Journal of Constructional Steel Research 71 (2012) 231–244

Contents lists available at SciVerse ScienceDirect

Journal of Constructional Steel Research

Elastic buckling load of multi-story frames consisting of Timoshenko members

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ARTICLE INFO

Article history:
Received 20 April 2010
Accepted 5 November 2011
Available online 9 December 2011

Keywords:
Shear deformation
Timoshenko beams
Buckling
Slope-deflection
Multi-story frame
Semi-rigid connection

ABSTRACT

The objective of this paper is to propose a method for the evaluation of the elastic critical buckling load of columns in frames consisting of members susceptible to non-negligible shear deformations, such as built-up members in steel frames, based on Engesser's approach. To that effect, a stability matrix is proposed and three general stability equations are derived for the cases of unbraced, partially braced and braced frames. Indicative graphic interpretation of the solutions for the stability equations of the braced and unbraced cases is shown. Slope-deflection equations for shear-weak members with semi-rigid connections are also derived and used for the presentation of a complete set of rotational stiffness coefficients, which are then used for the replacement of members converging at the bottom and top ends of the column in question by equivalent springs. All possible rotational and translational boundary conditions at the far end of these members, as well as the eventual presence of axial force, are considered. Five examples are presented, dealing with braced, unbraced and partially braced frames, with rigid and semi-rigid beam to column connections, loaded with concentrated or uniformly distributed loads, in a symmetrical or non-symmetrical pattern. In all cases the proposed approach is in excellent agreement with finite element results.

1. Introduction

Although deformations due to transverse shear are encountered in members of structural frames, they are generally considered to be small in slender members with solid cross-sections and are commonly neglected in the analysis. Members relying on this assumption are called Euler–Bernoulli beam-columns. Nevertheless, in shear-weak members, such as stocky and built-up columns, also known as Timoshenko beam-columns, shear deformations may be significant and must be taken into account. The first approach for the incorporation of shear deformations in structural analysis was proposed by Engesser [15]. An alternative approach for the evaluation of the buckling load of highly compressed helical springs was introduced by Haringx [22]. Both approaches are well presented by Timoshenko and Gere [40] and have been used by engineers in practice for the buckling analysis of built-up members. The superiority of Engesser's approach as far as the design of built-up members is concerned, has been pointed out by Nanni [31], Ziegler [44], Gjelsvik [21], Bazant [7–9] and Blaauwendraad [10]. Eurocode 3 [16] makes use of Engesser's method for the design of built-up members, providing guidance for their replacement with members with equivalent shear and bending rigidity. The shearing effect is also considered in LRFD [27] for built-up members with closely spaced flange components. Nevertheless, in the above codes and in the literature no specific guidance is provided for the calculation of the elastic buckling load of multi-story frames consisting of Timoshenko members.

Built-up members are the most common shear-weak members used in structural engineering nowadays. The calculation of the elastic buckling load of built-up columns for different types of boundary conditions has been carried out by many researchers. The influence of shear deformations has been investigated by Bleich [11], Timoshenko and Gere [40], Aslani and Goel [5], Temple and Elmahdi [37,38], Galambos [17]. Gjelsvik [21] obtained solutions for members with boundary conditions commonly used in the structural industry. Banerjee and Williams [6] explained the reason why the elastic buckling load of members with springs of different rotational stiffness at their ends cannot be derived by the general equation suggested by Engesser [15] and used by Eurocode 3 [16]. The effect of end stay plates on simply supported built-up columns was examined by Gjelsvik [20] by considering a layered sandwich cross-section and using a sixth order differential equation. This method was expanded for other possible boundary conditions by Paul [32] and experimental findings showed good agreement with analytical results [33]. Wang et al. [41] proposed an 8×8 matrix, providing exact stability criteria for Timoshenko columns with intermediate and end concentrated axial loads. Hashemi et al. [23] compared the elastic buckling loads of batten columns with end stay plates obtained by existing analytical methods, including Engesser's, with experimental results. They concluded that Engesser's method is always on the safe side. Aristizabal-Ochoa proposed a stability matrix for evaluating the elastic buckling load, based on Haringx's approach [3]. Gengshu et al. [19] used Engesser's method to investigate the buckling of dual shear-

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doi:10.1016/j.jcsr.2011.11.007