Practical Design of Cold-Formed Steel Sections by The Direct Strength Method

Gilson C. Filho[1], Luciano B. Santos[1], Wydem. L. E. Santos[1]

[1]*Center of Technology, Federal University of Alagoas*
Av. Lourival de Melo Mota, 57072-970, Alagoas/Maceió, Brazil
gilson.filho@ctec.ufal.br, lbsantos@ctec.ufal.br, wydem.santos@gmail.com,

Abstract. Cold-formed steel are among the most widely used in steel construction, being extensively employed in roofing and lightweight structures in general. Despite their popularity from a construction perspective, due to the existing manufacturing and utilization facilities, they prove to be quite complex from a design standpoint, as verifying these components involves extensive and complex calculation procedures due to the various global and local instability phenomena that may occur. Among the three design methods presented by the Brazilian standard NBR7190, this study applies the Direct Strength Method in the development of a computational application that allows for the practical design of cold-formed steel subjected to oblique composite bending. This addresses the vast majority of calculation situations encountered in practice. The application has been tested in various design scenarios, and the results have been compared with those provided by other methods recommended by NBR 14762:2010, showing a highly satisfactory performance.

Keywords: Direct Stiffness Method; Cold-Formed Steel; Computational Modeling.

1 Introduction

As noted by Yu [1], cold-formed steel profiles (CFS) were first used in construction in the United States and Great Britain in the 1850s. However, their widespread adoption in the U.S. did not occur until the 1940s. Yu [1] further highlights that, compared to materials such as concrete and timber, CFS offers several advantages, including lightness, high strength and stiffness, quicker and easier installation, and more efficient transportation.

Cold-formed steel sections are produced by bending flat steel sheets and are commonly used in roofing, small warehouses, and lightweight structures in general. Due to the manufacturing process, which involves cold bending of thin steel sheets, the elements forming the cross-section of the profiles often exhibit high width-to-thickness ratios, making them susceptible to various instability phenomena, particularly local instability. According to Schafer [2], the thin-walled nature of cold-formed steel (CFS) not only makes local buckling and distortions critical factors in the design of these members but also, due to local buckling, allows for an increase in strength through beneficial post-buckling reserve.

The Brazilian standard NBR 14762:2010 [3] provides three different design methods for calculating CFSS: (a) Effective Width Method (EWM); (b) Effective Section Method (ESM); and (c) Direct Strength Method (DSM). Both the EWM and ESM methods require the determination of the effective geometric properties of the cross-section to calculate the resisting forces of the members. In contrast, the DSM, as noted by Javaroni [4], assumes that buckling modes can be predicted using resistance curves adjusted from experimental results, allowing the use of the gross geometric properties of the cross-section in the calculations.

2 Objectives

The objective of this work is to present a computational application for the practical verification of cold-formed steel sections subjected to oblique combined bending, developed based on the Direct Strength Method, as outlined in Annex C of the Brazilian standard NBR 14762:2010 [3].

Oblique bending occurs when the load application plane does not align with one of the planes containing the principal axes of inertia of the cross-section, resulting in bending in both principal planes. If an axial force is added to this situation, it results in oblique combined bending.

The verification of cold-formed steel sections (CFSS) can be quite laborious, especially when using the Effective Width Method (EWM). When dealing with sections subjected to oblique combined bending, the calculation process becomes particularly challenging due to its volume and complexity. Nevertheless, this is a common practical situation, especially in roof purlins and lateral closure beams in warehouses.

The most common alternative to the Effective Width Method (EWM) has naturally been the Effective Section Method (ESM), which offers a much simpler and less voluminous calculation process. However, as stated in NBR 14762:2010 [3], the ESM only covers the verification of bending moments about the axis of maximum inertia, making it unsuitable for checking oblique bending, whether combined or not.

In this context, and despite its own challenges, the Direct Strength Method (DSM) has emerged as a viable alternative. The DSM provides a significantly simplified calculation process while addressing all verification stages for the sections.

3 The direct strength method

The Direct Strength Method (DSM), as described by Schafer [2], is an approach to determine the strength of cold-formed steel (CFS) members by considering various modes of instability. According to this method, the strength of a CFS member can be accurately assessed by analyzing the different types of elastic instabilities that affect the member. This involves defining and calculating the critical moments or loads for local buckling, distortional buckling, and global buckling also taking into account the moment or load at which the material yields. The method is predicated on the idea that, by fully understanding these buckling phenomena—local, distortional, and global—along with the material yield strength, one can establish a comprehensive picture of the member's performance under load.

Schafer [5] also pointed out several advantages of the DSM, including the elimination of effective width calculations, the use of gross section properties, and the absence of iterative procedures. Additionally, DSM simplifies the design of complex cold-formed steel (CFS) shapes, even in cases where standards design rules may not apply, requiring no more effort than for standard and traditional shapes, as specified by American Iron and Steel Institute [6]. This demonstrates DSM's flexibility in designing cold-formed steel structures.

The use of the Direct Strength Method (DSM) despite the advantages, relies on prior knowledge of the critical elastic buckling forces and moments of the section, as outlined by NBR 14762:2010, which can be a complex task and typically requires the use of a computational program for stability analysis.

Javaroni [4] and Carvalho et al. [7] discuss the DSM and present the CU-FSM program, developed by Schafer and Àdany [8], as a tool for applying the method in the verification of cold-formed steel sections (CFSS). Although using this program is not complex, it requires additional effort from the professional, including modeling each section individually and processing the data.

Pierin et al. [9] highlight that while the Brazilian standard requires the calculation of these critical buckling forces and moments for section verification, it does not provide specific procedures for this purpose. To address this, these authors developed the INSTAB computational program to determine the critical forces—axial force and bending moments—due to local and distortional buckling of cold-formed profiles as specified in ABNT NBR 6355:2003 [10].

With these critical buckling forces and moments for commercial profiles, it was possible to create a database for these profiles and develop a practical verification application for design situations.

4 Overview of the program's capabilities

Using Python and the PyQt5 library for the graphical interface, the program allows users to specify the dimensions of the profile they wish to check and input additional data such as applied forces, buckling lengths, and steel properties. The program then performs the verification according to Annex D of NBR 14762:2010 [1], which details the Direct Strength Method (DSM).

The development of the program was carried out in several stages, each addressing a specific functionality. The main libraries used were:

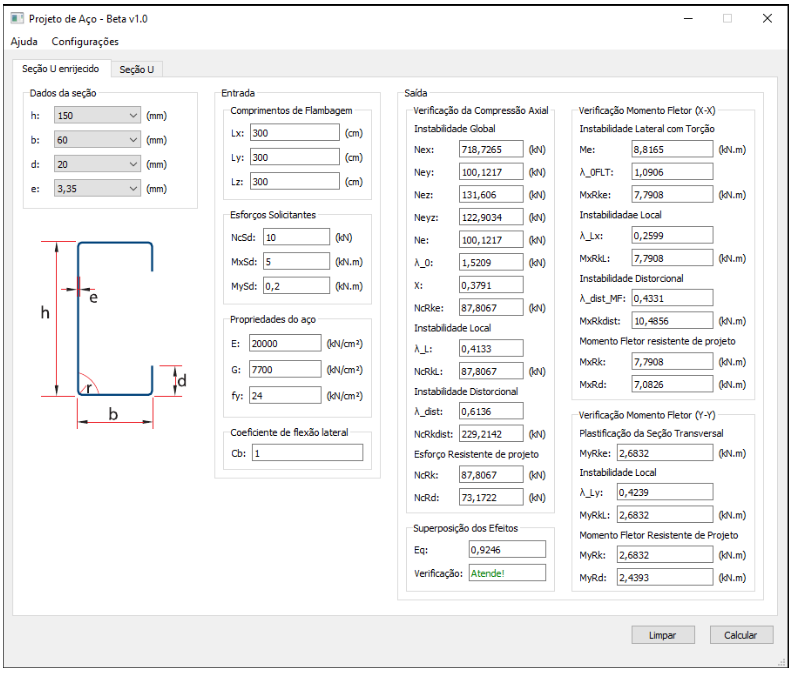
- PyQt5: Used for creating the graphical user interface (GUI);
- Pandas: Used for handling spreadsheets containing tabulated data;
- Numpy: Used for numerical calculations and mathematical operations.

The graphical user interface (GUI) was developed using PyQt5, which allows for the creation of sophisticated and responsive user interfaces. The GUI is composed of several sections, including:

- Profile Selection: A combobox allows the user to select a pre-tabulated, stiffened U-profile;
- Data Input: Input fields for applied forces and buckling lengths;
- Results Output: Display of verification results, including global, local, and distortional instabilities, among other critical parameters.

Figure 1 shows the general interface of the program.

Figure 1. Program interface



The application is launched by the user with the initial configuration of the main window and the definition of widgets. The combobox is populated with pre-tabulated values of stiffened U-profiles. For data entry, the user inputs values for applied forces and buckling lengths into the appropriate fields. These values are stored in variables for later use in calculations.

When the user clicks "Calculate," the program verifies the dimensions of the selected profile by querying a spreadsheet that contains the geometric properties of the section. It then consults another spreadsheet to retrieve the critical values for elastic buckling forces and moments, which are also pre-tabulated. Using the input data and stored values, the program performs the necessary calculations to assess the safety of the section as specified by NBR 14762:2010 [3].

The results are displayed in the interface, including information on global instability, local instability, and distortional instability, as well as the resisting forces and effects of load superposition. The results are shown in output fields on the GUI, allowing the user to quickly see whether the profile meets the normative requirements.

The code was compiled for Windows using PyInstaller, enabling the program to be distributed as a standalone executable without the need for a prior installation of Python or the used libraries.

5 Application example

As an example of the program's application, consider a truss with a Ue 150 x 60 x 20 x 3.35 profile, made of steel with a yield strength of 240 MPa, with a clear span of 3 meters, simply supported with bracing only at the supports, subjected to the following design loads: N_{cSd} = 10 kN; M_{xSd} = 500 kN.cm e M_{ySd} = 20 kN.cm. Table 1 below presents the results obtained using the program developed in this work, which employs the Direct Strength Method (DSM), compared to those provided by the DimPerfil 4.0 [11] program, which uses the Effective Width Method (EWM). In Tab. 1, Eq represents the ratio between the load and the member's resistance. To ensure that the member can withstand the loads, it must be ensured that Eq $\leq$ 1.

Table 1. Results obtained with this works program (DSM) and DimPerfil (EWM)

Method	N_{cRd} (kN)	M_{xRd} $(kN \cdot cm)$	M_{yRd} $(kN \cdot cm)$	Eq
DSM	73.30	699.63	225.84	0.94
EWM	73.13	708.43	243.93	0.92

It can be observed that the results obtained were quite compatible, even though they were achieved using different verification methods and computational tools.

6 Conclusions

In summary, the development of the program discussed in this work involved integrating various libraries and programming techniques to create a robust and efficient tool for verifying cold-formed sections subjected to combined oblique bending. The intuitive graphical interface and automation of the extensive calculations involved in the verification of these sections made the tool very practical and useful for professionals in structural design. The method used for verifying the safety of the sections was the Direct Strength Method, with critical buckling forces and moments obtained from national technical literature. The results obtained during the validation process of the tool were considered satisfactory, as they consistently showed good agreement with those available in technical literature and/or provided by other methods.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] Yu, Wei-Wen. "*Cold-formed steel structures*." (1973): 500.
[2] B. W. Schafer. "The direct strength method of cold-formed steel member design." *Journal of constructional steel research* 64.7-8 (2008): 766-778.
[3] ABNT, NBR 14762: 2010 – *Dimensionamento de estruturas de aço constituídas por perfis formados a frio*. Rio de Janeiro. 2013.
[4] C. E. Javaroni. Estruturas de aço: *dimensionamento de perfis formados a frio*. Elsevier editora ltda. São Paulo, SP.
[5] B. W. Schafer. "*Designing cold-formed steel using the direct strength method*." (2006).
[6] American Iron and Steel Institute. Committee on Specifications for the Design of Cold-Formed Steel Structural Members. *Direct strength method (DSM) design guide*. American Iron and Steel Institute, 2006.
[7] P. R. M. Carvalho, G. Grigoletti, and G. D. Barbosa. *Curso básico de perfis formados a frio*. 3ed. Published by the authors. Porto Alegre, RS. 2020.
[8] B. W. Schafer and S. Àdany. “Buckling analysis of cold-formed steel members using CUFSM: conventional and constrained finite strip methods”. *Eighteenth International Specialty Conference on Cold-Formed Steel Structures*, Orlando, FL. 2006.
[9] I. Pierin, V. P. Silva, and H. L. La Rovere. "Forças Normais e Momentos Fletores Críticos de Perfis Formados a Frio." *Revista da Estrutura de Aço*, v. 2, n. 1, p. 21-40.
[10] ABNT, NBR 6355:2003 – *Perfis estruturais de aço formados a frio - Padronização*. Rio de Janeiro. 2003.
[11] UBAS ENGENHARIA LTDA. Software DimPerfil 4.0*: dimensionamento de perfis de aço formados a frio.* Available at: https://www.cbca-acobrasil.org.br/. Last accessed on July 26, 2020.