SIMPLIFIED METHODS TO OBTAIN EFFORTS IN THE JOINT LINES OF METAL CONNECTORS OF WOOD TRUSS

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Abstract

This paper presents three simplified methods to obtain the distributions efforts in the joint lines in a wood truss node connected by metal plates fasteners, as function on the efforts transferred by each wooden element to the connection node. Although this verification is simple to solve in cases of simple joint geometries and/or symmetrical loading in relation to the node. The problem becomes complex in cases where the connection is composed of more than one joint line, without axis of symmetry and/or cases in which the loads are not symmetrical in relation to the node. This work aims to verify and compare three methods to obtain the distribution efforts in the joint lines. Method 1 is based on the static balance between the efforts in anchors and their distribution over the adjacent joint lines. Method 2 (fictitious line) was presented to obtain the distributions efforts in the rupture lines from the distribution of efforts into composite lines (ensuring the balance of efforts on the fictitious line and the transmission of these efforts to the various rupture lines). Method 3 (obtaining the distribution by numerical models, in this case the MEF) allows to obtain the distribution along the line(s) for any configuration and composition of this(s), in addition it also allows to introduce the real stiffness of the plate and consequently a more realistic deformation/stress. The checks are carried out through Eurocode 5 EN 1995-1-1: 2004 [1] and through the CSI (Combined Stress Index), which represents the structural efficiency, in order to conclude the veracity of the method.

Keywords

Author Keywords: metal plate fasteners; efforts distribution; fictitious line; breaking lines

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SIMPLIFIED METHODS TO OBTAIN EFFORTS IN THE JOINT LINES OF METAL CONNECTORS OF WOOD TRUSS

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ABSTRACT

This paper presents three simplified methods to obtain the distributions efforts in the joint lines in a wood truss node connected by metal plates fasteners, as function on the efforts transferred by each wooden element to the connection node. Although this verification is simple to solve in cases of simple joint geometries and/or symmetrical loading in relation to the node. The problem becomes complex in cases where the connection is composed of more than one joint line, without axis of symmetry and/or cases in which the loads are not symmetrical in relation to the node. This work aims to verify and compare three methods to obtain the distribution efforts in the joint lines. Method 1 is based on the static balance between the efforts in anchors and their distribution over the adjacent joint lines. Method 2 (fictitious line) was presented to obtain the distributions efforts in the rupture lines from the distribution of efforts into composite lines (ensuring the balance of efforts on the fictitious line and the transmission of these efforts to the various rupture lines). Method 3 (obtaining the distribution by numerical models, in this case the MEF) allows to obtain the distribution along the line(s) for any configuration and composition of this(s), in addition it also allows to introduce the real stiffness of the plate and consequently a more realistic deformation/stress. The checks are carried out through Eurocode 5 EN 1995-1-1: 2004 [1] and through the CSI (Combined Stress Index), which represents the structural efficiency, in order to conclude the veracity of the method.

Keywords: metal plate fasteners, efforts distribution, fictitious line, breaking lines.

INTRODUCTION

The wood used in civil construction has evolved over the years both in its derivative products, in the variety of structural systems and also in the connections that make up its structure. The variety of structural systems has evolved due to the different types of industrialized wood products with the truss system being one of the most used structural systems in residential and industrial roofs [2].

In the production of wooden structures the elements are connected to each other through various types of connectors such as: nails, pins, clamps, screws and metallic connectors [3]. The search for fast construction, large-scale and inexpensive led the industries to develop a connector that would meet this need. Thus in 1954, in the United States a metal plate fastener was developed that facilitated the production of large-scale wooden trusses. These plates are pressed against the wood providing a connection equivalent to a metal plate with multiple nails.

In detailing the calculation of the connections it is necessary to correctly obtain the forces to which each break line is subjected for a correct verification of the resistant capacity of the plate.

These break lines are formed when two or more wooden elements meet. The force and moment acting on the interface generate shear stresses between the facing sheets and the wood (see **Error! Reference source not found.**).

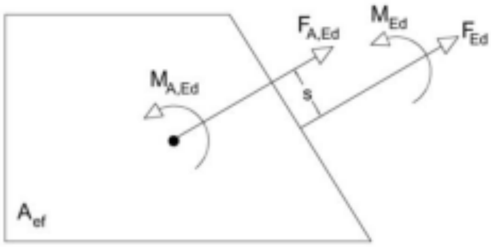


Fig. 1 - Active efforts on the plate

Where, $F_{A,Ed}$ is the force acting on the geometric centre of the plate's anchoring area, $M_{A,Ed}$ is the value of the moment acting on each plate, A_{ef} is the effective contact area of the plate with the wooden element.

Obtaining these stresses on the break lines becomes complicated when the connection is made by bar elements that are not symmetrical in relation to the node axis when the break lines are not perpendicular to each other or when the loads are not symmetrical in relation to the node.

In view of the need for a simple analytical calculation in the procedure for obtaining efforts in the breaking lines in the wooden connections by metal plates since the achievement of these efforts is not possible to be carried out in more complex cases of connections due to the degree of hyperasticity in the balance of efforts, the aim of this article is to develop a simplified method of calculation that can find the efforts in the breaking lines in a truss connection node that has its breaking lines connected by metal plates fasteners, called fictitious line method.

The fictitious line method will be compared with the effort distribution based on static balance and with the effort distribution model obtained through the MIDAS software. Thus the fictitious line method must be validated based on verification in accordance with Eurocode 5 EN 1995-1-1: 2004 [1].

METHODOLOGY

The fictitious line method called in this work method 1, is described in [4] was proposed to obtain the efforts in each stretch of the line of rupture (which is located in the meeting of the wooden elements) from a simplification of the calculations being the transfer of the efforts made from the efforts obtained in the centre of gravity of each anchorage area of the plate.

To find the position of the fictitious line, a geometric centre belonging to the composite line must be calculated which is obtained by averaging the centre of each line in relation to the x and y axes with the length of each breaking line. The coordinates of the geometric centre of the composite line are calculated using Eq. (1) and Eq. (2).

$$x_G = \frac{l_{x1}cl_1 + l_{x2}cl_2}{cl_1 + cl_2} \tag{1}$$

$$y_G = \frac{l_{y1}cl_1 + l_{y2}cl_2}{cl_1 + cl_2} \tag{2}$$

Where, l_{x1} and l_{x2} are the lengths in the *x* direction in relation to the axis from the centre of each line, respectively; cl_1 and cl_2 are the length of the lines; l_{y1} and l_{y2} are the lengths in the y direction in relation to the axis from the centre of each line, respectively.

The angle of inclination of the fictitious line is calculated through the weighted average between the angles of the lines and their respective lengths (see Eq. (3)).

$$\theta = \frac{\theta_1 cl_1 + \theta_2 cl_2}{cl_1 + cl_2} \tag{3}$$

Where, θ_1 and θ_2 are the angles of inclination of the lines in relation to the x axis.

With the coordinates of the geometric centre of the composite line and its slope the fictitious line is inserted into the gravity centre (CG) of the composite line. The total length of the fictitious line is obtained by extending the line until it forms an angle of 90° with the end of each breaking line. The efforts applied to the geometric centre of the plate's anchoring area are transferred to the centre of the fictitious line with the total length of the line divided by two.

Each section of the fictitious line corresponds to a line of rupture. For the value of the efforts to be proportional to the length of each breaking line, a line is drawn from the meeting of the lines of failure to the fictitious line forming an angle of 90° with it. The length of this difference between the new line and the centre of the fictitious line will influence the effort calculation.

The efforts of the centre of the fictitious line are distributed along the sections, in order to find the resulting efforts in each section from them. The normal stress due to the bending moment, the vertical stress and the horizontal stress along the fictitious line are calculated in the Eq. (4), Eq. (5) and Eq. (6):

$$\sigma_M = \frac{4M}{c_{lf}^{\ 2}} \tag{4}$$

$$\sigma_V = \frac{V}{c_{lf}} \tag{5}$$

$$\sigma_H = \frac{H}{c_{lf}} \tag{6}$$

Where M is the value of the moment acting at the centre of the fictitious line; V is the value of the vertical force at the centre of the fictitious line; H is the value of the horizontal force at the centre of the fictitious line; c_{lf} is the total length of the fictitious line.

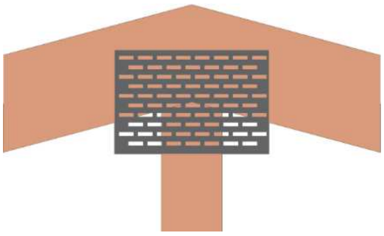
From the calculated stresses and with the length of each section it is possible to concentrate the efforts in the centre of each section of the fictitious line, in order to find the reactions for each line of rupture.

In order to compare the efforts found in the breaking line through the fictitious line have the method 2, in which the transfer of the efforts is carried out through the equations of static balance between the anchoring efforts and the distribution of these by the adjacent breaking lines. Thus, this method is only possible when the lines are symmetrical in relation to the node, when the loads are symmetrical, or when the line of failure is composed of a single line.

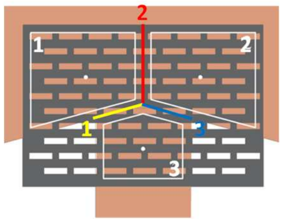
Subsequently, numerical modelling of the rupture lines was performed using the MIDAS software. The purpose of this modelling is to obtain the distribution of the resulting efforts along each line of rupture for the loads applied in the geometric centre of the composite line called method 3 also in order to make comparisons.

In method 3 the respective nodes at the beginning and end of each line are inserted in the software. The nodes are then connected by bar elements (rigid elements) which are independent of the type of material and its section with equal size of lines and slope of the previous methods.

The connection node under study is shown in Figure 2(a). Consists of three wooden elements (two diagonal and one vertical) joined by a pair of metal plates. This node presents three anchoring areas. Area 1 is limited by line 1 (inclined) and line 2 (vertical). Area 2 is limited by line 2 (vertical) and line 3 (inclined). Area 3 is limited by lines 2 and 3 both inclined presented in Figure 2(b).



(a)



(b)

Fig. 2 - (a) Metal plate connected wood truss, and (b) anchorage areas and rupture lines

The anchoring centre of gravity efforts for each area are (see Figure 3):

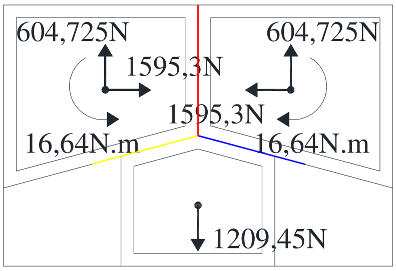


Fig. 3 - Efforts at the centre of gravity of the anchorage area

From the efforts found for each breaking line, it is then possible to verify the resistant capacity of the plate according to Eurocode 5 EN 1995-1-1: 2004 section 8.8 [1] which is based on the determination of the utilization index of the section of the plate in each breaking line being necessary to verify all the rupture lines between the elements. After transferring the forces acting on the geometric anchoring centre to the centre of the breaking line, it is possible to obtain the calculating efforts acting in the x and y directions. The verification of the plate in the rupture line is expressed by the condition described in Eq. (7):

$$\left(\frac{F_{x,Ed}}{F_{x,Rd}}\right)^2 + \left(\frac{F_{y,Ed}}{F_{y,Rd}}\right)^2 \leq 1 \qquad (7)$$

The study of the method was applied in a possible case of transferring efforts through the balance equations to be possible to compare the results.

RESULTS

A fictitious line was calculated for anchorage area 1 the details of which are shown below. From method 1 the fictitious line geometry was calculated using the Eq. (8), Eq. (9) and Eq. (10):

$$x_G = \frac{20.21 \times 43.08 + 41.61 \times 51}{43.08 + 51} = 32.08mm \quad (8)$$

$$y_G = \frac{5.58 \times 43.08 + 36.65 \times 51}{43.08 + 51} = 22.42mm \quad (9)$$

$$\theta = \frac{15 \times 43.08 + 90 \times 51}{43.08 + 51} = 55.67° \quad (10)$$

With the coordinates of the geometric centre of the composite line and with its slope the fictitious line is inserted into the CG of the composite line (see Figure 4).

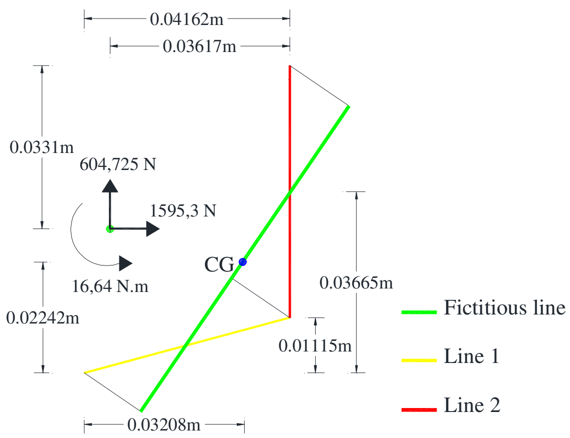


Fig. 4 - Fictitious line for area 1

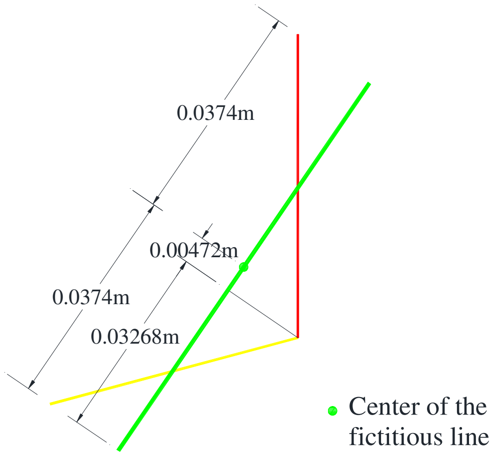


Fig. 5 - Lengths in each section of the fictitious line

The efforts are transferred from the geometric anchoring centre to the centre of the fictitious line and subsequently distributed along it having:

$$\sigma_M = 6.6352 kN/m$$

$$\sigma_V = -8.09 kN/m$$

$$\sigma_H = -21.33 kN/m$$

The section corresponding to line 1 has a length of 0.03268m and the section corresponding to line 2 has a length of 0.04212m (see Figure 5). Subsequently, efforts are concentrated in the centre of each section of the fictitious line.

For method 2 the reactions at break lines 1 and 3 caused from the force at the centre of gravity of the anchorage area 3 were calculated. The reactions are concentrated at the centre of the breaking line (see Figure 6).

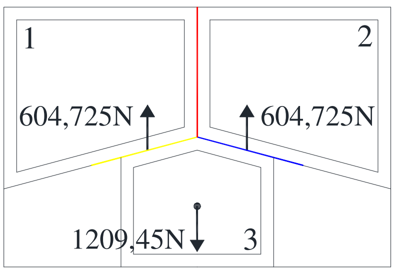


Fig. 6 - Reactions at the centre of breaking lines

Obtaining the stresses on the breaking line 2 in relation to the anchorage area 1 is carried out using the static equilibrium equations between the reaction on the break line 1 and the efforts on the center of gravity of the anchoring area 1 (see Figure 7).

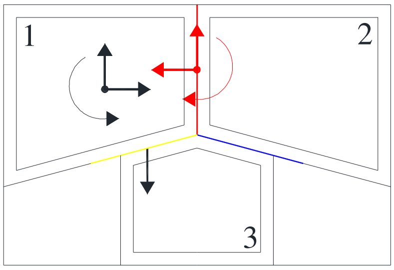
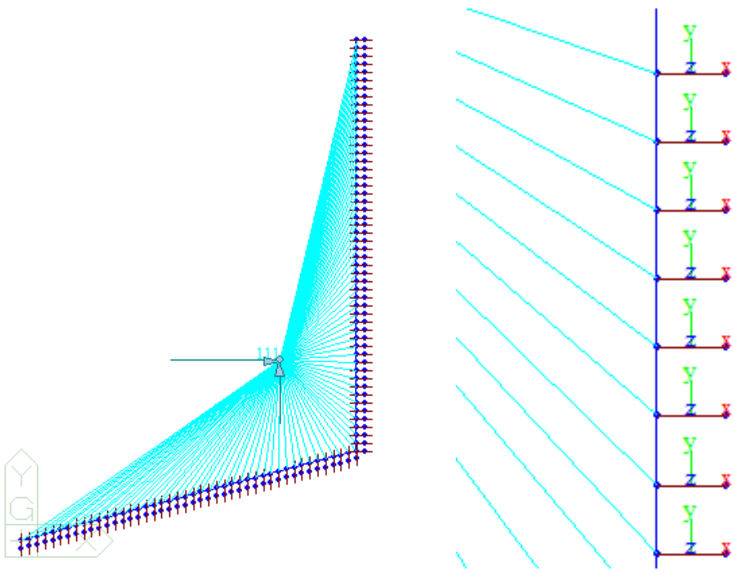


Fig. 7 - Stress at line 2 obtained through static equilibrium equations

The stresses obtained at the centre of line 2 are as follows:

$$V = 0N$$
$$H = 1595.3N$$
$$M = -19.4N.m$$

In method 3 each line corresponds to a member of the bar being divided into nodes. Subsequently, each node was then copied and transferred at a distance of 0.001m from the lines of rupture towards the face of the other anchorage areas. In each transferred node, displacements and rotation in all directions were restricted. The nodes belonging to the rupture line are connected to the nodes that were transferred through elastic limit elements with the used stiffness value being 14.7 N / mm³. The division of the lines into nodes was performed to have a unitary length between them and an equivalent force value for each length. A node was added that represents the geometric centre of the composite line where the equivalent efforts are inserted. This node is connected to the rest in order to restrict the relative geometric movements of a structure. (See Figure 8 (a) and (b)).



(a) (b)

Fig. 8 - (a) Modeling of rupture lines in the software, and (b) zoom on nodes connected by elastic links

After the analysis, the reactions of the initial efforts are given by the software. From the effort distribution for the breaking lines the resulting force between the horizontal and vertical forces at the centre of each line was calculated.

The effort values on line 1, using methods 1 and 3, can be different when looking at different effective areas. For method 2 as the balance of static efforts is performed, when looking at the different effective areas that limit the same line, the value of the efforts in this line of rupture must be the same for the different areas.

The different methods of analysis are compared with the effort's distribution from the centre of anchoring area to the rupture lines.

Table 1shows the results of the efforts obtained by the 3 methods, looking at the anchorage area 1 and consequently the values of the efforts obtained for lines 1 and 2. The CSI value is also show, according to [1] and [5].

Table 1 - Difference between the three methods in the efforts obtained in Line 1 and 2, anchorage area 1 (as a %)

	Area 1 Line 1			Area 1 Line 2		
	Method 1-2	Method 1-3	Method 3-2	Method 1-2	Method 1-3	Method 3-2
V (vertical force)	56.39%	3.49%	62.05%	100%	6.02%	100%
H (horizontal force)	100%	13.49%	100%	48.07%	6.50%	58.36%
M (Moment)	0%	100%	100%	67.68%	61.62%	336.94%
CSI²	68.97%	201.72%	89.71%	22.02%	59.17%	198.88%
CSI	44.48%	73.71%	68.04%	10.61%	36.06%	7.98%

It is observed for this example a proximity between the results of the efforts in methods 1 and 3 for area 1.

CONCLUSIONS

For the three different methods of effort transfer analysed in this work the rupture lines were verified according to Eurocode 5 [1].

The fictitious line method has a simplified methodology that has limitations in its application namely in defining the length of the line and the distribution of efforts along it since it is assumed that there is always a continuous distribution of normal stress due to the bending moment at along the line which may not be in accordance with the actual distribution which may have intermediate variations in the normal stress distribution due to different bending moments resulting from variations in the angles of the breaking lines however when this method is compared with the numerical model which allows to introduce the real rigidity of the sheet and consequently obtain a more realistic deformation the fictitious line method obtained values close to this.

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