COMPRESSION NUMERICAL TEST OF A STEEL ANGLE SECTION CONSIDERING ITS GEOMETRICAL IMPERFECTIONS

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Abstract. *One of the difficulties in numerical modeling of non-linear response of metallic profiles subjected to compression loads is the large sensibility in determining the collapse load due to the eccentricities that the profile may have. There are methods implemented in commercial softwares, as the used in this article, in which a linear combination of the buckling modes of the element using several criteria to consider them are used to model the eccentricities. The overall objective of this paper was to conduct a study of a cold-formed profile of L section subjected to axial load, and to evaluate it under different geometrical imperfections. In order to obtain a more rigorous estimate on that numerical methodology would be more appropriate to model the eccentricities, three-dimensional scanning of an element of angle section was carried out. It was acquired the geometry of this element together with its eccentricities and subsequently it was elaborated a finite element model of this geometry. Some geometrical non-linear analyses were carried out. The description of all analyses, as well as the comparison of the obtained numerical results is presented, suggesting which method would be more appropriate to represent the eccentricities of the profile.*

Keywords*: Geometrical imperfections, axial loading, instability, collapse load.*

1. INTRODUCTION

The existence of eccentricities or residual stresses in steel profiles influences the collapse load, but they are very difficult to be evaluated. In case of bar elements, the codes takes into account the eccentricities by means of semi-empirical expressions that were fitted thought experimental results as a function of profile shape and how it is manufactured.

Chodraui (2006) shows an experimental analysis of profiles U, U stiffened and single and double angle section (L profile) and a non-linear numerical analysis, considering the effects of global and localized geometrical imperfections and residual stresses in order to obtain a reliable value of the collapse load of the bar. The results demonstrated the viability of using the current curves of compressive strength for cold formed steel.

Grigoletti (2008) proposes a parametrical optimization of a cross section profile of U and U-walled stiffened when subjected to compression. The author employed tools as the Method of Finite Restricted Tracks, the Direct Strength Method and the Method of Effective Widths, and a finite element model considering physical and geometrical non-linearities, which was calibrated with experimental results found in literature, was used to verify the results.

After this introduction, Section 2 presents the description of the studied problem and the methodology used in both the experimental procedure as in the various theoretical analyses developed. Section 3 presents the results and discussions. Finally, Section 4 presents the main conclusions.

2. PROBLEM PRESENTATION AND METHODOLOGY

It is wanted to find which numerical method is more suitable to determine the collapse load of an L profile, taking into account their eccentricities. For that, a three-dimensional scanning of an element of L section of a guyed tower was carried out. Getting the geometry of the profile with its eccentricities, subsequently it is made a finite element model of this geometry and a geometrical non-linear analysis is carried out. The description of the performed tests and the comparison of results are presented, as well as a description of the equipment and methodology for conducting the scanning of the L section profile.

2.1. Determination of collapse load

Figure 1 presents a flowchart that resume the methodology used to determine the collapse load of the L section profile subjected to compression. It was followed the methodology suggested by Grigoletti (2008), which was implemented in ANSYS system.

First the calculation of elastic buckling critical load of the profile is completed. So, from the mode associated with it, it is calculated the eccentricity proposal for the profile which will be a configuration with imperfections given by buckling mode scaled by a constant. After this determination, the next steps are the commonly followed in non-linear analysis of structures using finite elements.

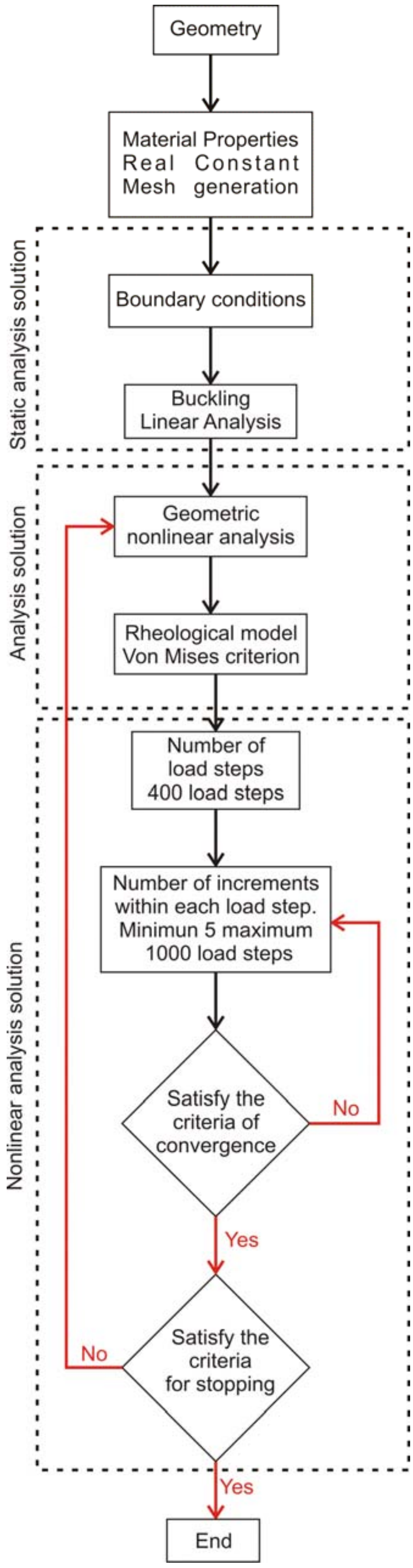

Figure 1: Flowchart for analysis of buckling critical load.

2.2. Techniques for numerical solution

The stability analysis involves solving a problem of eigenvalues and eigenvectors defined by the elastic and geometrical stiffness matrices of the profile. This resolution is made in ANSYS by the method of subspace iteration (Bathe, 1998). The paths of post-buckling elastoplastic are determined by a numerical technique based on the incremental-iterative method of Newton-Raphson. To determine the cutoff point (value of ultimate strength) and to be able to describe the ascending or descending part of the equilibrium path of a bar is necessary to use resolution strategies to control displacement or arc length.

In this paper is used, via ANSYS, the Riks Method (control of arc length) [Riks (1979), Criesfield (1981, 1988a, b)], which is a highly efficient iterative method to solve the non-linear equations of equilibrium, since the increments and tolerances relevant to method are correctly configured.

2.3. Steel profile

The studied angle section has dimensions of 25.4mm × 25.4mm × 3.175mm × 500mm. The mechanical properties are given in Table 1, where the values are defined based on commercial profile tables.

Table 1: Mechanical properties of the studied angle section.

Mechanical Properties	
Mass density [kg/m^3]	7850
Poisson's ratio	0.3
Young's modulus [GPa]	210
Shear modulus [GPa]	80

2.4. Three-dimensional laser scanning

To scan the profile, it was used the three-dimensional laser scanner, Tecnodrill brand, model Digimill 3D, shown in Figure 2, installed in Laboratory of Design and Material Selection (LdSM), Federal University of Rio Grande do Sul (UFRGS). This equipment was developed in partnership between the LdSM and the Tecnodrill company, located in Novo Hamburgo / RS.

Figure 2: Three-dimensional laser scanner, Digimill 3D model, and studied L profile being scanned.

The Digimill 3D is a CNC (numerically controlled by computer) equipment. In the operation, the 3D scanner moves over the plane of X and Y axes, while a laser head measuring the height goes in the Z axis. As a result of the scan, text files with the surface points of the object described in coordinates (x, y, z) are obtained. Figure 2 shows the studied angle section being scanned by Digimill 3D.

After scanning and getting the points (x, y, z), the three-dimensional mesh was generated. The L profile was divided into 30 planes along its longitudinal axis (Figure 3). Three reference points (1, 2 and 3) were identified in each plan. The points 1, 2 and 3 are coincident with the median planes of the angle section.

Point 1 and point 3 varied in relation to the axes Y and Z. Point 2 has not change in relation to the axes because this point is a result of the other two points (point 1 and point 3). These points were used to determine the geometrical properties of each section, such as angle between the flaps and the difference between the centers of gravity of each section. After the determination of these coordinates, the same was used to model in finite element the angle section that was scanned.

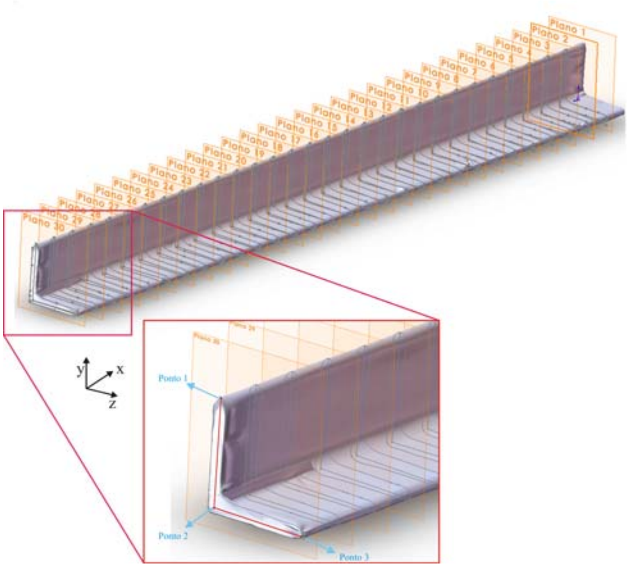

Figure 3: Geometrical planes of the scanned angle section.

3. NUMERICAL COMPRESSION TEST OF THE ANGLE SECTION

This item describes the procedures used in the numerical analysis of buckling of a bar with the same geometrical characteristics of the scanned L profile. It was compared the results of numerical simulations of axial compression (critical load) of the scanned geometry with a perfectly straight geometry where imperfections were added by means of methods proposed in literature.

3.1. Profile geometry

Three different numerical models with the collected geometrical coordinates were developed. The adopted boundary conditions, loads, physical properties, element type and non-linear analysis remained the same in all three cases. The geometrical shapes adopted in each model are described below. The length adopted to model the profile was 500mm for the three types of geometry and the coordinates of points 1, 2 and 3 (Figure 3) were used as reference.

Case 1: In this numerical model the coordinates of points 1, 2 and 3 of each cross section were used to describe the profile. Totalizing 30 sections with different values and uniformly distributed over the 500mm length, as shown in Figure 4 (a).

Case 2: The 30 sections previously determined were divided into three parts, each part contained ten cross sections with their respective points 1, 2 and 3. Of these ten sections of each part was made an average of coordinates of points 1, 2 and 3, and these mean values of the coordinates of each point were located on the numerical model, being one at each end and another at half length of the bar, as shown in Figure 4 (b).

Case 3: Of the 30 cross sections were made an average of the coordinates of each point, resulting in a single average value, as shown in Figure 4 (c).

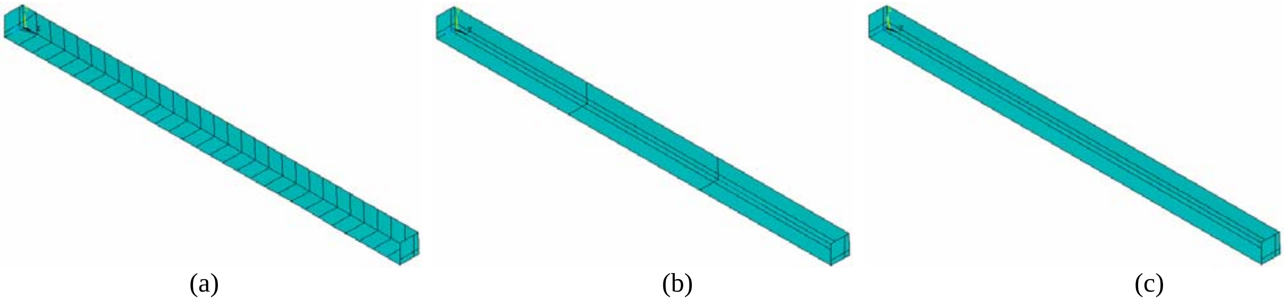

Figure 4: (a) View of the distribution of the 30 cross sections in the numerical model, (b) View of the three regions corresponding to the average coordinates of the ten cross sections and (c) View corresponding to the average of 30 cross sections.

3.2. Boundary conditions

The boundary conditions applied in the three models are the same. One point at each end of the plates that are perpendicular to the L profile was selected, being one of the points for fixing and the other for application of force. The point of fixing was restricted in all directions Ux, Uy and Uz, the rotations were allowed at this point in all directions.

In the point of load application were restricted the displacements in the directions Uy and Uz and the rotation was restricted only around the X axis, this rotation restriction was done with intent to avoid motion of rigid body during the scanning process.

These selected points are located exactly at the centroid of the angle section, which has 6.35mm as theoretical value. This was used in order to try to approach the numerical test to an experimental test.

3.3. Constitutive relations

The material was considered elastoplastic with three inclinations to model the strain hardening predicted. The linear elastic portion is defined by the values of the Young's modulus and Poisson's ratio, the plastic portion exhibits the behavior usually adopted for steel with isotropic hardening and Von Mises yield surface (Chen and Han, 1987).

Figure 5 shows a graph of adopted steel behavior, with trilinear elastoplastic model. It is important to point out that for the construction of stress-strain graph of the steel (Figure 5), the values adopted correspond to conventional values, so the conventional stress and strain (engineering values), obtained from this graph, were converted to true stresses and strains (true values), once the software ANSYS when performing non-linear analysis for large deformations, uses routines that work with the true stresses and strains.

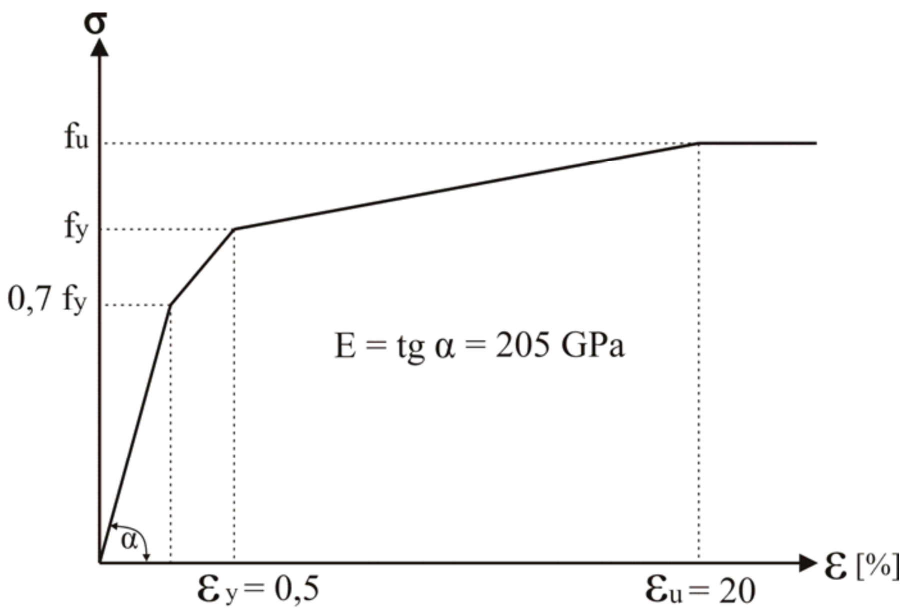

Figure 5: Stress-strain curve: adopted trilinear elastoplastic model to simulate the behavior of steel.

3.4. Instability analysis

Initially linear analysis of instability was conducted in order to determine the buckling modes of the studied L profile and its critical load of linear elastic buckling. The obtained value of buckling critical load for the first mode was 29249N and the critical loads for second and third modes are 97983N and 149484N, respectively. Figure 6 shows the first three buckling modes of the angle section with dimensions of 25.4mm × 25.4mm × 3.175mm × 500mm.

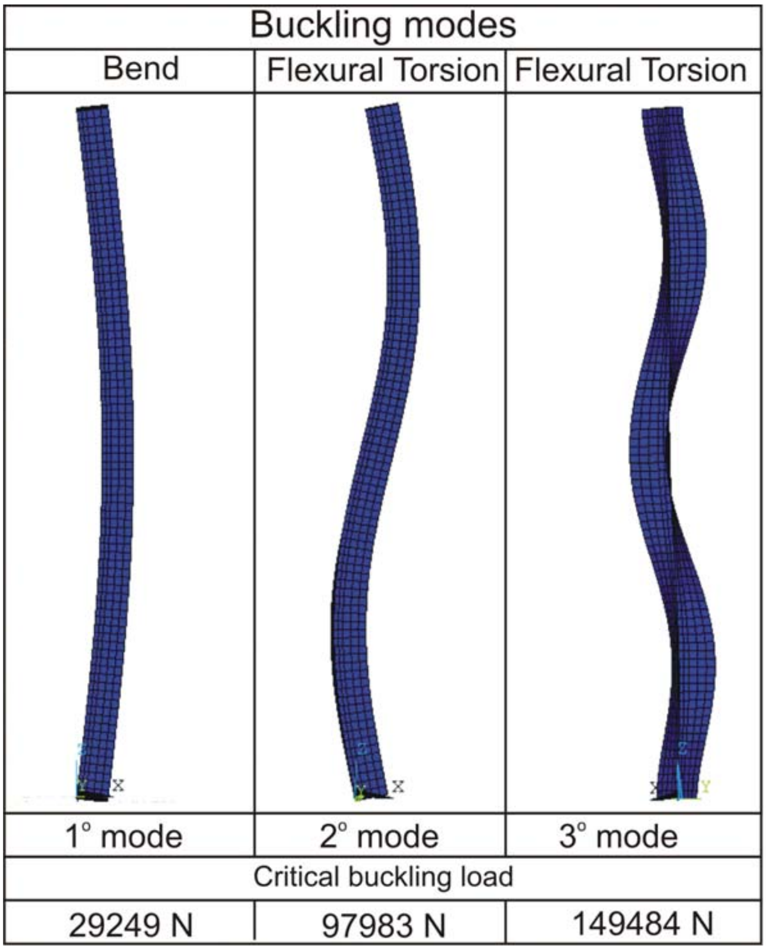

Figure 6: Buckling modes of the angle section without geometrical imperfections.

3.5. Non-linear analysis

Six simulations were performed using geometrical non-linear analysis. First the geometrical imperfections were considered with the maximum amplitude of eccentricity given by L/1000, L/1500 and L/2000 respectively, in which L is the length of the analyzed profile.

The shape of the adopted initial geometrical imperfection is a linear combination of instability modes of the profile, determined by a previous linear stability analysis. So, first a stability analysis by eigenvalues and eigenvectors via ANSYS is made, which provides the values of critical forces (eigenvalues) and corresponding buckling modes (eigenvectors), and then, when possible, choosing pure buckling modes, referring to the modes of local, global and distortional buckling, when applicable. In this paper the first buckling mode was considered as a way of initial geometrical imperfection.

Figure 7 shows the loads imposed on the studied profile with different geometrical imperfections. It is observed in Figure 7 and Table 2 that when the geometrical imperfection is smaller, the collapse load from the non-linear analysis increases, approaching to the Euler buckling critical load.

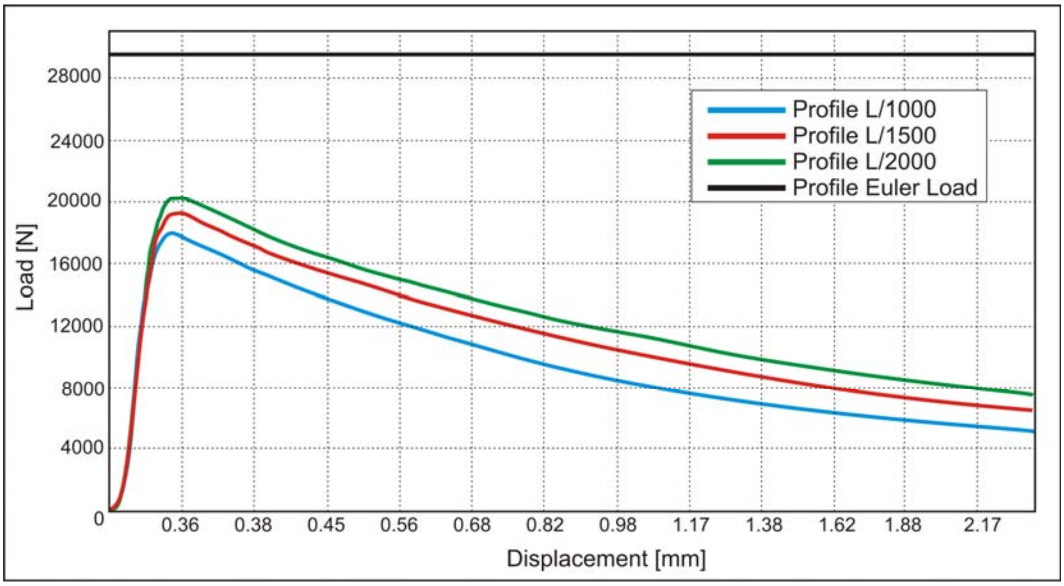

Figure 7: Collapse load for profiles with theoretical geometrical imperfection.

Table 2: Collapse load for profiles with theoretical geometrical imperfection.

Geometrical imperfection	Critical load [N]
L/1000	17866.0
L/1500	19222.1
L/2000	20103.4

Collapse loads of angle sections on which the imperfections that were imposed were obtained from the three-dimensional scanning of the own element were also determined. The implementation of the scanned imperfections was carried out in three different ways, which were presented in Figures 4(a-c). Table 3 shows the buckling critical loads from the non-linear instability analysis of the three types of tests on the scanned profile.

Table 3: Collapse load of the scanned angle section.

L profile	Critical load [N]
30 sections	20238.8
10 sections	20625.1
1 section	20501.1

It is noticed in Table 3 that there was no significant change in the collapse load considering the three approaches of the scanned profile. Figure 8 shows the load-displacement curve for the simulations with the scanned imperfections implemented in different ways.

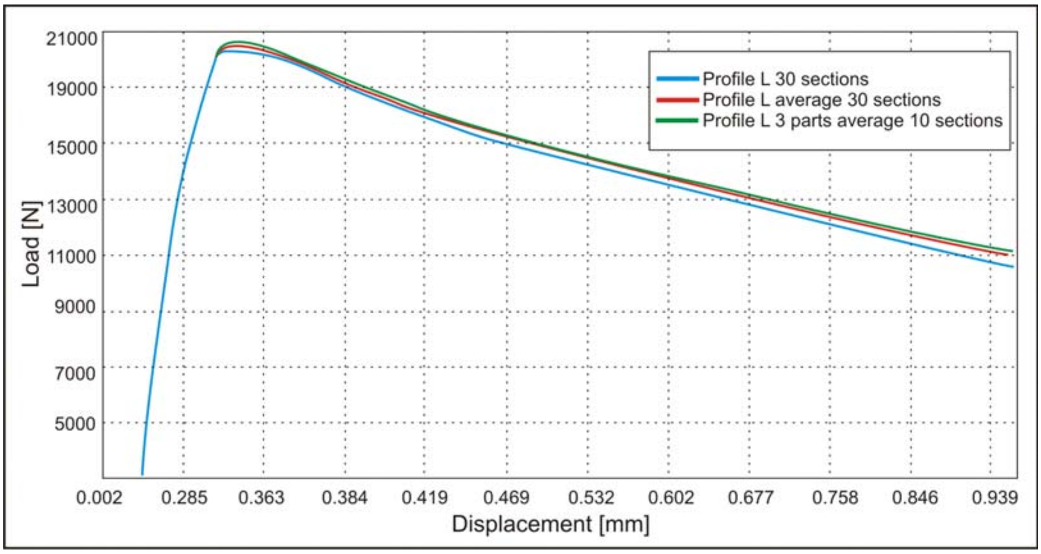

Figure 8: Simulations considering various ways to implement the scanned geometrical imperfections.

Figure 9 shows the stress distribution on the X axis, longitudinal axis of the profile, in which can be observed that there is a distribution of compressive stress in the blue color in the central region of the profile in the three studied cases. This occurs, as previously mentioned, due to the low rate of geometrical imperfection.

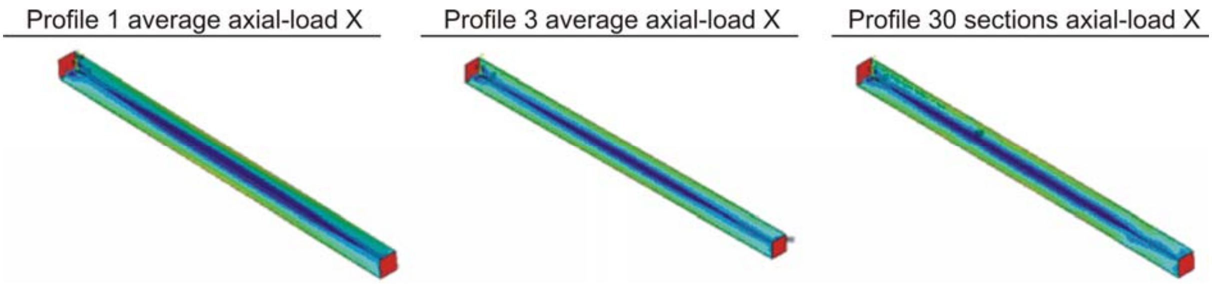

Figure 9: Distribution of axial stress of a scanned profile.

Comparing the tests of the theoretical profile added of imperfections with the three cases of the scanned profile, in which the imperfections are already incorporated and observing Figure 10, it is noticed that the collapse loads are almost the same in all simulations, however it can be observed that the collapse loads of the three cases of the scanned profile approached the theoretical geometrical imperfection of L/2000. As the results of the three simulations of the scanned profile were very close, Figure 10 presents only one curve, which represents the average of three curves of the scanned profile.

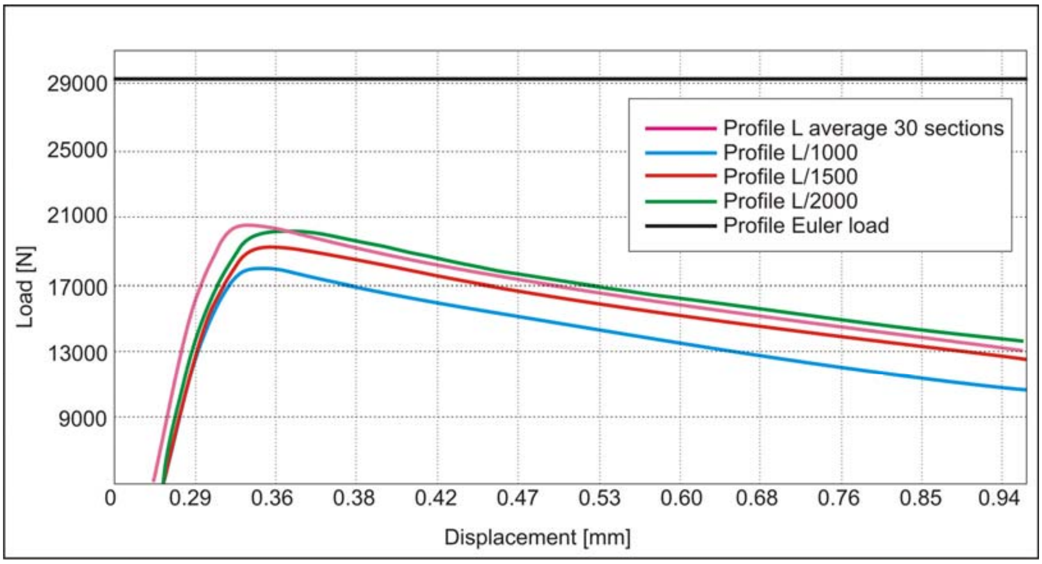

Figure 10: Comparison of collapse loads of the different simulations carried out.

May be also observed in Figure 10 that in the elastic region all cases behaved similarly, showing a similar inclination. From this figure it is also concluded that the behavior is similar among all studied curves.

The critical load of the analyzed profile without imperfections was significantly higher than the critical loads obtained in the simulations. Also in Figure 10 is evident that the load-displacement response using the theoretical imperfection with a magnitude of L/2000 was very close to the curve of the simulation where the imperfections were scanned, but to confirm this, would be necessary to conduct a statistical study.

4. CONCLUSIONS

The method of scanning the profile can be used as a tool to determine geometrical imperfections in profiles with complex geometry or in sections that require an accurate calculation. However, this method demands a high computational cost since it is necessary to have a satisfactory amount of results in order to estimate with some precision the geometrical imperfection in a profile.

For use in profiles with simple geometry, this tool cannot be considered the most useful for determining the geometrical imperfections. The results obtained by non-linear analysis of the three cases of the scanned profile presented no significant differences when compared with the results obtained by non-linear analysis of the profiles in which the geometrical imperfections were added in a theoretical way. Thus it would validate the theoretical methods proposed in the technical literature to assess the eccentricities.

Evaluating different models of different levels of complexity become clear the variability of results and the need to always cross information with models that work with different assumptions and calibrate them with experimental values.

5. ACKNOWLEDGEMENTS

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