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FACULTY OF MECHANICAL ENGINEERING IN NIŠ

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MECHANICAL ENGINEERING IN XXI CENTURY

PROCEEDINGS

Niš, April 19 - 20, 2018

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PREFACE

More than half a century of tradition, high standards in education of generations of students, modernly equipped classrooms, professional teaching and associate staff, their references and recognisability, position the Faculty of Mechanical Engineering, University of Niš, as the leader in the field of engineering sciences and technologyical sciences, not only on the territory of the Republic of Serbia, but also in the wider region of the Western Balkans.

The proceedings of the 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** appear in the year when the Faculty of Mechanical Engineering, University of Niš, celebrates its fifty eighth anniversary. The Department of Mechanical Engineering of the Faculty of Engineering in Niš was founded on May 18, 1960, and it developed into the Faculty of Mechanical Engineering of the University of Niš in 1971. The Faculty of Mechanical Engineering grew intensely, thus becoming one of the most renowned scientific and educational institutions in the country.

The mission of the Faculty is to organize and conduct academic study programmes and to develop and perform scientific and professional work in the field of engineering sciences and technology. Its vision is to be recognisable in the European and global academic environment in the areas of mechanical engineering and engineering management.

More than 100 teachers and associates, around 45 members of non-teaching staff, as well as numerous teachers and associates from other faculties and from the industry, are working hard every day to accomplish the mission and vision of the Faculty.

The Faculty of Mechanical Engineering, University of Niš, is accredited in compliance with the Law on Higher Education within the scientific and educational field of engineering sciences and technology. It conducts the academic studies of the first degree – undergraduate studies, the second degree – master academic studies, and the third degree – doctoral studies, within the scientific area of mechanical engineering and engineering management.

The Faculty of Mechanical Engineering is a scientific research institution, in addition to being an educational one. There are 11 international scientific research projects within the framework of FP7, TEMPUS, CEEPUS, DAAD, bilateral and cross-border programmes, as well as 24 national scientific research projects, being implemented at the Faculty this year. The participation of teachers and associates from the Faculty in these projects is of utmost importance for their educational and research work and their further career.

The 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** represents a forum for the presentation of latest results, basic and developmental research and application within the topics of:

- Energetics, Energy Efficiency and Process Engineering,
- Mechanical Design, Development and Engineering,
- Mechatronics and Control,
- Production and Information Technologies,
- Traffic Engineering, Transport and Logistics,
- Theoretical and Applied Mechanics and Mathematics,
- Engineering Management,
- Future of work, engineering and professional ethics in the era of globalization.

The Conference will also host the assembly meeting of Serbian Association for the Promotion of Mechanism and Machine Science (SAToMM), as well as the meeting of the National Science Board for Mechanical Engineering and Industry Software, will be held.

One hundred and eight papers, whose authors come from 10 countries, are published in these Proceedings. The papers present the research results of numerous projects financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, as well as the research results within international projects.

The main goal of the Conference is to bring together researchers from scientific and industrial institutions so that they can present and communicate their newest results, create personal contacts, promote research within the area of mechanical engineering, and stimulate the exchange of results and ideas within the fields encompassed by the Conference.

As Dean of the Faculty of Mechanical Engineering in Niš, I am honoured to greet all participants of the Conference and wish them very successful work.

Dean of the Faculty of Mechanical Engineering,
University of Niš

Prof. Dr Nenad T. Pavlović

Niš, April 2018

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FEM Analysis of Welded Joints

Stefan OGNJANOVIĆ, Vladimir MILOVANOVIĆ, Miroslav ŽIVKOVIĆ

Faculty of Engineering University of Kragujevac, Kragujevac, Serbia
ostefanmf.kg@gmail.com, vladicka@kg.ac.rs, miroslav.zivkovic.mfkg@gmail.com

***Abstract*— The paper presents a comparative analysis of the welded joints numerical analysis results that resulted from different methods of modeling. The aim of the paper was to determine which of the methods considered is the most suitable from the aspect of modeling speed, and the relevance of numerical results. For the verification of numerical results, T specimen is a compound of simple geometry in order to make it easier to compare and analyze the obtained results. The welded joints were modelled with 3D solid elements and shell elements. Four models were analyzed and the results were compared. On the basis of the deductions made, the guidelines and directions for future research have been developed. The paper represents a good basis for future research in the solution of complex problems in the FEM analysis of welded joints.**

***Keywords*— Stress, deformations, FEM, welded joints, T-specimen**

I. INTRODUCTION

Welding has a wide and highly diverse application in mechanical engineering and other industrial branches. It enables the production of machine parts and complete structures by joining parts of different shapes. All welded structures and elements are exposed to different type of loads that can be static or dynamic. The most powerful and widely used tool for numerical simulations of welded structures and their parts is Finite element method (FEM) [1]. This paper describes in detail the comparative analysis of different techniques of FEM modeling welded joints, in order to save time and money in modeling them.

The T specimen of simple geometry was used as example for comparative analysis. The T specimen of simple geometry were modelled with four different techniques. 3D eight-node elements and 2D four-node shell elements were used for FEM modeling. All four models were analyzed and the obtained results were compared with each other in order to find as efficient and more precise methods of modeling welded joints.

II. TECHNIQUES FOR MODELING WELDED JOINTS

In order to increase the accuracy of the estimation of the value of the stress and the time of modeling of welded joints, a number of modeling techniques have been developed [2] [3]

A. *Modeling welded joints with 3D elements*

In solid element models since the geometry and stiffness the simplest way for creating finite element mesh of welded is using 3D elements (Figure 1). Due to uniformity, it is always easier for FEM model to be made all of 3D elements. Sometimes some complex FEM model of welded constructions contains combination of 3D and shell elements. In that cases it is necessary to introduce a technique for connecting shell elements and 3D elements to transfer the bending point from shells to the 3D elements of the model. One of the methods is to connect the elements of the MPC (Multi Point Constraint) equations. This method provides the equations with which the rotation from shell elements are transferred to 3D elements.

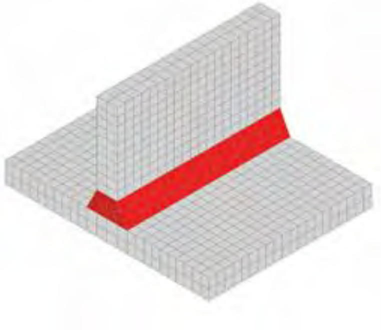

Fig. 1 Modeling welded joints with 3D elements

Modelling of the welds with shell elements require some modelling effort. In shell element models the stress value at welded regions can be dependent on the weld modelling technique. Recently several weld modelling techniques were developed to decrease the modelling work effort and also to increase the accuracy of representing the stiffness of welds.

B. *Modeling welded joints with cross-shell elements*

The finite element mesh of thin-walled structures is most often created by shell elements, where the welds in the zones of welded joints are modelled with cross shell elements [4]. This modeling technique provides the ability to fully represent the geometry and strength of welded joints. For example, the modeling of the T specimen with the cross-shell elements is shown in Figure 2

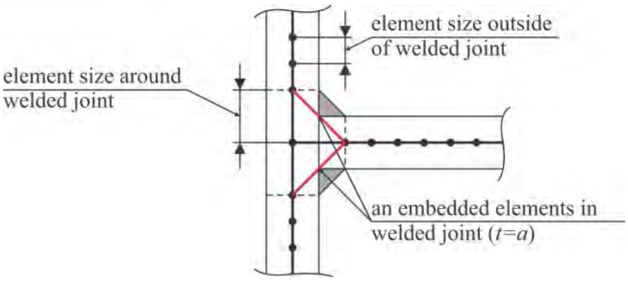

Fig. 2 Modeling of welded joints with cross-shell elements [5]

The length and thickness of cross-shell elements depend on the geometry of the weld and the height of the root of the welded joint. This modeling technique requires a very precise creation of a mesh that fully follows geometry. The stress values obtained in this way can be used with high reliability for cracks calculations at the root of the welded joint. For this reason, this technique is most useful for estimating fatigue failure at the tips of welded joints.

C. Modeling welded joints with rigid links

The modeling of welded joints with rigid links is first encountered in literature [6]. The aim of the development of this technique is to better determine the concentration of the stress in the top of the welded joint. In accordance with this technique, the stress at the top of the welded joint can be read directly in the center of gravity (Figure 3). The basis of this technique is to model local stiffness in a welded joint as a result of the weld itself. This local stiffness as a result of welding can be modelled by connecting adjacent shell elements to rigid bonds, which are defined by pairs of nodes along the entire welded joint. The size of the elements E1 and E2 (Figure 3) should be defined so that, together with the rigid links, they represent real local stiffness due to welding and in this way the relevant stress values are obtained for further analysis.

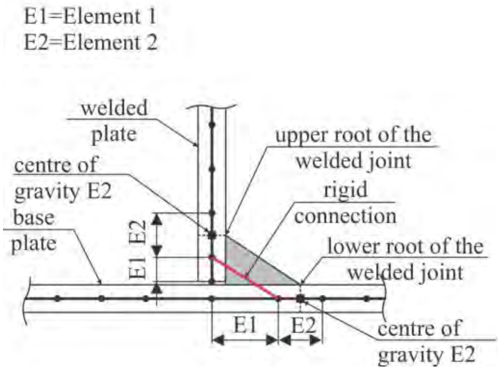

Fig. 3 Welded joint made on one side modelled with a rigid links [7]

III. MODEL SETUP

The sample on which the static load test was done is the T specimen/piece with dimensions shown in Figure 4. The T specimens was made by welding two plates with 10mm of thickness.

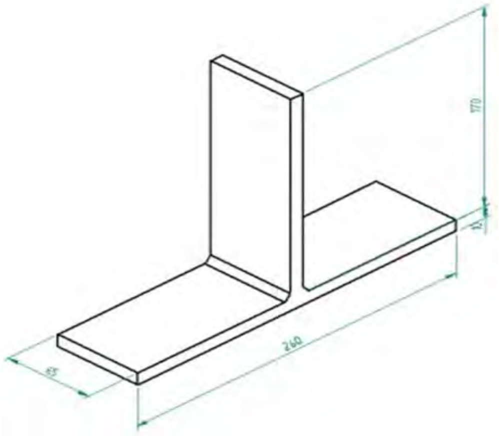

Fig. 4 Geometry and dimensions of considered T specimen

For numerical research, four FEM models of the T specimen were made. The boundary conditions are set so that the ends are fixed in all six degrees of freedom and the vertical plate is loaded with tension force. Figure 5 illustrates two of the four models of the finite element mesh. The size of the elements in the models is equivalent to the value of 0.5t where t represents the plates thickness. In Figure 5, constraints and loads for corresponding FEM models are given.

For all FEM models linear static analysis were performed. Steel for welding 300W with material characteristics (Tensile strength 300 MPa, density 7850 kg/m^3, 206 GPa Young Modulus and 0.33 Poisson ratio) is used for both plates.

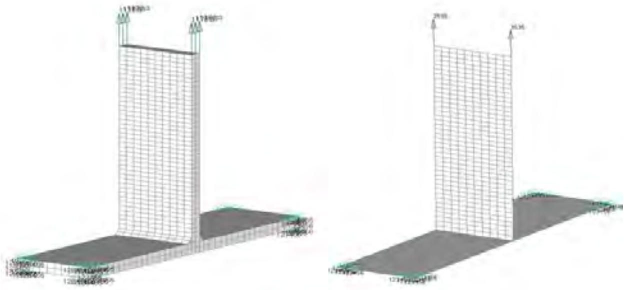

Fig. 5 FEM model with 3D 8-node elements and model with 4-node shell elements

The structural analysis was done using finite element model created in software Femap and NX Nastran [8]. According to corresponding boundary condition and load, strength calculation of considered T specimen was done for four models of the finite element mesh. All models with relevant results of the analysis will be presented in this paper.

IV. CALCULATION RESULTS

A. Welded joint modelled with 3D eight-node elements

In this case finite element mesh of all model, as welded joint, modelled with 3D 8-node elements. Figure 6 shows field of von Mises equivalent stress of FEM model with 3D 8-node elements.

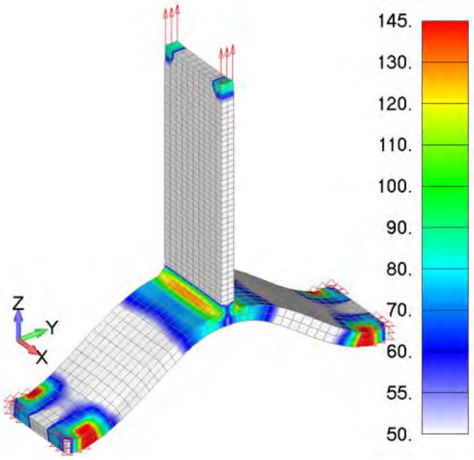

Fig. 6 Von Misses equivalent stress field – 3D eight-node elements – deformed configuration

Table I shows the results of the group of elements (10 elements) at the place of considered welded joint of T specimen for Solid von Misses equivalent stress and Solid X and Y normal stress. Because of symmetry further in the Tables stress values will be shown only for 5 elements.

TABLE I CALCULATION RESULTS - MODEL WITH 3D 8-NODE ELEMENTS

Solid Von Misses Stress	Solid X Normal Stress	Solid Y Normal Stress
152.31	18.32	162.76
147.19	39.22	176.21
144.19	52.72	178.75
143.58	59.45	180.83
143.53	62.21	181.85

B. *Welded joint modelled with cross-shell elements*

In this case, plates with corresponding thickness were modelled with shell elements, where the welded joint was modelled with cross shell elements. The aim of modeling a welded joint with shell elements, as well as other techniques, is to obtain the best and accurate results Based on the static analysis, obtained Von Misses stress field when welded joint was modelled with cross-shell elements is shown in Figure 7.

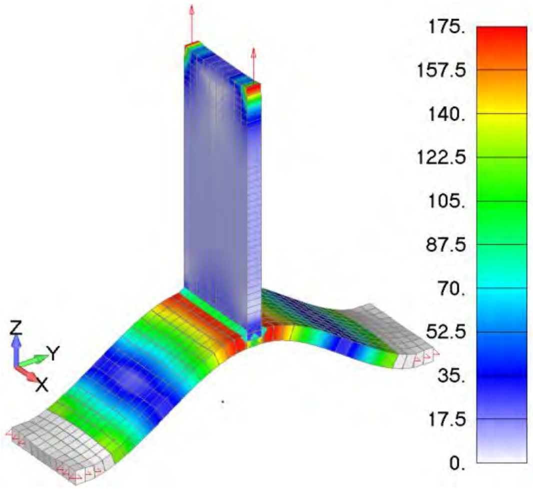

Fig. 7 Von Misses equivalent stress field – Cross-shell elements – deformed configuration

Table II shows the results of the group of elements (10 elements) at the place of considered welded joint (modelled with cross-shell elements) of T specimen for Plate von Misses equivalent stress and Plate X and Y normal stress.

TABLE II CALCULATION RESULTS FOR WELDED JOINT MODELLED WITH CROSS-SHELL ELEMENTS

Plate Von Misses Stress	Plate X Normal Stress	Plate Y Normal Stress
156.23	211.58	5.60
150.33	169.34	17.07
145.45	166.40	21.17
144.15	159.11	22.73
143.89	156.03	23.53

C. *Model without modelled welded joint*

This model did not have a modelled welded joint, only plates with corresponding thickness were modelled with shell elements. The aim was to examine the behavior of the shell elements in the case where the welded joint is 'ideal', i.e., there isn't weld toe. Based on the static analysis, obtained Von Misses stress field without modeling welded joint is shown in Figure 8.

Table III shows the results of the group of elements (10 elements) at the place of considered welded joint (model without welded toe) of T specimen for Plate von Misses equivalent stress and Plate X and Y normal stress.

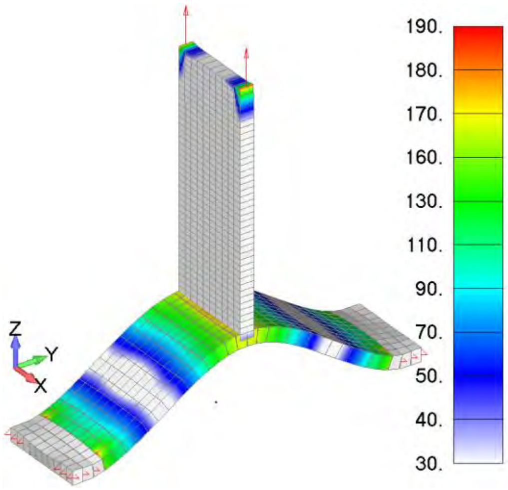

Fig. 8 Von Misses equivalent stress field – model without welded toe – deformed configuration

TABLE III CALCULATION RESULTS FOR MODEL WITHOUT WELDED TOE

Plate Von Misses Stress	Plate X Normal Stress	Plate Y Normal Stress
164.02	166.46	5.46
158.76	167.04	17.99
155.53	167.93	30.73
154.89	169.85	39.16
154.96	171.04	43.18

D. *Welded joint modelled with rigid links*

The last case of testing, in this paper, is the examination where plates with corresponding thickness were modelled with shell elements and welded joint is presented as a rigid links between the elements of the horizontal and the vertical plate. In modeling the welded joint using this method, the MultiLinks option was used. Figure 9 shows field of von Mises equivalent stress of FEM model where welded joint is modelled with rigid links.

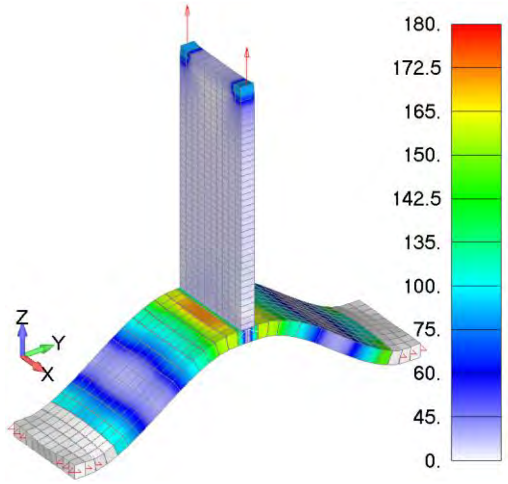

Fig. 9 Von Misses equivalent stress field - Rigid links elements – deformed configuration

Table IV shows the results of the group of elements (10 elements) at the place of considered welded joint (modelled with rigid links) of T specimen for Plate von Misses equivalent stress and Plate X and Y normal stress.

TABLE IV CALCULATION RESULTS FOR WELDED JOINT MODELLED WITH RIGID LINKS

Plate Von Misses Stress	Plate X Normal Stress	Plate Y Normal Stress
150.80	168.14	23.00
147.27	174.96	36.75
143.39	183.98	46.02
142.95	188.36	51.12
142.97	190.24	53.40

V. COMPARATIVE ANALYSIS OF THE OBTAINED RESULTS

According to obtained calculation results for all four cases – four FEM models comparative results for von Mises equivalent stress values and node displacements value for considered groups are shown in Figure 10 and Figure 11, respectively.

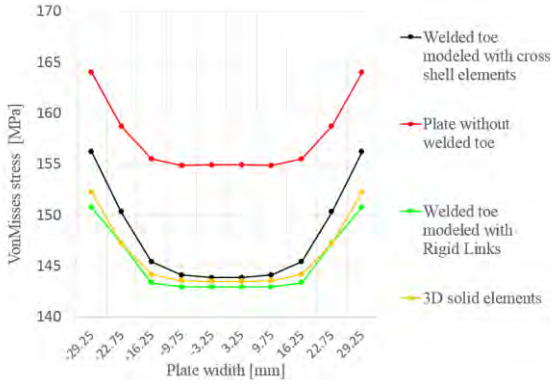

Fig. 10 Comparative results of stress values for considered groups

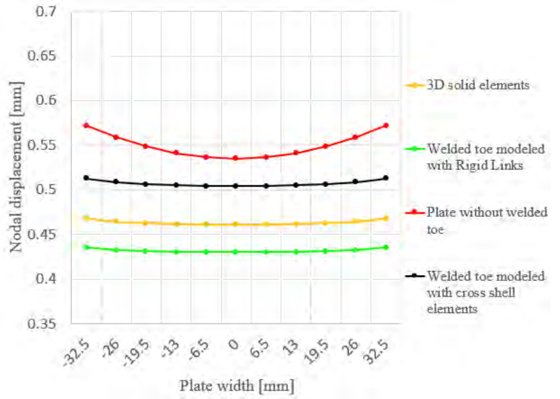

Fig. 11 Comparative results of node displacement values for considered groups

Based on earlier research and the experimental values, taken from [3], it is clear that 3D finite elements are best for the FEM calculation of welded joints. Analyzing the obtained results presented in Figure 10 it can be notice little mismatch between stress value along welded joint for considered models. The model without modeling welded joint gave the highest stress values as expected, but other two models give good matches with 3D FEM model, especially in the central zone of weld.

From the Figure 11, it can be seen that the matches, between the 3D FEM model and the models with shell elements, where the welded joint is modelled with a rigid link, there are a small difference between the displacement values. The model where the welded joint is modelled with cross shell elements has very little deviation and the model without the modelled welded joint has the greatest deviation.

VI. CONCLUSIONS

The aim of this paper was to show comparative analysis of numerical results for different methods of modeling welded joints. As an illustrative example, the T specimen as welded part of the simple geometry used for analysis. According to observed results and their comparison some conclusions is determined to show which of the presented methods from the aspect of the speed of modeling and the reliability is the most appropriate and can be reliably used in the future for calculation of welded structures of complex geometry.

As it was expected and based on the analysis 3D finite elements gives the most reliable results. However, for creating an FEM model of complex geometry with 3D elements, it takes far more time for modeling than 2D shell elements. Therefore, another goal is set to verify accuracy and eventual future application on more complex constructions by other modeling techniques (2D elements - shell). For this reason, three other FEM models of T specimen were made, where the base plates were modelled with shell element, while the welded joint was modelled with a cross-shell element, rigid links and a FEM model without modeling of welded joint.

On the basis of everything shown in the paper, it can be concluded that the model of 3D finite elements must not be used exclusively for the calculation of complex constructions, but that simpler models can also be used. In this way, there would be considerable savings in time and effort needed to create a reliable FEM model.

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