable parameters that must be considered when building up any model to obtain accurate results. As shown in figure 3, ANN showed higher results than those given by the theoretical models. This may be attributed to the fact that the model given by Eurocode 4 was proposed for circular and rectangular columns.

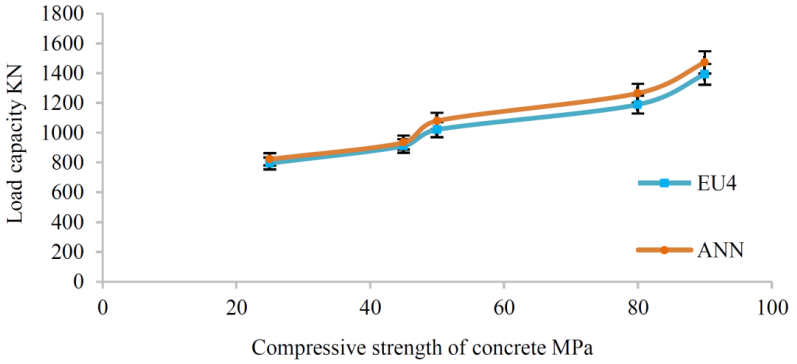

Figure 2. Relation between compressive strength and load capacity

4.2 Length of column

Figure 3 illustrates the influence of the length of columns on the load capacity. As shown, the increase in length caused a decrease in the load capacity. The right relation was conducted, which means the model work perfectly and EU4 gave a close result to predictive one by model.

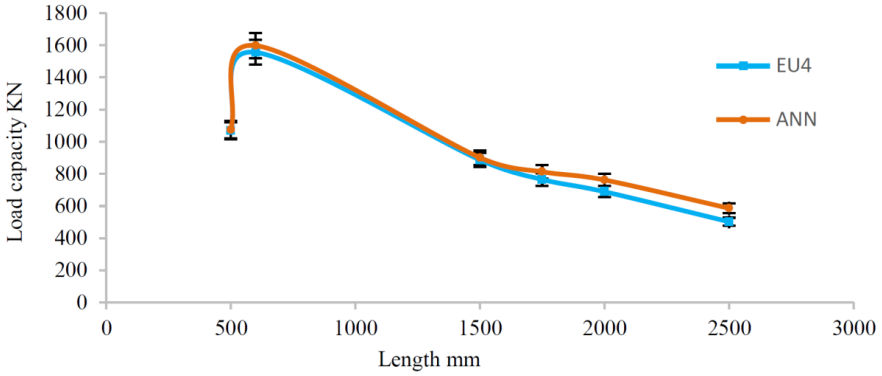

Figure 3. Relation between Load capacity and length

Conclusions

In this paper, a multi-layer back propagation artificial neural network (ANN) model was created. The proposed model was used to forecast the load capacity of ETC filled with concrete. A comprehensive database collected from different sources in the literature was used to develop the ANN model by feeding its main parts. The proposed model was compared to a theoretical model suggested by Euro code 4. Based on the analysis presented in this research, the following conclusions may be drawn:

- The regression value, R, obtained by the proposed model after training the database, was close to 1, which means that acceptable correlation between training, testing and validation was achieved. Therefore, it can be concluded that the proposed ANN can be effectively used to expect the load capacity of ETC filled with concrete.
- The theoretical model suggested by Eurocode 4 showed conservative results when applied to predict the load capacity of elliptical tube columns. This may be related to the fact that this model was proposed for rectangular and circular columns.

- The comparisons between the results predicted by the proposed model and those resulted from the theoretical expressions of Eurocode 4 showed very close results, with an average of 1.03, standard deviation of 2.97% and a coefficient of variation of %2888. However, for all specimens considered, the values predicted by EC4 were lower than those obtained from the proposed model.
- The parametric study conducted in this research showed that the compressive strength of concrete has a high influence on the load capacity of elliptical tube columns. Therefore, compressive strength is one of the most important parameters that must be considering when building up any model with the aim of achieving accurate results.

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