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Effect of geometric imperfections on the ultimate moment capacity of cold-formed sigma-shape sections

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Abstract In recent years, cold formed steel sections are used more and more as primary framing components and as a secondary structural system. They are used as purlins and side rails or floor joist, and after that in the building envelops. Beams are not perfectly straight and are usually associated with geometric imperfections. Initial geometric imperfections can significantly influence the stability response of cold-formed steel members. This paper reports a numerical investigation concerning the effect of these imperfections on the behavior of the simply supported beams subjected to a uniform bending moment. The beam profile is cold formed sigma sections. Group of beams with different overall member slenderness ratios were studied. Several approaches have been utilized to model the geometric imperfections. First, the elastic buckling modes were considered as the imperfect beam shape. In this approach, the elastic buckling analysis was done first to get the elastic buckling modes. In the second approach, the imperfections were considered by assuming the beam bent in a half sine wave along its length. Finally, combination of these two approaches was considered. Results reveal that, the ultimate bending moments of beams with short and intermediate overall slenderness ratios are sensitive to the imperfect shape that comprise compression flange local buckling.

Introduction

Real beams are not perfectly straight and are usually associated with geometric imperfections that may affect their buckling behavior and strength. Generally, geometric imperfections can be divided into two categories; global imperfections and cross-sectional imperfections. Cross sectional imperfections represent the change of the cross section from its ideal shape, while overall imperfections represent the

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deviation of the member centerline from its straightness. For global imperfections, typically $L/1000$ was used as the imperfection magnitude (the exact value is $L/960$ for hot-rolled steel column based on ASTM A6/A6M) [1]. The most common approach for considering cross-sectional imperfections is to use a factor of the cross section thickness as the imperfection magnitude (e.g. 0.1 t). However section imperfections can be classified into local and distortional imperfections. Local imperfections demonstrate the out of flatness in the plate elements forming the section, while distortional imperfections reflect the translation of one plate end with respect to the other end.

In the last 20 years several attempts were done to study the effect of geometric imperfections on the ultimate strength of cold formed sections. Schafer and Peköz [2], analyzed the frequency and the amplitude of two types of sectional geometrical imperfections. Based on probabilistic analysis of the measured imperfections and using the Fourier transform, they evaluated the frequency of appearance of the so-called 'imperfection signal' in terms of the instability modes. Each instability mode is characterized by its half wavelength. If the critical instability mode is identified using an elastic eigen buckling analysis then, for the critical imperfection, the frequency of appearance is estimated and the corresponding maximum amplitude of this imperfection can be obtained. Rzeszut and Garstecki [3], present approach based on the concept of developing the imperfections in series of eigen modes computed from a linear stability problem. The coefficients in the series were evaluated using imperfections accounting for Gauss probability factors and implementing error minimization in the approximation. The method is applied to the stability analysis of structures made of steel thin-walled cold-formed sigma profiles. It was found that the initial sectional imperfections did not remarkably reduce the maximum bearing capacity of the column, but they made the post buckling behavior unstable. Moreover, geometric imperfections measurements of cold-formed sigma profiles were presented by Garstecki et al. [4]. It appeared that the variations of the contour of cross-section have periodic distribution within the member length. The mean value of the measured distortion in flanges was approximately equal to 0.11 t. The distribution and the intensity of the initial imperfections can be used in generation of finite element meshes of imperfect structures. Sadovský et al., [5], presented the guidance on choice the most unfavorable geometric imperfections represented by the eigen mode shapes. The ideas presented were illustrated on lipped channel columns in the axial compression with the initial geometric imperfections exhibiting local-distortional interactions. The commonly used amplitude is accompanied with an energy measure derived from the hypothetic elastic strain energy of the imperfect surface. Two approaches are suggested. The first one, imperfections are normalized by the amplitude, while the energy measure is shown as a useful parameter indicating the severity of an imperfection. Analogously in the second approach, along with the normalization by the energy measure, the amplitude is used as a supporting parameter. Bonadan et al. [6] recommended an iterative method to select the eigen mode that if used as imperfect shape leads to the lowest ultimate load. Their study concentrated on the capacity of an imperfect cold-formed steel rack section with lengths where distortional buckling is predominant. Dubina and Ungureanu [7], showed that for cold-formed steel members in bending, the influence of sectional imperfections is low. However, if there is initial unfavorable twist combined with deflection, the ultimate strength is affected considerably. Borges Dinis et al. [8], present a numerical investigation concerning the elastic and elastic–plastic post-buckling behavior of the simply supported cold-formed steel lipped channel columns affected by a local-plate/distortional buckling mode interaction. The analyses involved columns containing several initial imperfections with similar combined amplitudes, obtained through different combinations of the competing buckling modes (three-wave local-plate and single wave distortional modes). The study shows that the pure distortional initial imperfections are the most detrimental ones, in the sense that they correspond to the lowest column strengths. Seo et al. [9], investigate the initial imperfection characteristics of the new mono-symmetric Lite Steel beams (LSB) and their effects on the moment capacity. In addition several researchers studied the behavior of the sigma section beams in bending. Yang and Liu [10], present an experimental study on the flexural behavior of single span CFS sigma purlins connected to the roof sheeting with large screw spacing. Test results are used to develop design proposals for the sigma purlins for which most codes or standards have not yet covered. Li [11], studied the influence of support conditions at both the tension and the compression ends of the web on the critical distortional buckling stress of the sigma sections purlins using EN1993-1-3. The influence of the support conditions on the spring stiffness can be applied to other analytical models for calculating the critical stress of distortional buckling. Li and Chen [12], calculated analytically the critical distortional buckling stress of the compression flange and the lip in channel, the zed, and the sigma sections under either compression or bending about an axis perpendicular to the web.

This work is aiming to study the sensitivity of the ultimate bending moments to the shapes and values of the initial geometric imperfections. The study concerned with simply supported beams subjected to equal end moments. The beam profile is the sigma CFS. Different shapes of the initial geometric imperfections have been considered. First, the elastic buckling modes only, second, the traditional imperfection shape which consists of half sine wave along the member length. Finally, combination of these two shapes was assumed as the imperfect beams.

Finite element model

A three-dimensional (3D) finite element model was developed to determine the elastic and the inelastic buckling loads of the cold-formed sigma section beams. Note that, the residual stresses were not considered in this study.

Fig. 1 shows the finite element model, loads, and boundary conditions. To simulate the required simply supported conditions, all nodes at both end sections were restrained against vertical displacements, Y-direction, and out-of-plane displacements, Z-direction. In addition, all the nodes at middle section are restrained against displacement along horizontal axis, X-direction. These boundary conditions allow in-plane rotations and warping displacements at the beam ends. The applied end moments were simulated with forces acting at each node of the beam end sections, where the upper part of the section was subjected to compressive forces and its lower part was

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