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NUMERICAL EVALUATION TO DETERMINE THE LOAD CAPACITY OF LIGHT STEEL FRAME WALLS

Kildenberg Kaynan Felix Nunes

Anne Caroline Linhares Monteiro

Hidelbrando José Farkat Diógenes

Andrea Brasiliano Silva

Paulo Vitor Mendonça Rezende

kildenberg@hotmail.com

anneclmonteiro@hotmail.com

hidelbrando@ct.ufpb.br

andreabrasiliano@gmail.com

paulovmrezende@gmail.com

Universidade Federal da Paraíba, Centro de Tecnologia, Departamento de Engenharia Civil e Ambiental, Cidade Universitária, s/n - João Pessoa, PB, Brasil

Abstract. *Among the rational construction methods, stands out a system that is not widespread in Brazil, but already well established in developed countries, the Light Steel Frame (LSF). Because it is a recent structural system, especially in Brazil, there are not many studies related to its structural behavior. Considering the importance of the insertion of new technologies in civil construction and the need to understand the structural behavior of the technique used, this study aims to study the structural performance of LSF panels when submitted to compression efforts, from the numerical modeling using the Finite Element Method, focusing on the linear analysis of structural behavior. Numerical models were developed in the SAP2000® computer program and simulated small LSF walls of dimension 1.20 x 1.20 meters. From the application of successive vertical loads on the small walls, the numerically obtained values of axial strain were compared with the expected theoretical and experimental responses. Thus, analyzing the obtained results it was possible to observe a good convergence between the theoretical, numerical and experimental analyzes. Considering the representativeness of the numerical model, it is possible to use it as a basis for further studies.*

Keywords: *Numerical modeling, Light Steel Frame, Axial Compression*

1 INTRODUCTION

Despite the relevance of civil construction in the Brazilian economic scenario, Ceotto (2005) states that in the last decades there were no significant changes in the construction techniques employed, that culminated in the technological development of this sector. From the systemic point of view, it can inferred that it is constructed very similarly than seventy years ago.

At present, in Brazil, the building sector predominantly adopts the conventional constructive system of reinforced concrete associated with masonry. Because it is a completely craft technique, it is generally characterized by low productivity, estimated to be only one third of that observed in developed countries, and the occurrence of serious product quality problems, resulting in costs of corrections and post-delivery maintenance (ABIKO *et al.*, 2005).

Contrary to this scenario, the construction industrialization proposes to optimize the deficient stages of the existing constructive processes, perfecting them or creating new methods that generate greater productivity and quality. In civil works, the process of industrialization can be observed with prefabricated structures and the use of machines, which gradually replace or reduce craft production.

According to the Brazilian Center for Steel Construction (CBCA, 2015), one of the most industrialized sectors in Brazil is the steel construction. This type of construction has grown annually and tends to expand further with the advantages provided over the conventional system.

Among the rational construction methods, stands out a system that is not widespread in Brazil, but already well established in developed countries, the Light Steel Frame (LSF). The LSF is a constructive system built in galvanized cold-formed steel profiles, designed to withstand the building loads and to ensure its operating requirements.

Cold-formed steel (CFS) profiles are increasingly viable for use in construction, given the speed and economy demanded by the market. This structural element can be used in medium sized sheds, roofs, mezzanines, in popular houses and small and medium buildings. In addition, the CFS profiles has a reduced execution time compared to the conventional method and because it is composed of thin sheets, has lightness, ease of manufacture, handling and transport.

In the case of a relatively recent structural system, especially in Brazil, there are not many studies related to this subject. Therefore, it is of fundamental importance, the knowledge of the structural behavior of this system, so that the structure is designed either in a safe, rational and economic way.

In this context, an experimental evaluation associated to a numerical modeling is essential for an analysis of the structures, because it permits to idealize previous responses of stress, strain and deformations that would not be possible before its actual conception.

Given the importance of the insertion of new technologies in civil construction and the need to understand the structural behavior of the employed technique, this study aims to evaluate the structural performance of LSF panels, from an analytical and numerical approach using MEF, when submitted to compression stress. In addition, in this study, the numerical modeling aims to evaluate the contribution of the Oriented Strand Board (OSB) panels associated with the light steel profiles in the resistance to compression of the walls, an aspect not observed in the available bibliography.

For comparison purposes, it was used the experimental results obtained by Nunes (2017) who experimented small walls of LSF with dimensions of 1.20 m x 1.20 m. The experiments were carried out at the Materials and Structures Test Laboratory - LABEME, at the Federal University of Paraíba - UFPB.

2 MATERIALS AND METHODS

2.1 Modeled samples description

The small walls of LSF used in the work of Nunes (2017) were composed of: steel studs, U-channel profiles; Lower and upper tracks, Lipped-Channel type; and braced (on both sides) with OSB, as shown in Figure 1. In Nunes (2017), the Brazilian code NBR 15961-2 was used as a reference for the realization of tests, since there is no Brazilian code for performing compression tests of small walls of LSF.

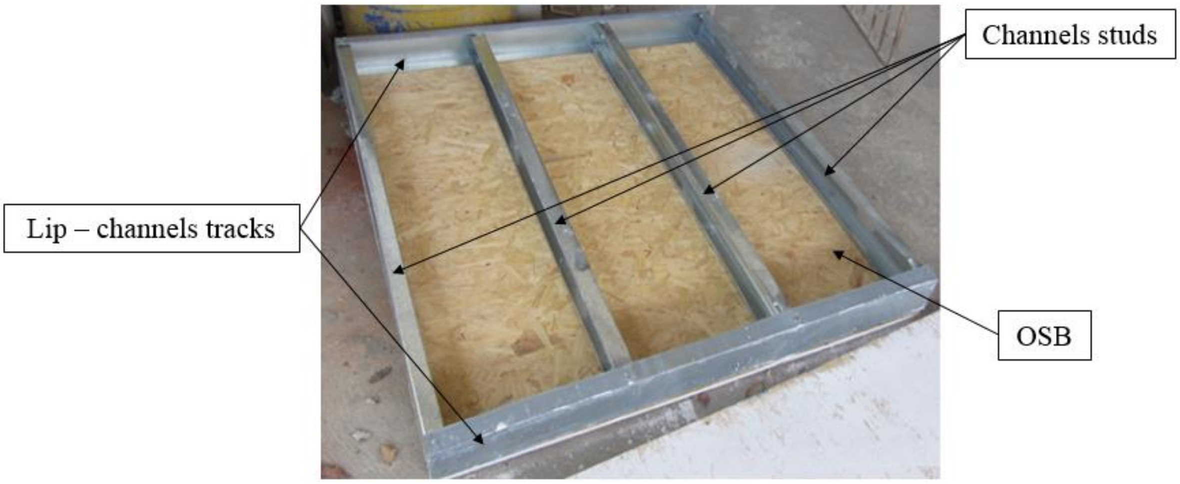

Figure 1. Small LSF wall without one of the OSB covering faces (NUNES, 2017)

2.1.1 Studs and tracks

The employed studs and tracks are titled by the manufacturer as Stud 90 and Track 90, with nominal thickness of 0.95 mm. For these specifications, the distributor's catalog presents the geometry of these components without details, indicating possible variations in dimensions. In order to verify the values presented by the manufacturer and to compare them with those indicated in the normative references their dimensions were checked.

Considering the millimetric variability of the dimensions inherent to the manufacturing process, the geometry used for the cross sections of the thin sheets of the tracks and studs was adopted according to NBR 15253: 2014, for the marketed profiles. Figure 2 illustrates some of the characteristic dimensions used.

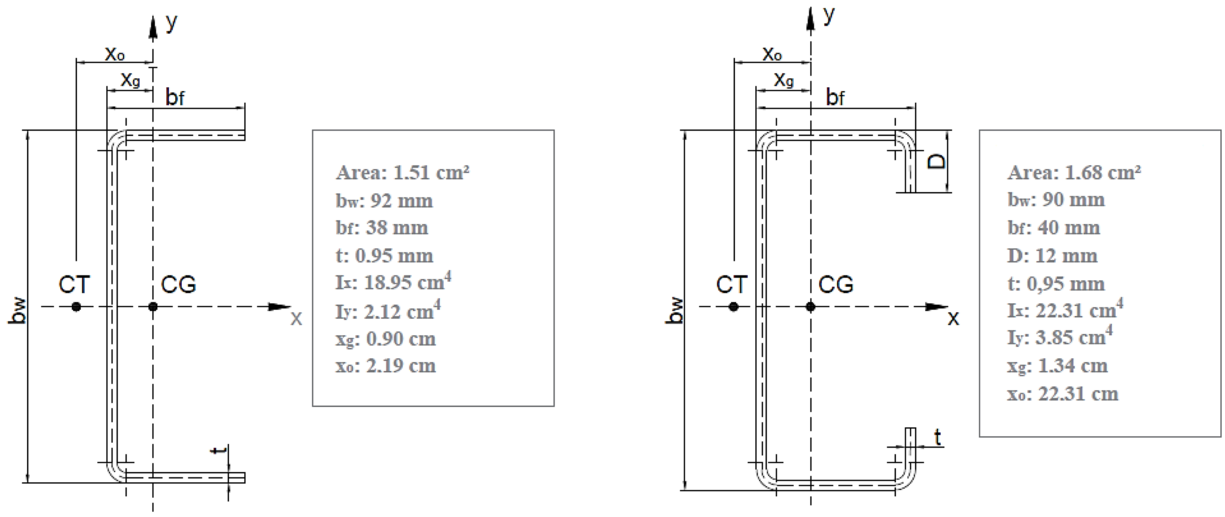

Figure 2. Geometric characteristics of the profiles, tracks and studs, respectively

In the studs of small walls tested there were voids spaced approximately every 52 cm, as in Figure 3, for the passage of electrical and hydraulic installations.

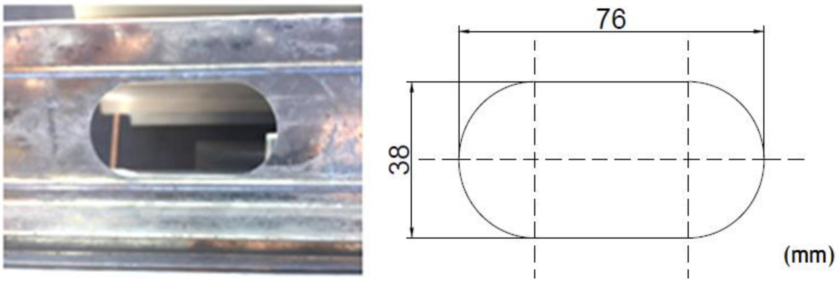

Figure 3. Hole in the stud for passage of electrical and hydraulic installations

As the Brazilian code NBR 14762:2010 - Design of steel structures consisting of cold steel formed profiles – Procedure does not refer to the profile voids, the procedure presented by AISI (2007) was used, in which there is a decrease in the flange size (b_w) of the stud due to the presence of the void. From the calculation script presented in the item B.2.2 of AISI (2007), the reduced value (b_{wred}) obtained was 56 mm.

The material used is a metal coated sheet called ZAR 230, which has 230 MPa of yield strength (f_y) and 310 MPa of rupture strength (f_u), according to the manufacturer's specification. Due to the impossibility of carrying out tests for a better characterization of the steel, the other mechanical properties used are those indicated by code NBR 14762: 2010 for this material. Thus, it were adopted: E = 200000 MPa, ν = 0,3, G = 77000 MPa e ρ = 7850 kg/m³.

2.1.2 OSB panels

OSB panels are marketed in four different thicknesses. In this study, plates with a nominal thickness of 11.1 mm (12 mm, real) were used.

Table 1 shows the mechanical properties used for this material, the values were extracted from the technical report of the material characterization carried out by the Technological Research Institute (IPT) and made available on the manufacturer's website.

Table 1. Mechanical Properties of the OSB Panel.

Mechanical property	Unit	Value
Modulus of elasticity, longitudinal (E_x) and vertical (E_z)	N/mm²	5090
Transverse modulus of elasticity (E_y)	N/mm²	2490
Shear modulus, longitudinal (G_x) and vertical (G_z)	N/mm²	2036
Tranverse shear modulus (G_y)	N/mm²	1131,82
Density (ρ)	N/mm²	6,28
Poisson's ratio, longitudinal (ν_x) and vertical (ν_z)	-	0,25
Transverse Poisson's ratio (ν_y)	-	0,1

The Poisson coefficient and shear modulus data presented in Table 1 are not included in the IPT report. The value of the Poisson coefficient was adopted according to Bevilaqua (2005). The shear modulus was calculated from the latter and the modulus of elasticity.

2.2 General aspects of numerical modeling via MEF

To obtain the results of the analyzes performed in this study, the steps illustrated in Figure 5 were followed.

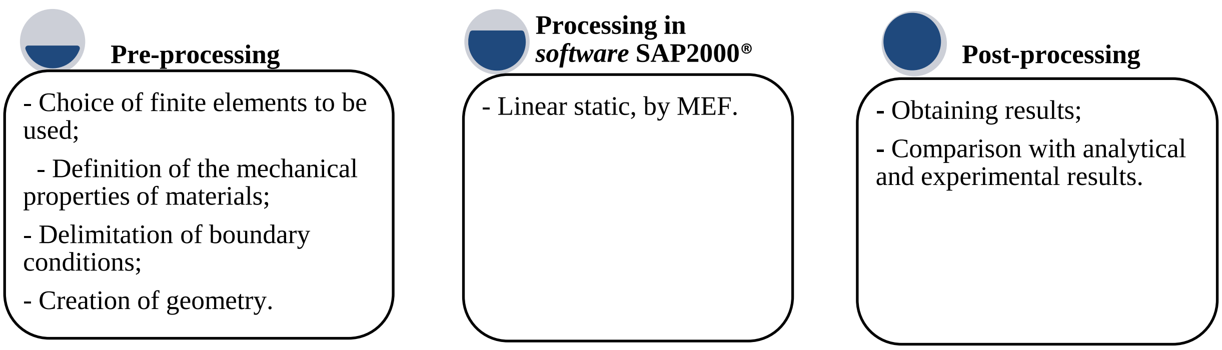

Figure 5. Stages of computational numerical modeling

For the LSF studs and tracks modeling, it was used the element frame, available in the SAP2000® library. According to CSI (2002), The Frame geometry considers axial, bending, torsion and shear strains in the deformations calculation, and can be used to model bars of flat or spatial structures.

In order to characterize the behavior of the OSB panel, the Shell element was used, that is employed in model shells, membranes or plates in flat or spatial structures.

In order to simulate the actual behavior of the small wall during the compression test, the panels were considered simply supported at their bases, pinned at all connections and the top nodes had the displacement constrained in the horizontal direction.

In relation to the geometry adopted, this is in accordance with the average dimensions of the 4 small walls tested by Nunes (2017). The width and height values are equal to 120.73 cm and 119.90 cm, respectively. The studs were equally spaced, being 4 and there were 2 tracks, one upper and one lower. OSB panels covered the entire wall area and had a thickness of 12 mm.

The choice of the stud mesh, represented by the frame element, was verified by means of the critical load of elastic buckling. For an element of homogeneous section, pinned at the ends, Euler calculated the critical load value in 1744. The analysis was performed by discretizing the studs in several elements in order to evaluate which mesh leads to the result that is closer to that obtained analytically.

Considering the error of 0.22% obtained, the mesh of the Frame element of the stud was discretized in 10 elements of 11.19 cm.

For the OSB panel, mesh selection and model validation was performed by means of the comparative analysis of the numerical and analytical responses of the compression stress at the base, from the equation that relates the applied load and the contact area.

In order to compare the results, an arbitrary load was assumed at the top of the wall. To ensure that the load was evenly distributed on the upper and lower surface of the wall, high rigidity beams were included in the model.

Because it is an element with a very small dimensions, high stresses were generated in the OSB, which led to small errors due to the discretization of the mesh. with the 12x12 mesh, (with approximately 10 cm) it were guaranteed errors in the order of 0.035%, demonstrating a satisfactory precision, so that this was the mesh adopted for the model.

2.3 Analytical estimate of responses

The analytical response for the deformations of the small LSF wall was obtained from Eq. (1). Where F is the vertical load that is applied on the central studs, the A_{stud} is the cross-sectional area of the stud and E_{stud} is the modulus of elasticity of the steel. In this study, it was considered the linear behavior of the steel until the yield strength.

For A_{stud}, two values were considered: with and without voids analysis. As mentioned, the calculation of the reduced web size for the analysis of results was obtained in accordance with AISI (2007).

$$\varepsilon = \frac{F}{A_{stud} \times E_{stud}} \tag{1}$$

2.4 Description of the analyzed numerical models

From the methodology presented in item 2.2 of this work, the numerical model of the small wall LSF was developed according to three distinct forms, represented by three cases:

- Case 1: LSF studs with entire cross-sectional area, that is, without voids in the web and without OSB panel (Figure 6.a);
- Case 2: LSF studs with reduced cross-sectional area by the consideration of voids in the web and without OSB panel (Figure 6.b);
- Case 3: LSF studs with reduced cross-sectional area by the consideration of voids in the core and OSB panel (Figure 6.b);

The study of the model with distinct areas (Case 1 and Case 2) aims to verify the influence of the voids in the response, as well as to analyze if the reduction of the size of the amount leads to a conservative analysis.

Case 3 corresponds to a simplified modeling methodology, in which the OSB is inserted between the amounts. This case represents a simplification of the actual model, since in practice the OSB panels coat the steel profiles externally. As in the actual small wall there are two OSB panels, one on each side, in the model, it was inserted with double thickness.

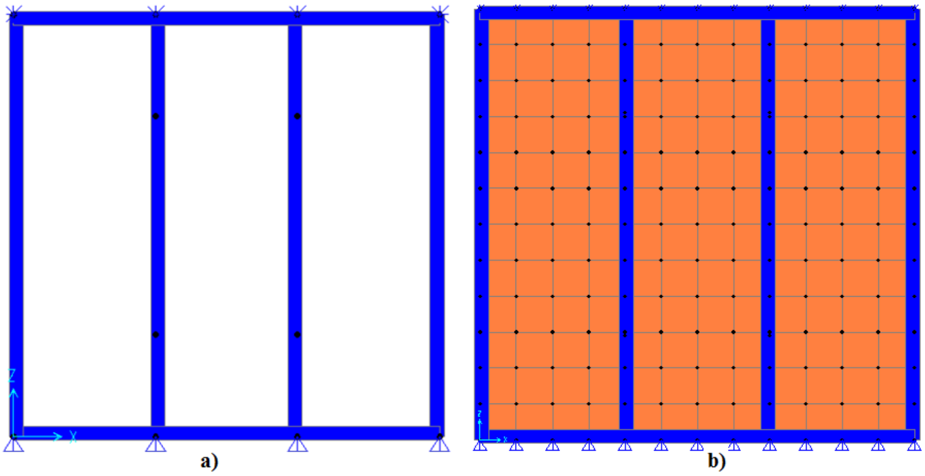

Figure 1. a) case 1 e 2; b) case 3

3 RESULTS AND DISCUSSION

3.1 Experimental work

In the Figure 7, the y axis shows the compression stress in the small walls, in MPa, and in the x axis, they are the strain for LVDT 1 (in blue) and 2 (in red).

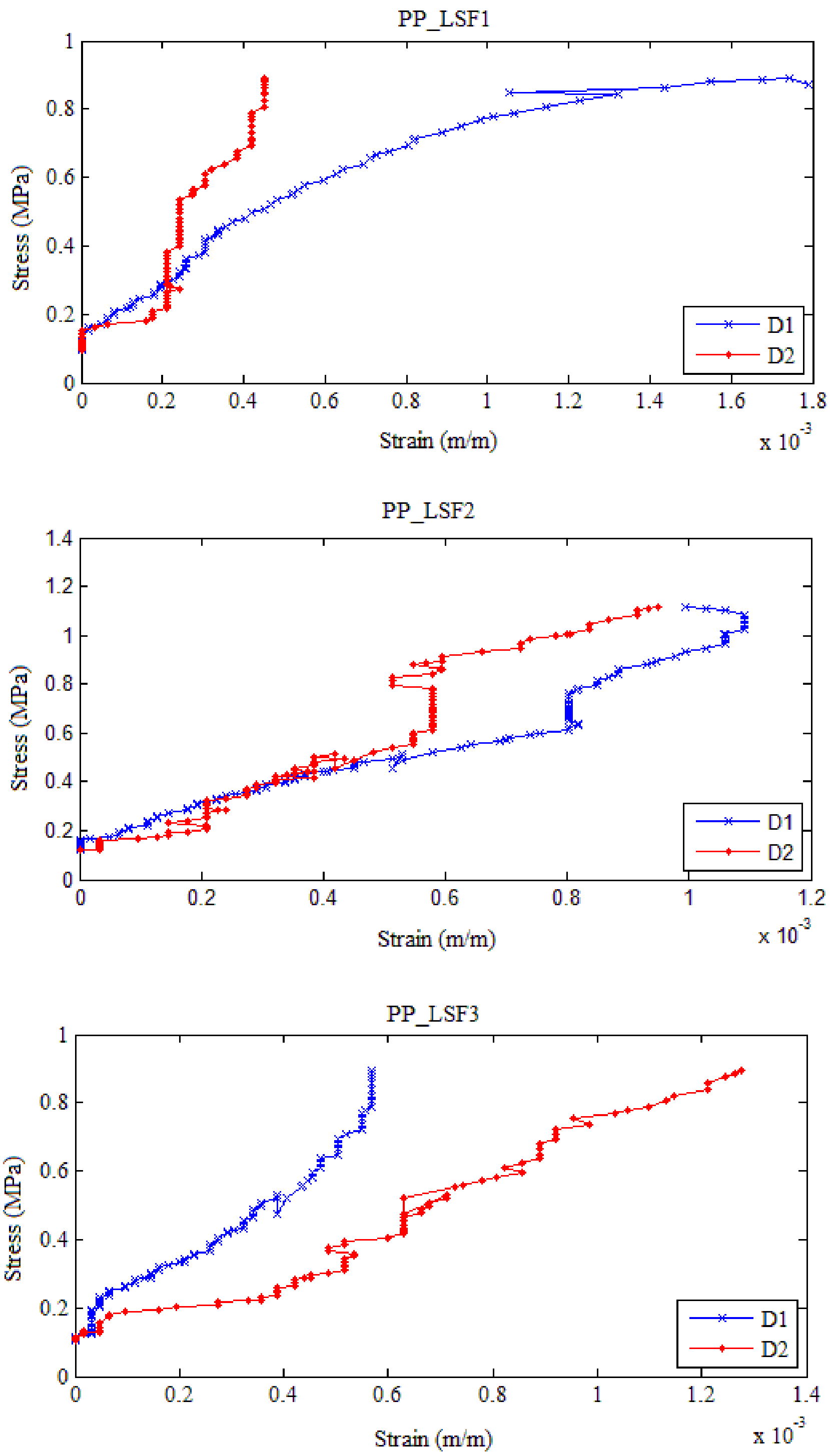

Figure 7. Stress-strain curves experimentally obtained for the small LSF walls (NUNES, 2017)

3.2 Analytical prediction

With the large amount of data collected experimentally, ten values of F load were chosen to compare the results. The maximum value of the load considered in this analysis corresponds to the highest value at which it was possible to obtain deformation data in the experimental test.

The graph of Figure 8 shows the result obtained for the two considered cross sections of studs.

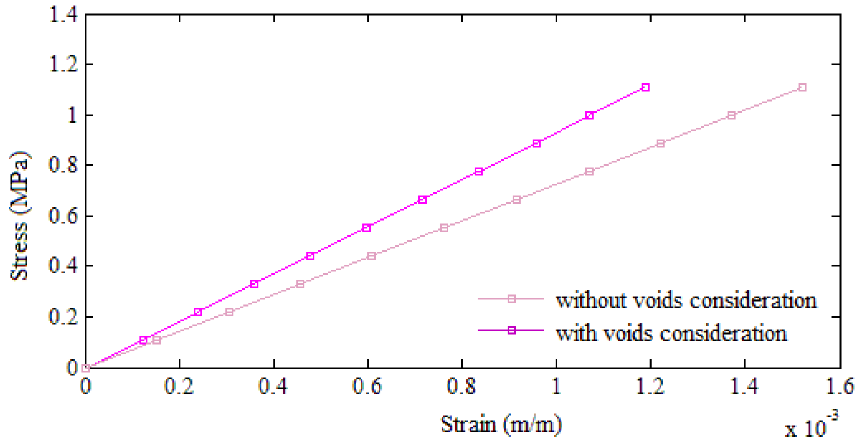

Figure 8. Stress-strain curve of the small wall LSF obtained analytically, with and without consideration of voids in the studs

3.3 Numerical analysis

A numerical solution was obtained through the software SAP2000® and followed the same methodology adopted in the analytical prediction for the applied loads, limiting to ten elements the data sample studied. Figure 9 shows the results obtained.

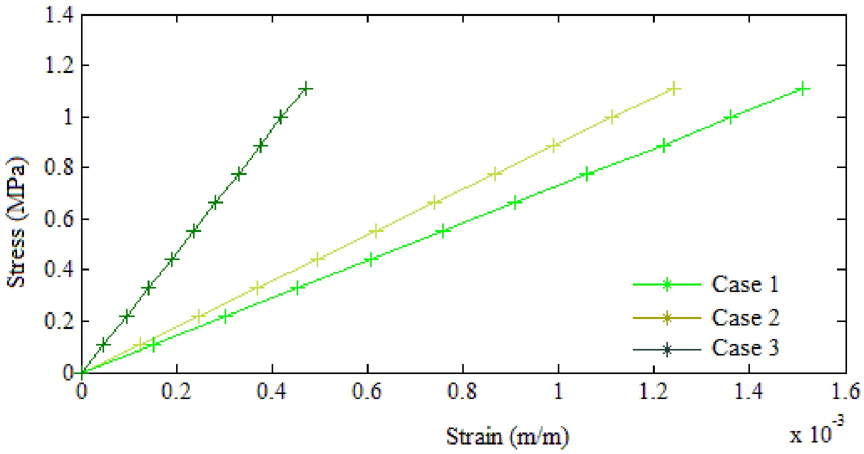

Figure 9. Stress-strain curve of the small wall LSF obtained numerically, with and without consideration of voids in the studs

3.4 Discussion

In order to facilitate the comparison of the obtained data, Table 2 was elaborated, in which the deformations obtained in each analysis are presented, for some values of tension. In this table, ε is the strain; Subscript D1 and D2 refer to LVDTs 1 and 2, respectively; And PP_LSF refers to the small Wall Light Steel Frame. In column 7 to 12 are presented the data collected experimentally.

Table 2. Summary of the results obtained in the analytical, numerical and experimental analyzes.

Stress (MPa)	**Analytical ε Case 1 (10^{-4})**	**Analytical ε Case 2 (10^{-4})**	**Numerical ε Case 1 (10^{-4})**	**Numerical ε Case 2 (10^{-4})**	**Numerical ε Case 3 (10^{-4})**	**PP_LSF1**		**PP_LSF2**		**PP_LSF3**	
						ε_{D1} (10^{-4})	ε_{D2} (10^{-4})	ε_{D1} (10^{-4})	ε_{D2} (10^{-4})	ε_{D1} (10^{-4})	ε_{D2} (10^{-4})
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0,111	1,26	1,53	1,24	1,52	0,477	0,00	0,00	-	-	0,00	0,00
0,222	2,39	3,05	2,48	3,04	0,949	1,19	2,09	1,12	2,05	0,486	3,32
0,332	3,58	4,57	3,71	4,55	1,42	2,53	2,09	2,25	2,41	2,00	5,17
0,443	4,78	6,09	4,95	6,07	1,89	3,39	2,41	4,07	3,75	3,24	6,30
0,554	5,97	7,62	6,19	7,59	2,36	5,22	2,73	6,42	5,47	4,33	7,28
0,665	7,17	9,14	7,42	9,10	2,83	7,29	3,86	8,03	5,79	5,02	8,89
0,776	8,36	10,7	8,66	10,6	3,31	10,1	4,18	8,15	5,79	0,557	10,6
0,886	9,56	12,2	9,89	10,8	3,78	16,7	4,50	9,38	5,68	0,567	12,6
0,997	10,7	13,7	11,1	13,6	4,20	-	-	10,6	7,82	-	-
1,108	11,9	15,2	12,4	15,1	4,72	-	-	10,3	9,33	-	-

From the obtained results, it was verified the convergence between the numerical and analytical values, which presented maximum errors of 4.04% for a tension of 1.108 MPa, in Case 1 and 0.75% for the tension of 0,997 MPa, in Case 2. The margin of error proves that the choice of the Frame numerical element and the 10x10 mesh generated satisfactory results for the geometric and mechanical parameters adopted in the small walls.

By analyzing data from columns 7 to 12 of Table 2, it can be observed that the deformation obtained in LVDTs 1 and 2 presented a certain lag between them, without a constant behavior pattern throughout the test. The differences are possibly attributed to the lack of plumb observed throughout the experimental test. Due to the reduced thickness of the LSF walls, during load application, small displacements of the structure were observed. Still, since they are values of very small order of magnitude, the absolute differences are minimal.

Table 3 presents some statistical parameters of these results. The values that are in the range of variation of deformation obtained experimentally are highlighted in red (column 7).

Table 3. Numerical Strain in Cases 1, 2 and 3 and the range of the experimental results.

Stress (MPa)	**Numerical ε Case 1 (10^{-4})**	**Numerical ε Case 2 (10^{-4})**	**Numerical ε Case 3 (10^{-4})**	**Average (10^{-4})**	**Standard deviation (10^{-4})**	**Interval of variation of experimentally obtained strain (10^{-4})**
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0,222	**2,48**	3,04	**0,949**	1,71	0,996	0,714– 2,70
0,332	**3,71**	4,55	1,42	2,74	1,21	1,54 – 3,95
0,443	**4,95**	6,07	1,89	3,86	1,32	2,54 – 5,18
0,554	**6,19**	7,59	2,36	5,24	1,59	3,65 – 6,84
0,665	**7,42**	9,10	2,83	6,48	1,91	4,57 – 8,39
0,776	**8,66**	10,6	3,31	7,40	2,63	4,77 – 10,0
0,886	**9,89**	12,2	3,78	9,10	4,81	4,29 – 13,9
0,997	**11,1**	13,6	4,20	9,21	1,96	7,25 – 11,2
1,108	12,4	15,1	4,72	9,80	0,665	9,13 – 10,5

It can be concluded that Case 1 presented the greatest convergence with the experimental results obtained by Nunes (2017).

Case 2 generated larger deformations in all the analyzed stresses, which shows that the reduction of the cross section due to the voids, calculated based on the norms of AISI (2007), are conservative, when compared to the actual behavior of the CFS profiles. Although it seems to be a consideration with more refinement of the model, in relation to the small real wall (with voids), the reduction of the inertia that was imposed by the decrease of the length of the web was not equivalent to the reduction of the inertia generated by the presence of the hole.

In a way, this result was expected, since it is a normative recommendation for designing of the studs, in which one takes into account not only the steel yielding, but also all the buckling modes that the profiles can be submitted.

Despite the consideration of the voids were considered conservative for the analysis of axial deformation of the studs, the influence of these on their mode of instability was observed during the experimental tests. These were the weakest points to buckling. From Figure 10, local and distortional buckling of the steel can be observed in the regions near the hole.

Figure 10. Buckling of the stud in the region of the holes

In Case 3, for the different stresses, the strains remained lower than the minimum value of the interval, showing that the simplified modeling methodology (OSB sheets inserted between the amounts and not, outside them, as in practice) Generates a more rigid structure than the real one.

Although the numerical model of Case 1 has presented a satisfactory response in the representation of the real model, it can be highlighted some causes that led to small divergences between the numerical and experimental values:

- Support conditions: despite trying to reproduce, in the numerical model, the restrictions and releases of motion verified on the small wall tested, what is considered is only an approximation of the real situation. This can vary with a number of external factors, such as wall caps, press accommodation and lack of plumb. In the tests, a horizontal displacement of the order 10^{-4} to 10^{-3} was verified, however in the numerical model the top nodes were considered plumb. Another point is that the supports adopted in the model are nodal, while the real support is continuous;
- Characterization of materials: for the steel profiles, the values of the mechanical properties used were those extracted from ABNT NBR 14762: 2010. Although the manufacturer claims that the product conforms to standards, it is necessary to carry out tests to better estimate their values. The same applies to the OSB.
- Possible eccentricities in load application;
- Type of analysis: as in the model the analysis was made considering the geometric linearity, that is, the load was applied on the undeformed structure. The strain, however small, accumulated throughout the experimental test was not taken into account in the model. As the order of magnitude observed for the deformations was very small, this should be a factor taken into consideration.
- LVDT accuracy: As noted, the order of magnitude of strain obtained is 10-4 and 10-5. The accuracy of the appliance is ± 0.01 mm.

4 CONCLUSIONS

With regard to numerical and analytical analysis, from the obtained results, it can be confirmed that these responses presented an acceptable convergence of values, with errors varying between 0.75 and 4.04%.

Comparing the numerical and experimental responses collected by Nunes (2017), it can be stated that:

- For the analysis of the axial strain of the stud, the code consideration of reduction of the cross section (Case 2) ensured conservative results, that is, it generated a more deformable model than the real one. In this way, it is possible to affirm that for analysis of axial deformations it is possible to discard the presence of voids;
- Simplified OSB modeling between the studs led to a behavior contrary to Case 2, generating a more rigid model than the real one;
- Case 1 (small LSF wall with cross-sectional area without consideration of voids) obtained satisfactory answers, with values obtained within the range of the experimental result.

Finally, it is concluded that from the numerical model developed, it was possible to analyze the compressive performance of the LSF panels, comparing the responses obtained with the analytical and experimental solutions (Nunes, 2017), as proposed. Considering the representativeness of the numerical model, it is possible to use it as a basis for further studies.

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