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NUMERICAL EVALUATION OF LOCAL BUCKLING COEFFICIENTS OF “S” STIFFENED PROFILES WITH SLOPED WEB

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Abstract. *The cold formed profiles developed through the conformation of thin plates of steel, has been an attractive constructive solution for several aspects such as economy and speed to execute some works. Furthermore, its high slenderness allows to build lighters and more efficient structures. So, the buckling coefficient has great importance to design a profile because it is possible to calculate the critical buckling stresses. Thus, the objective of this work is to obtain the curve of the buckling coefficients of the cold formed profile S with a sloped web with compression stress causing local buckling. This profile can be used in industry to build light steel frame structures and do not have specific studies of buckling coefficients. The numerical analysis software Abaqus™ and CUFMS were used to obtain the critical buckling loads. The results obtained were used to adjust a curve of the buckling coefficient versus the geometry ratios and will contribute to future structural stability calculations.*

Keywords: *cold formed profiles, local buckling, buckling coefficient, numerical analysis, S Stiffened Profiles.*

1. INTRODUCTION

Cold formed profiles are being increasingly used in civil construction due to the low weight resulting from the slenderness of the plates, speed of execution and low cost required by the market. They can be found in large, medium and small works such as houses, industrial sheds and buildings.

The manufacture of the cold formed profiles is made by simple equipment due to the malleability of the thin steel plates, allowing a wide variety of sections. This process alters the mechanical properties of the steel generating an increase of the yield stress and the reduction of the ductility of the material.

Open section profiles are constituted by elements formed by plates which can be supported by one (AL) or two longitudinal edges (AA) subject to the mode of instability called local buckling (Rodrigues, 2016 e ABNT NBR 14762:2010, 2010). This mode is characterized by the formation of longitudinal half-waves with no change of the position of the median longitudinal axis of the plate, as shown in Figure 1.

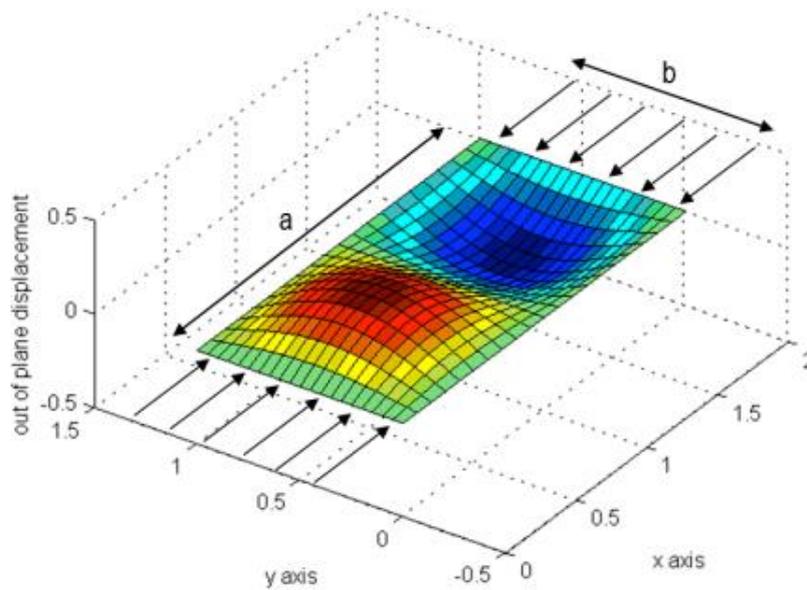


Figure 1: Local buckling of a simple supported plate under axial loading (Neto, *et al.*, 2014).

Local buckling reduces significantly the axial and bending stiffness of the material and may not represent its structural collapse, with the intensifying factors being: residual stresses, geometric imperfections and non-linear behavior of the plate. To calculate the critical buckling stress of the profile is necessary to solve a complex differential equation which the modes and buckling load are study as the displacements and working load, respectively, to satisfy the equation and the boundary conditions of the element.

The purpose of this work is to obtain the curve of the buckling coefficients of the cold formed profile S with sloped web submitted to compression stress causing local buckling. The numerical analysis software Abaqus™ and CUFSM were used to obtain the critical buckling loads (eigenvalue results).

2. DEVELOPMENT

2.1 Geometry

To obtain the geometry of the profile studied here, the geometry of two other profiles on the market was taken as the basis, being the profile Z stiffened and the box profile. The designations of the dimensions of the S profile studied are shown in Figure 2.

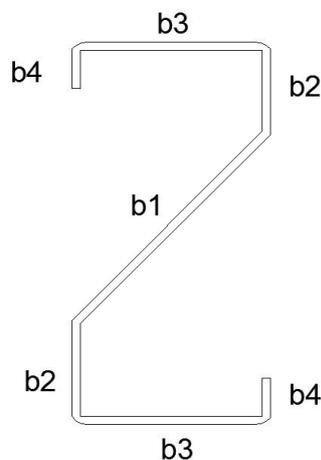


Figure 2: Section of the studied profile.

The profiles Z (Figure 3) and box (Figure 4) found on the market were initially used as models to obtain cross sections, maintaining the angle of element b1 with the horizontal axis at 45 degrees. The width (b4) and thickness (t) of the stiffeners are, respectively, 20 mm and 2 mm. However, in order to better distribute b2 / b1 ratio, other profiles were created only by changing the width b2, thus totaling the 22 profiles analyzed (Table 1).

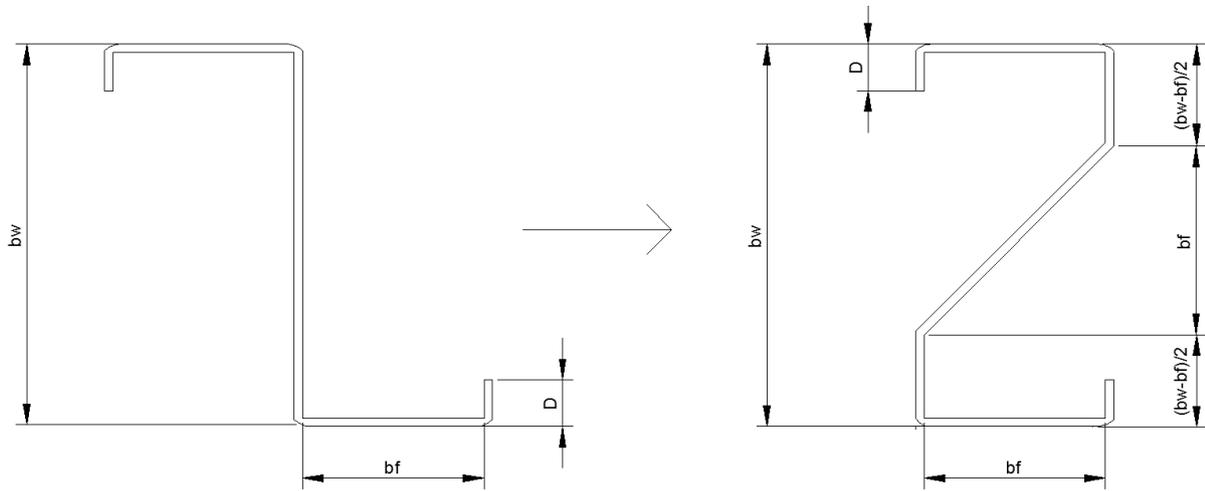


Figure 3: Obtaining the profile through the Z profile

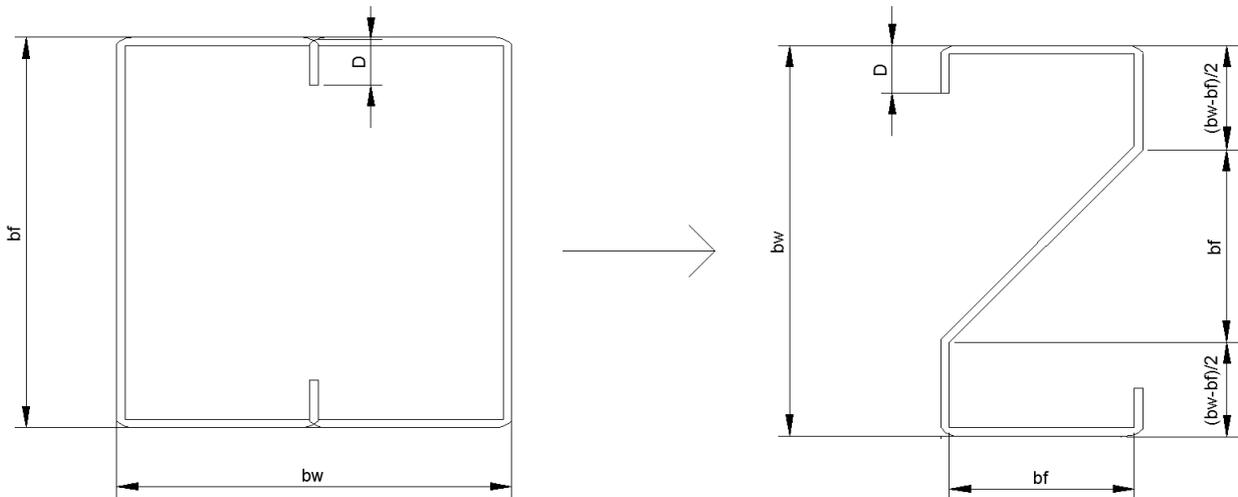


Figure 4: Obtaining the profile through the box profile

Table 1: Geometry analyzed

n	Profile	bw	bf	b1	b2	b3	b4
1	S300X85X20	300	85	120,21	107,50	85	20
2	S250X85X20	250	85	120,21	82,50	85	20
3	S200X75X20	200	75	106,07	62,50	75	20
4	S150X75X20	150	75	106,07	37,50	75	20
5	S125X50X20	125	50	70,71	37,50	50	20
6	S100X50X20	100	50	70,71	25,00	50	20
7	S75X40X20	75	40	56,57	17,50	40	20
8	S50X25X20	50	25	35,36	12,50	25	20
9	S300X170X20	300	170	240,42	65,00	170	20
10	S250X170X20	250	170	240,42	40,00	170	20
11	S200X150X20	200	150	212,13	25,00	150	20
12	S150X120X20	150	120	169,71	15,00	120	20
13	S125X100X20	125	100	141,42	12,50	100	20
14	S140X100X20	140	100	141,42	20,00	100	20
15	S220X100X20	220	100	141,42	60,00	100	20
16	S225X100X20	225	100	141,42	62,50	100	20
17	S250X100X20	250	100	141,42	75,00	100	20
18	S270X100X20	270	100	141,42	85,00	100	20
19	S280X100X20	280	100	141,42	90,00	100	20
20	S310X100X20	310	100	141,42	105,00	100	20
21	S320X100X20	320	100	141,42	110,00	100	20
22	S340X100X20	340	100	141,42	120,00	100	20

2.2 Instability of profiles elements

As already mentioned, the profile elements are subject to local buckling, due to compression loads, for the present case. According to ABNT NBR (2010), the critical stress σ_{cr} of elastic buckling of the profile element is given by equation (1):

$$\sigma_{cr} = k \frac{\pi^2 \cdot E}{12 \cdot (1 - \nu^2) \cdot \left(\frac{b}{t}\right)^2} \quad (1)$$

where:

E is the modulus of elasticity

k is the buckling coefficient

t is the element thickness

ν is the poisson coefficient

b is the element width

The critical stress for an insulated plate depends on the boundary conditions imposed on the edges and the geometry. The modes of instabilities are characterized by one or more half-waves, of the sinusoidal type (Rodrigues, 2016), as shown in Figure 1. Therefore, the behavior of the buckling coefficient can be investigated by varying the geometry of the profile.

2.3 Computational procedure

Abaqus™ and CUFSM commercial software were used in the analysis to obtain numerical simulation results of local buckling. Abaqus™ software is a commercial program developed using the finite element method, with a wide variety of features that allow the modeling of structural instability problems of great potentiality and application (ABAQUS 6.10-EF, 2010). The CUFSM is specific software to calculate buckling in cold formed profiles and its program was used to compare and calibrate the Abaqus™ model. CUFSM software employs the semi-analytical finites strip method to provide solutions for the cross-section stability of such members (Li and Schafer, 2010).

For the consideration of elastic and isotropic behavior the modulus of elasticity was considerate as 200,000 MPa and the Poisson coefficient as 0,3. The geometry was defined by the middle lines of the profile as a coordinate system (Figure 5). The analyses were made using the linear perturbation step from Abaqus™, with buckle mode. The shell element S4 was used, this element has four nodes with double curvature, complete integration, finite deformation and six degrees of freedom.

To obtain a local buckling, the boundary conditions restricted transverse edges in "X" and "Y" directions, allowing the "Z" displacement and the "Z" rotation. The other rotations remained free. Table 2 present details of the boundary conditions used which U corresponds to the displacements, UR corresponds to the rotations and axes 1, 2 and 3 corresponds, respectively, to the x, y and z axes. Figure 5 present the boundary conditions set in the Abaqus™ model.

A mesh convergence test was then performed to ensure accuracy in the results (Dassault Systèmes, 2010). For the analysis with meshes smaller than 10 mm, the computational cost was very high and the results did not show great variations (see Fig. 6), so we used this mesh size in the simulations.

Table 2: Boundary conditions for displacement and rotation.

Degrees of freedom	Condition
U1	Fixed
U2	Fixed
U3	Free
UR1	Free
UR2	Free
UR3	Fixed

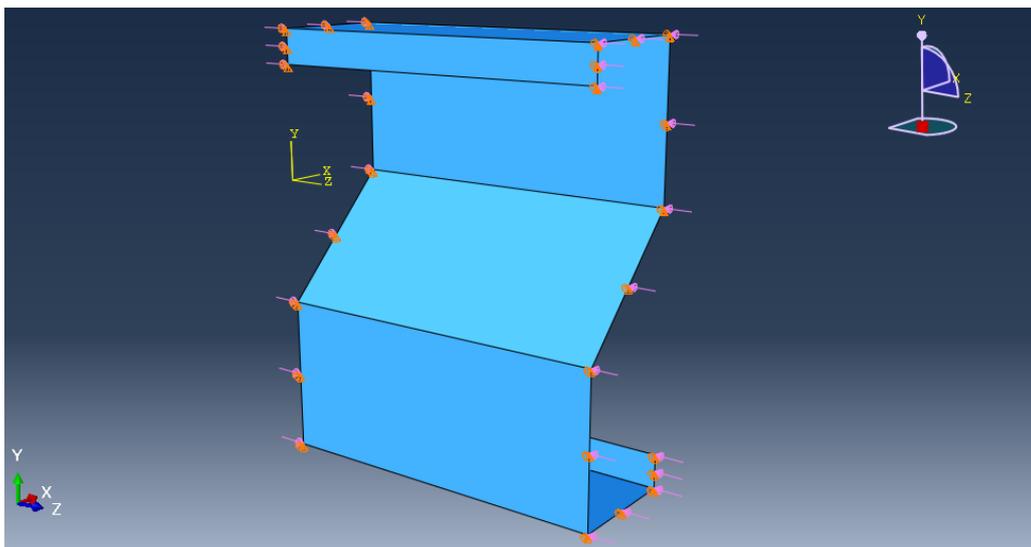


Figure 5: Boundary conditions applied in Abaqus™ model.

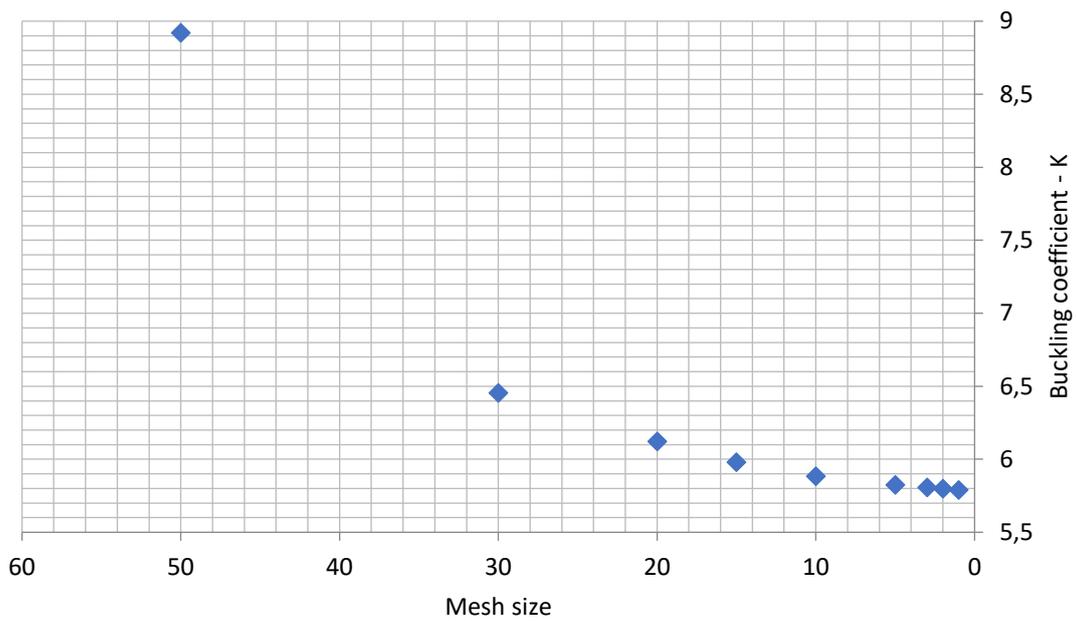


Figure 6: Mesh convergence test

3. RESULTS AND DISCUSSIONS

In the first part, the model S300X170X20 was simulated in AbaqusTM and then the results were compared with CUFSM. Figure 7 shows the result obtained by CUFSM and Figure 8 the result obtained by AbaqusTM. To compare both results, the error was calculated. The obtained error was 2.47%, considered small, therefore, it was considered the calibrated AbaqusTM model so that the other profiles selected were also simulated.

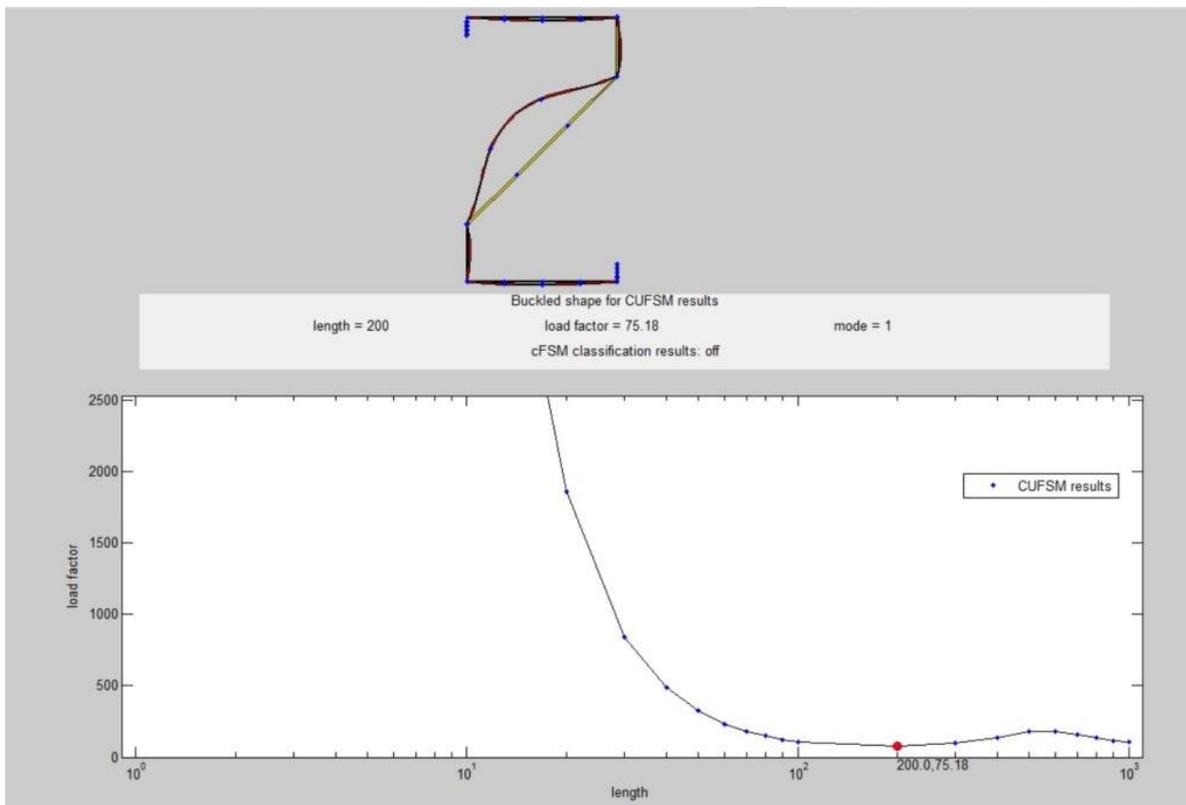


Figure 7: CUFSM model for local, distortional and global load buckling.

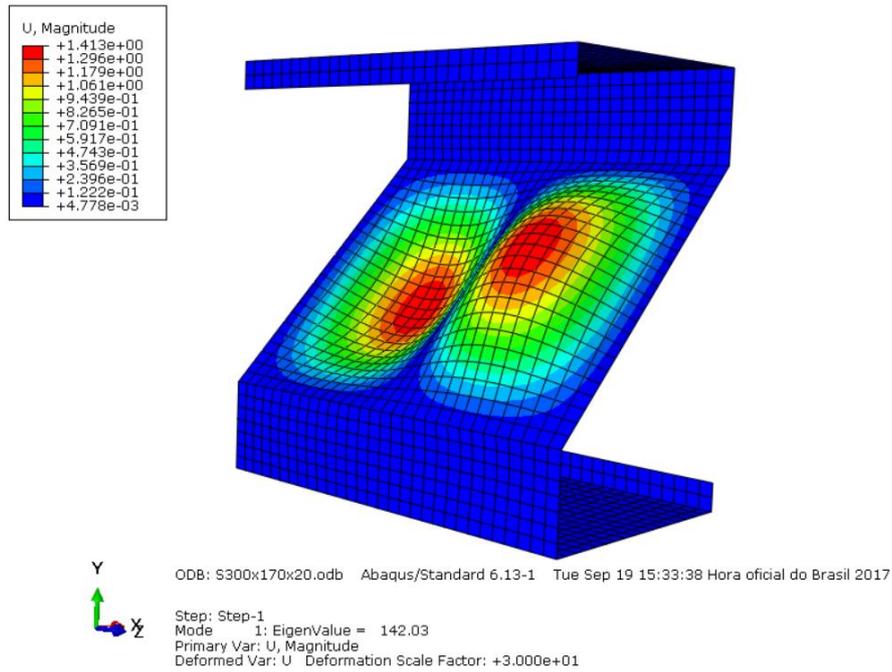


Figure 8: Abaqus™ model

The stiffness coefficients were then obtained for various ratios of b_2/b_1 . In Table 3 these values are organized for a range of b_2/b_1 ranging from 0.09 to 0.89.

Table 3: Buckling coefficients results according to the geometry and loads

n	Perfil	b_2/b_1	Carga Crítica (N)	k
1	S300X85X20	0,89	243,40	5,83
2	S250X85X20	0,69	272,96	6,53
3	S200X75X20	0,59	356,16	6,64
4	S150X75X20	0,35	366,02	6,82
5	S125X50X20	0,53	826,15	6,84
6	S100X50X20	0,35	836,05	6,93
7	S75X40X20	0,31	1270,20	6,73
8	S50X25X20	0,35	1802,65	3,73
9	S300X170X20	0,27	73,32	7,02
10	S250X170X20	0,17	74,19	7,10
11	S200X150X20	0,12	76,13	5,68
12	S150X120X20	0,09	133,20	6,35
13	S125X100X20	0,09	180,96	6,00
14	S140X100X20	0,14	219,92	7,29
15	S220X100X20	0,42	209,35	6,94
16	S225X100X20	0,44	208,85	6,92
17	S250X100X20	0,53	206,37	6,84
18	S270X100X20	0,60	204,44	6,77
19	S280X100X20	0,64	203,47	6,74
20	S310X100X20	0,74	197,40	6,54
21	S320X100X20	0,78	194,88	6,46
22	S340X100X20	0,85	185,37	6,14

In the next step was calculated critical load and consequently buckling coefficients for each configuration. Figure 9 shows the adjusted curve for the results obtained for the buckling coefficient K , (y-axis) versus b_2/b_1 (x-axis) ratio. A cubic-order polynomial was used because it adjusted well to the points. The resulting polynomial is presented in Equation 2.

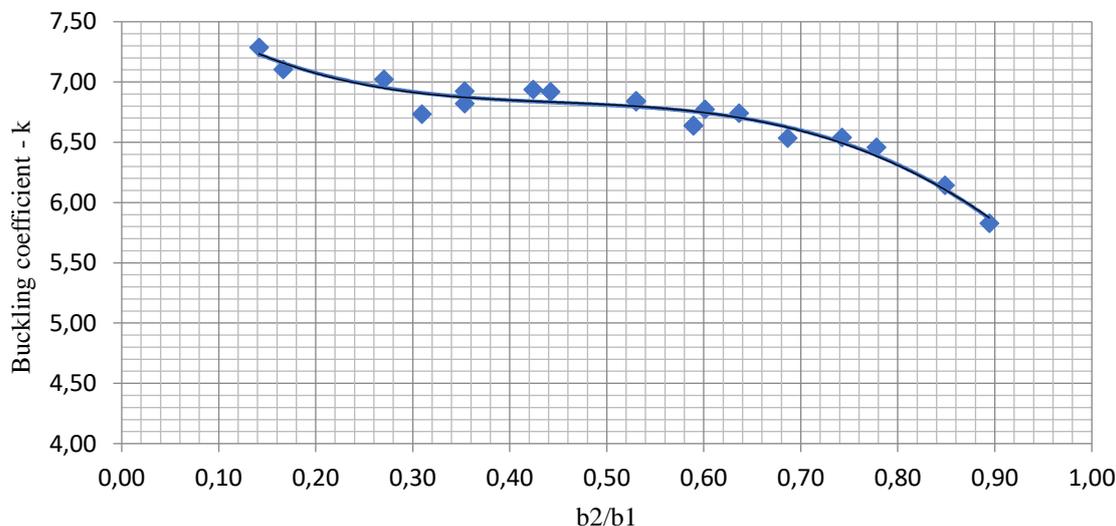


Figure 9: Adjusted curve for the results

$$k = -9,3937\eta^3 + 12,81\eta^2 - 6,1895\eta + 7,8764 \quad (2)$$

where:

$$\eta = \frac{b_2}{b_1} \quad (3)$$

4. CONCLUSIONS

The use of Abaqus™ software made it possible to find results for the buckling coefficient for the stiffened profile S with inclined core. The CUFSM software was also used for purposes of comparison with Abaqus™ results, which proved to be satisfactory. Therefore, it was possible to approximate a curve which represents the expected behavior of the buckling coefficient of type profiles. Thus, it is expected that the present work will contribute to future research or projects in which this type of profile can be used, given the care that must be taken with the consideration of the phenomenon of buckling.

5. ACKNOWLEDGMENTS

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