Thin-Walled Structures 94 (2015) 67–78

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Predictive models of the flexural overstrength factor for steel thin-walled circular hollow section beams

Mario D'Aniello [a], Esra Mete Güneyisi [b,*], Raffaele Landolfo [a], Kasım Mermerdaş [c]

[a] Department of Structures for Engineering and Architecture, University of Naples "Federico II", Naples, Italy
[b] Department of Civil Engineering, Gaziantep University, Gaziantep, Turkey
[c] Department of Civil Engineering, Hasan Kalyoncu University, Gaziantep, Turkey

ARTICLE INFO

Article history:
Received 24 February 2015
Accepted 20 March 2015
Available online 22 April 2015

Keywords:
Circular hollow section
Experimental database
Modelling
Overstrength factor
Steel beam
Genetic algorithm

ABSTRACT

Circular hollow section (CHS) steel beams are widely used in both mechanical and civil applications. CHS members are mainly subjected to bending. The flexural overstrength factor (namely the ratio between the ultimate bending strength over the plastic bending moment) characterizes the flexural behaviour of steel CHS beams. This paper describes an analytical study aiming to develop a new explicit formulation for predicting the flexural overstrength factor of steel CHS beams. The proposed models were derived from soft-computing techniques based on both neural networks (NNs) and gene expression programming (GEP), respectively. To this aim, experimental data available from scientific literature were analysed and collected to form a comprehensive dataset for developing the prediction models. A total number of 128 samples was considered in order to cover different geometric and mechanical properties. The input variables accounted for the modelling were the external diameter (D), wall thickness (t), shear length (L_v), and steel yield strength (f_y). The database was arbitrarily divided into two subsets to obtain both training and testing databases for the generation of the models. The prediction capability of the proposed formulations was assessed with respect to the experimental data and the levels of accuracy and performance were also compared with an existing analytical formulation available previously developed for cold-formed sections. The results showed that the novel proposed models derived from NN and GEP methods provide better prediction performances than those obtained by the existing analytical model.

1. Introduction

Steel circular hollow sections (CHS) are widely used in civil structures (e.g. buildings, bridges, wind towers, off-shore structures, land-based pipelines, etc.) thanks to their efficient geometry and aesthetically pleasing over open cross section shapes. Moreover, CHS members are also extensively adopted in mechanical applications (e.g. piping, vehicle trailers, fences and handrails, etc.) because of their higher strength-to-weight ratio than conventional sections, which enhances efficiency and reduces costs.

The wide range of applications for CHS members implies that these types of members should be design to resist various loading conditions and combinations such as axial forces, bending moments, and torsion [1]. However, CHS are generally prone to the ovalization of cross-section (which can be defined as the ratio of change of the outside diameter to original outside diameter) due to bending actions, which is anticipated by local buckling and characterized by significant alterations of cross section profile along the tube length, thus impairing both the flexural stiffness and the ultimate capacity. Therefore, the prediction of ultimate flexural performance of circular steel tubes has a key role in many structural applications [2–4].

The main response parameters governing the bending behaviour of steel beams are the rotation capacity (r) and flexural overstrength (s) [5–7], which are defined in Fig. 1. Especially for the earthquake-resistant design, such parameters are crucial to assure both the adequate energy dissipation capacity and the effectiveness of hierarchy criteria. In particular, r is the source of the beam ductility, which needs to achieve a global dissipative structural behaviour, while s governs the flexural overstrength, which must be accurately known to apply capacity design principles, as currently recommended by modern seismic codes.

At the Authors' knowledge, the analytical estimation of the rotation capacity and flexural overstrength factor of the CHS steel beams has not been studied comprehensively in the literature even though numerous studies have been carried out to obtain analytical formulations for predicting such response parameters of steel members with other cross section geometries (i.e., I–H section and rectangular and square hollow sections (RHS–SHS)).

* Corresponding author. Tel.: +90 342 3172423; fax: +90 342 3601107.
E-mail address: eguneyisi@gantep.edu.tr (E.M. Güneyisi).

http://dx.doi.org/10.1016/j.tws.2015.03.020
0263-8231/

List of symbols

a	normalization coefficient for outputs
b	normalization coefficient for outputs
f_{LB}	stress corresponding to the complete development of local buckling
f_y	yielding stress
m_i	measured values
m'	mean values of measured values
p_i	predicted values
p'	mean values of predicted values
r	rotation capacity
s	flexural overstrength
t	thickness of the tube
w_i	weight
D	diameter of the tube
E	modulus of elasticity
I_i	inputs
L	beam length
L_v	shear length of the beam
$M_{\max}$	maximum moment that can be developed by the beam
M_p	full plastic moment
R	correlation coefficient
α	slenderness parameter
β	actual input parameter or output values
$\beta_{\text{normalized}}$	normalized value of input parameters or outputs
$\beta_{\max}$	maximum actual values of either inputs or outputs
$\beta_{\min}$	minimum actual values of either inputs or outputs

List of acronyms

CBT	cantilever bending test
CHS	circular hollow sections
ET	expression tree
GA	genetic algorithm
GEP	gene expression programming
GP	genetic programming
MAPE	mean absolute percent error
MSE	mean square error
NN	neural network
PBT	point bending test
RHS	rectangular hollow section
RMSE	root mean square error
SHS	square hollow section

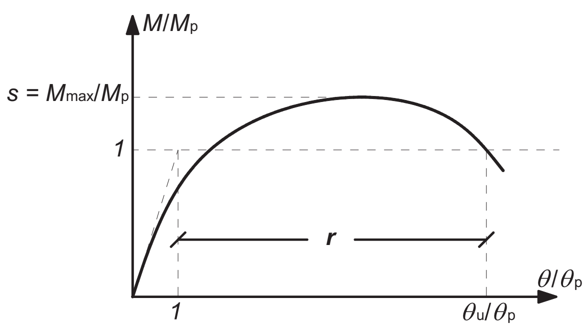

Fig. 1. Generalized moment–rotation curve for a steel beam [5].

For example, in the study of Wilkinson and Hancock [8], a finite element analysis was used to predict the rotation capacity of cold-formed RHS beams. Gioncu et al. [9] and Anastasiadis et al. [10] developed a computer programme (DUCTROT-M) to compute both the flexural strength and available rotation capacity of I beams. Recently, soft-computing based methods has also been applied on the field of steel beams by D'Aniello et al. [11] to estimate the available rotation capacity of cold-formed RHS–SHS steel beams. In another study, the Authors [12,13] proposed analytical formulation of the flexural overstrength of the steel beams fabricated with I–H section and RHS–SHS using soft computing techniques.

For what concerns the bending behaviour of the steel CHS beams, various types of manufactured tubes (e.g. hot-formed, cold-formed, and welded fabricated tubes) have been experimentally investigated considering different types of loading conditions and boundary conditions (i.e., simply-supported, cantilever, and pure bending beam tests) [14–22]. The review of these studies reveals that different geometrical and mechanical properties were experimentally evaluated. However, poor attention was addressed on the mathematical modelling of the CHS beams. Due to the high non-linearity and complexity of the ultimate response of circular tubes under pure bending, the accurate prediction of the ultimate bending strength of steel CHS beams using conventional analytical solutions requires rigorous mathematical procedures [4] incorporating simplified assumptions which affect the accuracy of the predicted performance.

An alternative approach that allows overcoming the limits of analytical solutions is the implementation of numerical finite element analyses. With this regard, numerical studies based on three-dimensional nonlinear finite-element models have been carried out to estimate the load-deformation response and ultimate strength of seam-welded structural stainless steel CHS beams subjected to bending [23].

Recently, two studies conducted by Shahin and Elchalakani [24,25] showed the feasibility of using both polynomial regression and neural network for modelling the ultimate pure bending of steel circular tubes. They demonstrated that these mathematical techniques are very efficient and are not affected by any assumptions or simplifications, enabling the limitations of most existing modelling techniques to be overcome since these techniques do not need predefined mathematical equations of the relationship between the model inputs and corresponding outputs.

The above consideration motivated the Authors to propose novel mathematical models based on soft computing techniques for the flexural overstrength factor of steel CHS beams. In order to achieve this purpose, two soft-computing methods were implemented, namely (i) neural network and (ii) gene expression programming approaches. The mathematical models were developed using a wide experimental database (covering 128 test results) that was collected from the review of the existing literature. The accuracy of the proposed models was also verified against the experimental data and the rates of efficiency were compared with the linear regression-based model developed by Kato [26,27].

2. Flexural overstrength factor

The flexural overstrength factor "s" is a non-dimensional parameter representing the ratio between the critical stress that brings to the local instability and the yielding stress. It is generally intended to be utilized for measuring the ultimate bending