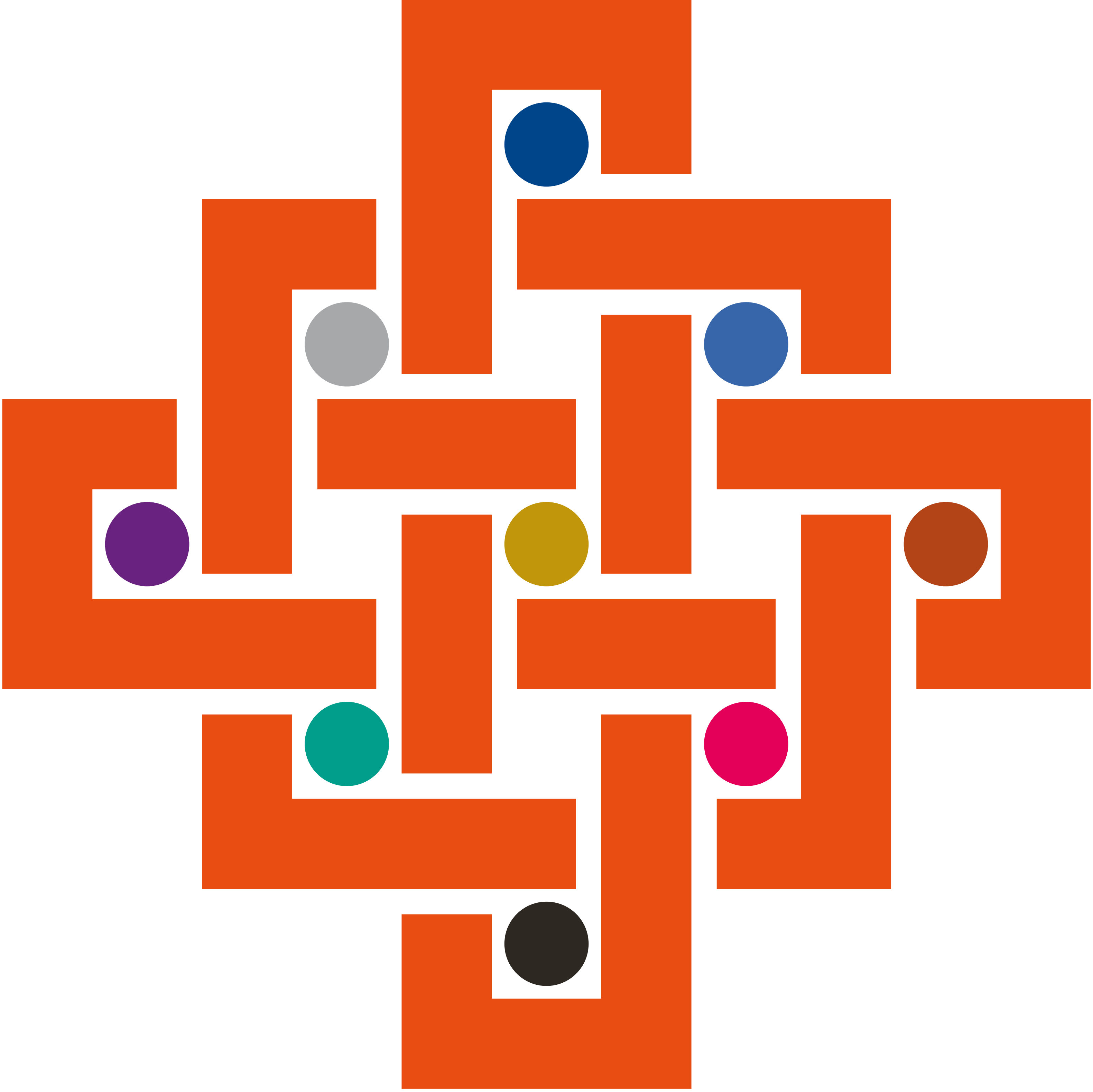

„ЕВРОКОДОВИ-ПОРТА КОН ЕВРОПА“ „EUROCODES-GATE TO EUROPE“

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MACEDONIAN
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19 МЕЃУНАРОДЕН СИМПОЗИУМ
INTERNATIONAL SYMPOSIUM

ОХРИД, С. МАКЕДОНИЈА
OHRID, N. MACEDONIA
27 - 30 април 2022
April, 27th- 30th , 2022

MASE ДГКМ

Macedonian Association of Structural Engineers

Друштво на градежните конструктори на Македонија

Proceedings
Зборник на трудови

19th International Symposium
19ти Меѓународен симпозиум

Ohrid, North Macedonia, 27 – 30 April 2022

Охрид, Северна Македонија, 27 – 30 април 2022

PROCEEDINGS
OF THE 19th INTERNATIONAL SYMPOSIUM OF MASE

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19ТИ МЕЃУНАРОДЕН СИМПОЗИУМ НА ДГКМ

Publisher:
MASE - Macedonian Association of Structural Engineers
Faculty of Civil Engineering, Blvd. Partizanski odredi No. 24 P.Box. 560,
1000 Skopje, Republic of North Macedonia
e-mail: mase@gf.ukim.edu.mk; website: www.mase.gf.ukim.edu.mk

Издавач:
ДГКМ - Друштво на Градежни Конструктори на Македонија
Градежен Факултет, бул. Партизански одреди бр. 24 П.Ф. 560,
1000 Скопје, Република Северна Македонија
e-mail: mase@gf.ukim.edu.mk; website: www.mase.gf.ukim.edu.mk

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e-book:
електронско издание: ISBN 978-608-4510-47-5

19th INTERNATIONAL SYMPOSIUM OF MASE
OHRID, 27 – 30 APRIL 2022
19ти МЕЃУНАРОДЕН СИМПОЗИУМ НА ДГКМ
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Кире СТАВРОВ
ПРОЕКТИРАЊЕ НА ВРСКИТЕ НА ЗАСЕК КАЈ ДРВЕНИТЕ КОНСТРУКЦИИ ПРЕКУ ПРИМЕРОТ НА ТРОНОЖНА ВРСКА

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A COMPARATIVE OVERVIEW OF THE ENERGY PERFORMANCE CERTIFICATE (EPCs) APPLICATION IN SOME EU COUNTRIES

ДГКМ
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STIFENESS COMPARISON OF UNSTIFFENED AND STIFFENED T-JOINTS OF HOLLOW SECTIONS

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ABSTRACT

The following paper is a summary of a research that studies the changes in the stiffness of unstiffened pinned T-joints and the same stiffened. Results of the unstiffened joints are taken from existing research and are also part of bigger study where, additionally the lattice truss's behavior is checked. These pinned joints are reinforced to increase their rotational stiffness and observe the possibility if higher strength class can be obtained. Reinforcement used complies with the Eurocode standard and recommendations. The analysis is performed on models of T-joints where variable thickness are used; size of the chord is constant of 100mm width, while truss's size vary from 40mm to 70mm width. The sections used are square hollow, and the method of reinforcement is by welding a plate on the face of the chord. The type of reinforcement is in relation with the expected failure mode and these unstiffened joints have a geometry with β - ratio of width of the vertical to the width of the chord smaller than 0,85. The analysis of the main model is performed in a software with finite element models. In the same software preliminary studies of the loads are analyzed. Preliminary studies are done not just for calculation of the maximal bending moment a model can bear but also to get information about the expected failure. Joints are loaded with maximal in-plane bending moment. The results are drawn in a form of moment – rotation diagram and table result and compared to results obtained for same unstiffened models. Reinforcement used assumes that all the models comply with chord face failure mode, which is expected for the geometry used for these types of joints. It is concluded that the type of reinforcement is properly chosen since in all models there is an increase of the initial stiffness. Additionally, is summarized that the increase of the stiffness relies greatly of the solidness of the used sections.

Keywords: T-joints; stiffness; hollow sections; steel.

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1. INTRODUCTION

The behavior of a lattice girder greatly relies on its geometry. But this is also related to the stiffness of the joints. While girders with trusses of diagonals and verticals have joints that behave almost always as pins, girders that are consisted of only verticals will have joints with various stiffness. Variations in the stiffness can lead to differences in the deformation but also in the internal forces in the chord. To be able to properly analyze these joints, classification should be done to determine the behavioral expressions. Some of the most used joints especially found in the Virendeel girder are the T-joints consisted of a vertical normally connected to the chord, and usually this connection is done by welding the webs of the vertical toward chord's face. In hollow sections this way easy connection can be executed but depending on the geometry different rotation stiffness will be obtained. The stiffness will greatly rely on the sizes of the connected profiles but also on their thicknesses. With these easy connections the created joints not always will satisfy the needed stiffness and depending on the economic factor either the geometry will be changed, or the joint will be reinforced for the required stiffness to be obtained.

Eurocodes have recommendations for reinforcement, and the choice is done according to the expected modes of failure which again relies on the geometry of the joint. This paper focuses on comparing the stiffness of unstiffened and stiffened T - joints of hollow sections and the usefulness of a reinforcement for different geometry joints.

2. RESEARCH

T-joints are part of the big classification of joints that are covered in Eurocode 3, part 1-8. These joints are in the same family with the X and Y joints, group distinguished by the other for being loaded with a combination of a axial force, bending moment and shear force. When it comes to analytical analysis it is clearly impossible to give conclusions from results where all these internal forces are active. So, it is recommended for research purpose this joints to be loaded only with the bending moment as the most significant force. Generally, they are loaded in-plane and the research is based on this type of loading. Aside, out of plane loading can also occur in some instances.

To reinforce a joint firstly its weakest plate should be indicated, and this is also closely related to the failure modes. Most characteristic modes expected to happen in T-joints are either plastification of the face of the chord or failure of the side walls of the chord. According to the geometry the first can happen in joints where the vertical is small and chords face is wide, while the second will happen when vertical is almost as wide as the chord. Depending on the expected failure different reinforcement will be offered, and the plastification will be avoided by reinforcing the face of the chord while the failure of the side walls will be avoided if the walls are strengthened. Few options can be recommended when reinforcements of the face of the chord is necessary. These reinforcements can vary from simple: plate welded on the face of the chord to more complex like angles that connect the vertical to the chord, haunches, ribs and similar. More complex solutions lead to better results but also to increase in costs.

Beside geometrical classification also strength classification should be performed. The joint can belong to one of the three groups: Pinned – joints that do not develop bending moments; Rigid – joints with insignificant change of original angles between members; Semi-rigid – joints which are assumed to have the capacity to furnish a dependable and known degree of flexural restraint.

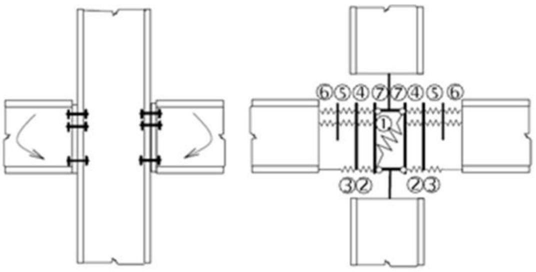
3. ANALYSIS MODELS

This research focuses on the analysis of T-joints classified as pins, whose geometrical factor $\beta \leq 0{,}85$ and factor $2\gamma > 16$. Reinforcement is performed by welding a stiffening plate $\beta p < 0{,}85$ on the face with of the chord what is according to the recommendations of Eurocode 1998, chapter 8, annex E table 7.17. The behavior of these models is compared to the behavior of the same unstiffened models and conclusions about the factors that influence the stiffness are drawn. Analysis models of 12 different geometries are considered divided into three groups of thicknesses. The material is steel S275JR. The welds of each model are one-sided filed weld with thickness same as the thickness of the plates they connect. In all models the used chord is a square hollow section with height/width of 100mm while the verticals are square hollow sections with height of 40mm, 50mm, 60mm and 70mm. Every model has a same thickness of chord and vertical welded to the stiffening plate. This plate has width of 90mm in order to provide nice welding and length that varies of 110mm for the smaller verticals and 115mm for bigger verticals. The thickness of all cross sections is either 6, 8 or 10mm.

Table 1.Model's geometry

Model	chord	vertical	reinforcement
1.1	[]100.100.3	[]40.40.3	≠90.6…110
1.2	[]100.100.3	[]50.50.3	≠90.6…110
1.3	[]100.100.3	[]60.60.3	≠90.6…115
1.4	[]100.100.3	[]70.70.3	≠90.6…115
2.1	[]100.100.4	[]40.40.4	≠90.8…110
2.2	[]100.100.4	[]50.50.4	≠90.8…110
2.3	[]100.100.4	[]60.60.4	≠90.8…115
2.4	[]100.100.4	[]70.70.4	≠90.8…115
3.1	[]100.100.5	[]40.40.5	≠90.10…110
3.2	[]100.100.5	[]50.50.5	≠90.10…110
3.3	[]100.100.5	[]60.60.5	≠90.10…115
3.4	[]100.100.5	[]70.70.5	≠90.10…115

The analysis is performed in software IDEA StatiCa which is FEM software that works on component-based philosophy (CM) which solves the joint as a system of interconnected items – components. Each component is checked separately using corresponding formula derived from the codes. To avoid the generality of the component-based method the internal forces in the components are calculated by FEA. Elastoplastic behavior with hardening of the material is considered. The welds are designed as a multipoint constraint that relate the finite element nodes of one plate edge to another. This way of modeling is conservative and leads to the fact that the resistance of the weld along the length will rely on the stress peaks that appear at the end of plate edges, in corners and rounding. To eliminate these effects, a special elastoplastic element is added between the plates that redistributes the stress peaks along the length of the weld and real values are obtained.



1 – column web in shear, 2 – column web in compression, 3 – beam flange and web in compression, 4 - column flange in bending, 5 – bolts in tension, 6 – end plate in bending and 7 – column web in tension.

Fig. 1. Component method explained

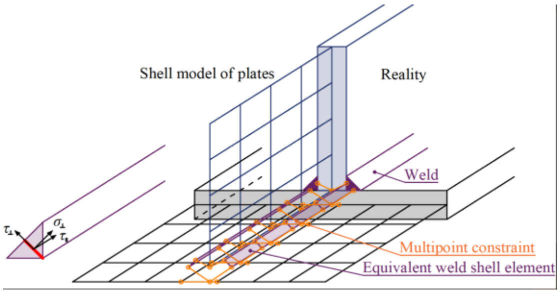


Fig. 2. Multipoint constraint weld model

With a focus on the main models, necessary parameters and information, a preliminary analysis is performed for the initial moments in the joints. These moments are results of a design capacity calculation, where one of the elements, in this case the vertical is loaded with bending moment in appropriate direction with intensity of 1kNm. The finished analysis gives information about a factor with which when this 1kNm is multiplied value of the limiting bending moment the joint can take will be obtained. Also, information about the weakest part in the joint will be provided and can be seen where the failure will happen. The design resistance module will give information about the stresses and the strain in the plates of the elements. Although the initial stiffness does not depend on the value of the external moment, it is good to have this value for results of the secant stiffness and possibility of a joint belonging to the nonlinear behavior zone. In this study this was not the case for any of the joints.

Main models are added in the software with their most important features like the geometry of the joints, (sections and angles); the analysis member is indicated as analyzed (this is the vertical) and also loaded with the proper bending moment; and for classification of the rigidity the theoretical length of the elements is inputted. The analysis is performed in iterations where the bending moment is incrementally applied in the joint. The finished analysis besides the initial stiffness will also provide information about joints ultimate resistant moment $M_{j,Rd}$, the ultimate plastic moment of the cross section of the analyzed member or the vertical $M_{c,Rd}$, value of the secant stiffness $S_{j,s}$, rotation deformation and rotational capacity φ and $φ_c$, boundary where rigids start $S_{j,R}$, boundary where pins end $S_{j,P}$ and class of joint. The results are given in table but also on a diagram with curve of the correlation ‘moment – rotation’ or short M-φ. Behavioral difference between the model also can be spotted on the diagrams.

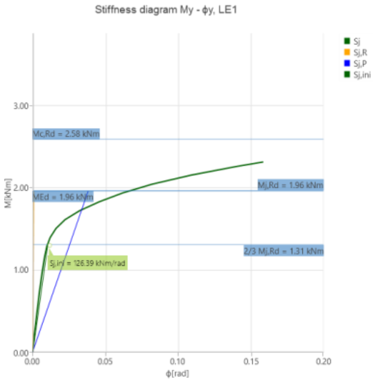


Fig. 3. M-φ curve for behavior of stiffened model 1.2. with vertical of SHS50.50.3

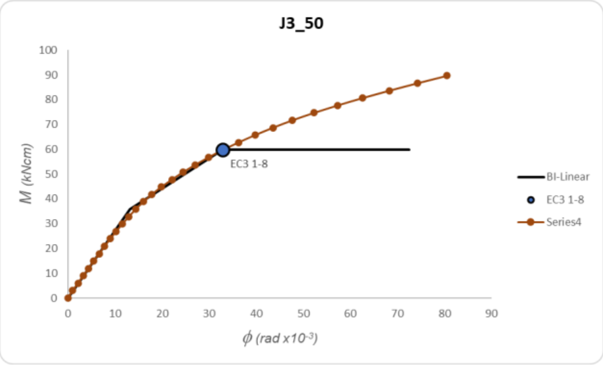


Fig. 4. M-φ curve for behavior of unstiffened model 1.2. with vertical of SHS50.50.3

4. RESULTS

Best results in the increase of the stiffness are registered in the model 3.1 with truss of 40mm width and thickness of 5mm while smallest increase happens in model 1.4 model with widest truss of 70mm and smallest thickness of 3mm. This increase is also significant in models 1.1 and 2.1 all with truss width of 40mm. This is also the case with the models with truss of 50mm width, but in wider verticals of 60mm and 70mm the increase is smaller. On the other hand, model with thicker verticals display greater increase in the stiffness compared to the thinner. By comparing the diagrams of unstiffened and stiffened joint can be assumed that the reinforced joints display smaller changes in the rotation. Also, the angle between the horizontal and the M-φ curve is bigger compared to the unstiffened ones.

Model	Stiffness increase	Increase in %
1.1	6.546547	655%
1.2	4.644983	464%
1.3	3.817177	382%
1.4	2.806147	281%
2.1	10.05679	1006%
2.2	6.271469	627%
2.3	4.97079	497%
2.4	3.851519	385%
3.1	22.87078	2287%
3.2	9.35701	936%
3.3	5.88871	589%
3.4	4.966853	497%

Table 2. Stiffness difference after applying reinforcement

Model	**Sj,P** [kNm/rad]	**Sj,R** [kNm/rad]	**Sj,ini** [kNm/rad]
1.1	24,47	1223,25	87,20
1.2	51,19	2559,38	126,39
1.3	92,14	4606,88	106,89
1.4	150,94	7546,88	333,23
2.1	29,14	1456,88	281,59
2.2	62,21	3110,63	308,18
2.3	114,45	5722,50	435,64
2.4	189,26	9463,13	672,09
3.1	35,18	1758,75	1083,16
3.2	70,88	3543,75	756,14
3.3	132,56	6628,13	912,22
3.4	222,08	11103,75	1288,65

Table 3.Class boundaries and initial stiffness

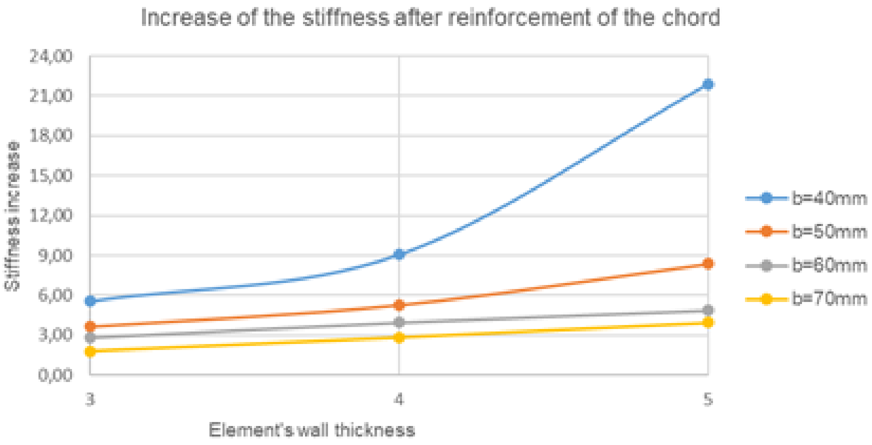


Fig. 5. Diagram of the relation element's wall thickness – stiffness increase after reinforcement

Comparing the concentration of the stresses can be seen that the stresses are still very much concentrated in the face of the chord in the models with 3mm thickness. Graduation of the thickness will start moving stress concentration from the chord towards the vertical and in the last model with 5mm can be seen that it is completely located in the vertical. While this is the case in the models with small vertical in the models with big vertical this movement of the concentration of the stresses due to the change of the thickness is going slower and as seen on the figures even in the models with thickness of 5mm the stresses are still located in the chord.

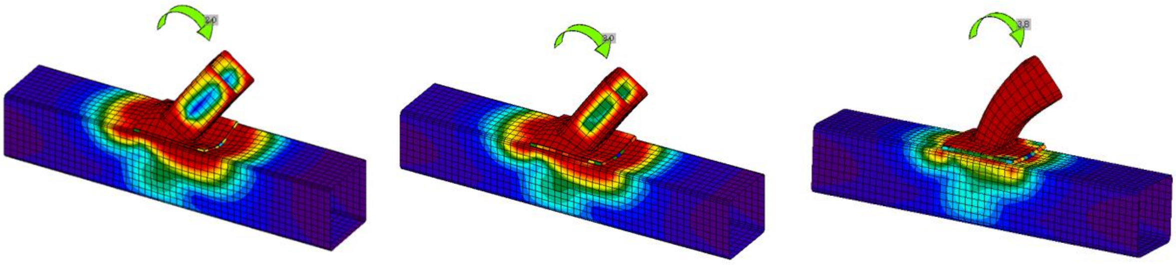


Fig. 6. Stress concentration in models with vertical of SHS50.50 and thickness 3,4,5 respectively

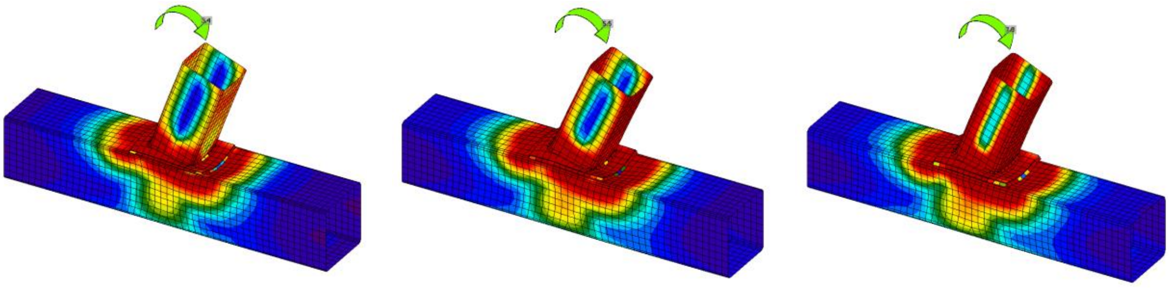


Fig. 7. Stress concentration in models with vertical of SHS70.70 and thickness 3,4,5 respectively

5. CONCLUSION

General conclusion is that after reinforcement, in all models of joints an increase of the stiffness will occur meaning that the assumption of plastification of the face of the chord is correct. This also applies to the class where all the reinforced pins will graduate to semi-rigid joints after reinforcement. But in none of the models, rigid class is obtained leading to a conclusion that other factors must have considerable influence on the stiffness of a T-joint.

The benefit of the reinforcement is greater in the models with thicker walls and smaller size vertical.

First two statements lead to a conclusion that the effects of thin-walled elements which persist after reinforcement of the chord will influence the general stiffness of the global system. Since in all models same size for the chord is used this behaviour can be associated with the cross section of the vertical/ the truss.

Models with large sized verticals don't have rapid increase of the stiffness like the small sized. The reason for this can be related to the value of β ratio and its limits; models with bigger vertical give values of β closer to the boundary of 0,85 which indicates that although their primary mode of failure is plastification of the chord they are also influenced of the side wall failure specific for models with β ratio bigger than 0,85.

T-joints with smaller sized verticals depict more drastic increase of the stiffness with the increase of their wall thickness, while this is not the case with the joints with wider verticals. It can be concluded that an increase of 1mm thickness makes significant difference of the ratio width to thickness of the vertical which leads to thicker cross sections, while this increase is not that remarkable in the big sized cross sections of the vertical. This also confirms the theory that the stiffness is greatly influenced by the thin-walled effects of the cross sections used.

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