Engineering Structures 160 (2018) 566–580

Contents lists available at ScienceDirect

Engineering Structures

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

Experimental and numerical research of the torsion problem of built-up steel columns laced in a single plane

Paweł Lorkowski*, Bronisław Gosowski

Wrocław University of Science and Technology, Faculty of Civil Engineering, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

ARTICLE INFO

Keywords:
Steel structure
Two-chords column
Laced column
Single lacing plane
Torsion
Experimental and numerical studies

ABSTRACT

This paper presents studies carried out on physical models and numerical analyses aimed at determining the equivalent pure torsion second moment of area of built-up steel columns laced in a single plane, with the lacing located on the symmetry axis of the column cross-section. Such columns are used in overhead contact line supporting structures and in industrial halls. In order to determine the spatial stability critical loads for such columns one needs to know their pure torsion rigidity. The experimental research were carried out on single-span column models fork-restrained at their ends and subjected to a concentrated twisting moment applied at the mid-span. Among other things, the dependence between the torsion angle of the column's mid-section and the twisting moment load was determined. A similar column model was studied numerically using the finite element method and the ABAQUS software. The experimental and numerical results and the results obtained by solving a proper differential equation for the non-uniform torsion of the column, formulated in terms of the Vlasov theory, were found to be in good agreement. Also the effect of the lacing of the column with a solid web with an equivalent thickness was analysed. In addition, extensive parametric analyses of similar columns, but with a wider range of cross-sections, subjected to pure torsion were carried out using the SOFiSTiK software. The aim was to devise practical formulas for calculating the equivalent pure torsion second moment of area on the basis of the cross-section. These relations ($I_{\overline{T}}$) together with sectorial second moment of area allow to calculate the critical load capacity of spatial stability (lateral and flexural–torsional buckling) of the considered columns. Practical conclusions have been drawn.

1. Introduction

Built-up steel columns laced in a single plane have found wide application in civil engineering structures in Poland, e.g. as tramway overhead contact line poles [1] (Fig. 1a) and railway overhead line gantry columns [2] (Fig. 1b). The chords of such poles and columns are usually made of channel sections connected in a single plane by a lacing consisting of flat bars or angles. Also industrial hall columns, both in Poland and in the world, can have a similar design [3–6] (Fig. 1c). In the case of industrial halls with gantry cranes, the column's part above the gantry usually has the form of a double-T while its part below the gantry is laced and its chords are made of channel sections, I-sections or hollow sections, connected with angle sections inclined at 45° [4].

Unlike columns laced in the planes of the channel section flanges, forming a quasi-closed cross-section characterized by considerable pure torsion rigidity, built-up steel columns laced in a single plane have little torsional rigidity. Consequently, similarly as open thin-walled sections [7–9], they are sensitive to spatial forms of stability loss. Therefore in order to determine the design loads critical for their spatial stability one must know the pure torsion rigidity and warping torsion rigidity of two-chord sections laced in a single plane.

This paper presents extensive torsion studies of the considered columns, carried out on physical models (made to a semi-commercial scale relative to the steel overhead line columns) and numerical FE models, and relevant parametric analyses. The aim of the investigations was to determine the torsional rigidity of the columns, i.e. pure torsion second moment of area $I_{\overline{T}}$ and sectorial second moment of area $I_{\overline{\omega}}$. These characteristics are needed to determine the critical load-bearing capacities for the spatial forms of stability loss, i.e. the critical force of flexural-torsional buckling in the case of eccentrically compressed columns and the critical load of the lateral-torsional buckling in the case of beams. Less extensively the torsion of the considered columns was presented at conference [10].

2. Studies of multi-chords columns

Studies of multi-chords columns concentrate on columns laced along their perimeter [11–15] or battened [16–19]. As already

* Corresponding author.
E-mail address: pawel.lorkowski@pwr.edu.pl (P. Lorkowski).

https://doi.org/10.1016/j.engstruct.2018.01.049
Received 25 September 2017; Received in revised form 21 December 2017; Accepted 16 January 2018

Fig. 1. View of: (a) tramway overhead contact line pole, (b) railway overhead line gantry column, (c) industrial hall column.

mentioned, such columns are characterized by high torsional rigidity, whereby they are not sensitive to spatial (torsional or flexural-torsional) buckling. Hence investigations of these columns focus on their local and overall flexural stability for, e.g., different types of perimeter lacing.

Paper [11] presents investigations of axially compressed multi-tube (3–8 tubes) columns in which both the batten and the lacing were made of circular pipes. Two versions of interbranch ties: (1) nondiagonal bracings and (2) diagonal braces and posts were investigated using the finite element method and the ANSYS software. The paper provides simple relations for the unit shear strain angle depending on the number of branches (chords), their spacing, the flexural rigidity of the branch and lacing cross-sections, the spacing of the posts (in columns with nondiagonal bracings) and the angle of inclination of the diagonal braces (in columns with a full lacing). There are also relations for the critical forces of elastic flexural buckling depending on the length of the columns and the parameters mentioned above, as well as relations for the equivalent slenderness of a multi-tube column. The analytical results were compared with the results of numerical studies.

Paper [12] presents studies of two-chord columns with the chords made of channel sections or I-sections with an N-type lacing in the planes of the flanges. The columns were eccentrically loaded with a longitudinal force. The cross-section of the chord sections, the density of the lacing and the eccentricity of the force applied to the top (e_{top}) and the bottom (e_{bot}) would be changed. The displacements in the lacing plane, the force and the stresses were measured. The results of the tests carried out on physical models were compared with the results of numerical FE studies. The elastic-plastic material model and the nonlinear finite element analysis with material and geometric imperfections were used.

Paper [13] analyses two-chord columns with the chords made of I-sections, and with an X lacing. In the case of such columns, the modulus of rigidity and the interactions between the local stability and the overall stability need to be taken into account when investigating stability. It is noted in [13] that standard [20] applicable to such members contains calculation guidelines for only the axial load at a simple support method. Different support methods, with the rotation axis and the displacement plane fixed, were considered. Also loads being a combination of the axial force and the transverse force were analysed. The analytical solutions derived for the considered parameters (load and support) were numerically verified using the ADINA software based on FEM. The computational model assumed geometric and material imperfections. The computation results were compared, assuming beam and shell finite elements. Similar problems were analysed in [14,15,21], but the chords were made of hot-rolled steel channel