TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

UNIVERSITY OF BELGRADE
Faculty of Mechanical Engineering

XXI INTERNATIONAL CONFERENCE ON "MATERIAL HANDLING, CONSTRUCTIONS AND LOGISTICS"

23rd - 25th September, 2015

MHCL '15

Edited by

G. Kartnig, N. Zrnić and S. Bošnjak

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PREFACE

The International Conference on Material Handling, Constructions and Logistics – MHCL is the 21th event of a series that has been started just 39 years ago, in 1976 by Professor Đorđe Zrnić. Up to now the Conference gathered together scientists and researchers from all republics (now independent states) of former Yugoslavia (Serbia, Montenegro, Croatia, Slovenia, Bosnia and Herzegovina, and Republic of Macedonia), as well as from Austria, Germany, Hungary, Poland, Slovakia, Bulgaria, Romania, China, Greece, Russia, Netherlands, Italy, Switzerland, Lithuania, Republic of Korea, USA, Japan and Australia, working in the field of Material and Mechanical Handling, Constructions and Construction Machinery, as well as Transport Logistics. This year, for the second time, MHCL is organized together by the Vienna University of Technology (Institute for Engineering Design and Logistics Engineering) and University of Belgrade (Faculty of Mechanical Engineering).

The aim of the Conference is to be a forum to exchange views, opinions and experience on MHCL from technical viewpoints in order to track the current achievements, but also to look at to future developments. Most of the authors of contributed papers are experts in MHCL and related topics. Also, one of the main goals of the Conference is to make the scientific/research exchange between similar academic Departments and Institutes from different countries, as well as individual researcher in the field, in order for possible cooperation in applying for international programs or bilateral research and scientific projects.

This year the International Conference MHCL'15 is held in Austria at the Vienna University of Technology (Institute for Engineering Design and Logistics Engineering) from 23rd-25th September. The Proceedings contain 48 submitted peer-reviewed papers by authors from 14 countries: Austria, Serbia, Germany, Poland, Greece, Montenegro, Slovenia, Republic of Korea, Netherlands, Republic of Macedonia, China, Japan, Bulgaria and USA. The papers are grouped in five sessions A, B, C, D and session E:

Session A: Hoisting and Conveying Equipment and Technologies - 13 papers
(Chairman: Prof. Nenad Zrnić)
Session B: Construction and Mining Equipment and Technologies - 2 papers
(Chairman: Prof. Srđan Bošnjak)
Session C: Logistics and Intralogistics Systems - 13 papers
(Co-chairmen: Profs. Georg Kartnig and Nenad Zrnić)
Session D: Constructions and Design Engineering - 9 papers
(Co-chairmen: Profs. Georg Kartnig and Srđan Bošnjak)
Session E: Maritime and Port Logistics – Operations Modeling and Sustainable Development - 11 papers
(Chairman: Prof. Branislav Dragović)

Proceedings contain also 5 invited papers presented in Plenary session. The invited lectures reflect the wide spectrum of important topics of current interest in MHCL. These Proceedings can also be considered as a kind of handbook on MHCL, and can be of interest for researchers, graduate students and engineers specializing or addressing attention to MHCL. We believe that a reader will take advantage of the papers in these Proceedings with further satisfaction and motivation for her or his work.

We would like to express our sincere thanks to all members of the Scientific and Organizing Committee, Session chairman and reviewers as well as to all participants including invited speakers for coming in Vienna to present their papers. On this occasion, we are particularly indebted to all people who rendered their help for the preparation of the Conference and publication of the Proceedings.

We are grateful to the authors of the articles for their valuable contributions and for preparing their manuscripts in time.

Vienna, September 2015

Editors

Georg Kartnig, Nenad Zrnić, Srđan Bošnjak

DISTINGUISHED PERSONS IN THE HISTORY OF THE MHCL CONFERENCE

Prof. Đorđe N. Zrnić, MHCL conference founder in 1976

Đorđe N. Zrnić, Full member of AESS (Academy of Engineering Science of Serbia) was born 1934, in Belgrade, where he graduated (Dipl.-Ing.), from the **F**aculty of **M**echanical **E**ngineering, University of Belgrade. He received Dr.Sc. from **FME,** University of Belgrade. He became full professor in January 1982. He was the Head of Department of Mechanization (Material Handling, Constructions and Logistics) 1988-1999, and Dean of the Faculty of Mechanical Engineering 1994 - 1997.

He lectured Plant Layout Design, Material Handling Systems Design, Optimization Methods in Design and Logistics. He was supervisor of eight Dr. Sc. dissertations in Beograd (Faculty of Mechanical Engineering, Faculty of Civil Engineering, and FON). He presented his researches at the Universities in: USA, UK, France, Germany, Greece, Hungary and Sweden.

He wrote 9 books with totally 20 editions (3 monographs). He received the award of Economy Chamber of Belgrade (1989) for the best project for industry of the year, The Maintenance of Energetic System of the City. He was expert of Federal Government. He was the leading person concerning scientific and professional activities in Serbia, also in former Yugoslavia. He is married, wife Ljiljana, son Nenad, and grandson Đorđe.

His most distinguished scientific, research and professional activities are: development of theory and practice in plant layout design, and material handling systems design, and development, design, and construction of complex material handling equipment.

He published 177 papers (82 in international publications). He formulated theoretical basis in the field of design of complex material handling systems and synthesis of theory and practice, with the confirmation in many realized projects. He developed the procedure for modeling complex material handling systems and applied it in practice. TPD (Total Performance Design) method enables parallel estimation (multi-objective analysis) and simulation of process through iterative procedure till finding the most suitable solution. TPD method has been presented in Large Scale Systems: Theory and Application, PERGAMON 1999. The paper based on TPD method was presented in Edinburgh, Scotland on IFORS 2002, The 16. Triennial Conference on Operational research in a Globalized, Network World Economy, and was one of the six awarded papers. He noticed the difference between results obtained by using existing theoretical models of queuing systems theory and real processes. He defined fields of real processes of material flow, and pointed out possible mistakes originated when the models from literature are adopted without correction. The results were presented in Manufacturing Systems: Modeling, Management and Control, PERGAMON, Elsevier Science in 1997.

He designed 93 projects, out of which 59 have been realized in the country and abroad. He developed, designed and constructed a series of complex, original and modern material handling machines (specially harbor and ship-building cranes) in the country and abroad (Burma, Indonesia, Bangladesh, Germany, Tanzania). All these devices have been manufactured in the factory "GOSA" Smederevska Palanka, and most of them are innovative. Some of his realized innovations will be mentioned below: Design of the boogie for motion of harbor cranes on curvilinear rails, construction for boom's outreach changing and level luffing with counterweight in the column, for portal cranes. Design and construction of scoop-wheel cutter with changeable teethes, for dredger, etc. He designed complex systems (port terminals, warehouses, foundries, maintenance plant storages, etc). The result of that is series of realized objects (Russia, Serbia).

ABOUT THE MHCL CONFERENCE ORGANIZERS

Vienna University of Technology looks back on a long tradition at the leading edge of scientific research and education: Founded in 1815 as Polytechnisches Institut (Imperial and Royal Polytechnical Institute), it was divided into 5 faculties in 1865. One year later the first freely elected rector was inaugurated. In 1872 its name changed to Technische Hochschule (College of Technology), and in 1902 the first doctorates were awarded. The institution has borne its current name – Technische Universität Wien (Vienna University of Technology) – since 1975. At the Institute for Engineering Design and Logistics Engineering the research group Engineering Design for Material Handling and Conveying Systems **(**Konstruktionslehre und Fördertechnik) is engaged with design principles in mechanical engineering and with material handling as technical as well as logistical tasks. Further key aspects of activities are: rail vehicles, ropeways and supporting structures.

The University of Belgrade is the oldest and largest University in Serbia. Technical Faculty at University of Belgrade was established in 1863, and the first subject in the field of Mechanical Engineering ("Mechanics and Science of Machines") in 1873. First subject as a forerunner of the Department of Material Handling, Constructions and Logistics (Department of Mechanization) was "Construction Machinery" established in 1897. Starting from 1907 some chapters on hoist machinery (cranes) have been lectured at the academic level. The Department of Construction Machinery and Facilities Layout was established in 1932. In 1948 was established the Department of Industrial Mechanical Engineering, renamed in 1959 to Department of Mechanization (Material Handling and Design Engineering). Up to now the members of Department of Mechanization published several hundred scientific papers in journals, books, and conference proceedings. The Department has an intensive cooperation with industry. That resulted in numerous projects and developed, designed and constructed series of complex, original and modern transporting and construction machines, devices, and systems in the country (former Yugoslavia) and abroad (Burma, Indonesia, Bangladesh, Germany, Russia, Tanzania, Greece and Azerbaijan – former USSR). All these devices have been constructed and functioning for years now and many of them are innovative.

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CONTENTS

PLENARY SESSION – INVITED PAPERS

SESSION A – HOISTING AND CONVEYING EQUIPMENT AND TECHNOLOGIES

Bojan Medjo
Research Associate
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Faculty of Technology and Metallurgy

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Principal Research Fellow
Institute for Testing of Materials, Belgrade

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Stress analysis of the additional loading device of the bridge crane for weights up to 500t

In this work, additional loading device of the bridge crane for loads up to 500t, used at the „Đerdap" Hydro power plant, is analysed. The main aim is to determine the stress state, especially the stress distribution along the cross sections at the position of the opening for weight attachment. The main reason for conducting this analysis was the fact that non-destructive examination (NDE) revealed some defects in the material. The stress values are determined using analytical and numerical methods. Both of them have shown that the safety factor value in the cross sections around the opening are acceptable, and that the material has sufficient remaining strength despite the defects observed using NDE.

Keywords: *Bridge crane, Loading device, Stress state, Stress concentration, Finite element method.*

1. INTRODUCTION

High-capacity lifting machines, such as cranes, are typically exposed to complex dynamic loading conditions, which can lead to different types of failures of their components. These failures can cause overall machine collapse, with possible significant consequences on the operation of entire industrial plant. Examples of loading conditions and failures of different cranes can be found in [1-6].

In this work, stress state in additional loading device of the bridge crane for loads up to 500t (Fig. 1), used at the „Đerdap" Hydro power plant, is analysed. Having in mind the considered geometry of the crane, the loading of this element is tensile. The main aim is to determine the stress state, especially the stress distribution along the cross sections at the position of the opening for weight attachment.

The main reason for conducting the stress state analysis was the fact that non-destructive examination (NDE) revealed some defects in the material. The stress values are determined using analytical and numerical methods.

Figure 1. Additional loading device of the bridge crane

The results have shown that the safety factor value in the cross sections around the opening are acceptable, and that the material has sufficient remaining strength despite the defects observed using NDE. Therefore, the element can remain in exploitation, with periodic examination of critical areas and assessment of the defect development.

2. PART GEOMETRY

Figure 2 contains a part of the assembly drawing of the bridge crane; analysed component (additional loading device) is denoted by 2. Detail drawing of this device is given in Fig. 3. As mentioned previously, the main aim is the stress analysis in the zone of the opening for weight attachment (by pin connection).

Visual examinations revealed certain amount of corrosion products and negligible local mechanical defects. These locations are subsequently treated by fine grinding, sandblasting and corrosion protection. Metallographic examinations are also performed, using the replication technique.

During the ultrasonic examination of the additional loading device, some lamellar defects inside the material are observed. Such lamellar defects are typical for large forged elements.

3. ANALYTICAL CALCULATION

Having in mind the discovered defects, analysis of stress in specific cross-sections is performed, starting with analytical determination of the average stress values. Two cross-sections which are considered here are A_1-B_1 and A_2-B_2, Fig. 4.

Pressure stress at the cylindrical surface of the opening is:

$$\sigma_{PU} = \frac{Q}{d_o \cdot s} = \frac{5000000}{280 \cdot 304} = 58,7 MPa \qquad (1)$$

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Based on this value, the stress in the cross-section A_1-B_1 can be determined (based on the theory of elasticity):

$$\sigma_{A1-B1} = \frac{\sigma_{PU}\left[(2R)^2 + d^2\right]}{(2R)^2 - d^2} = \frac{58,7\left[(2\cdot 445)^2 + 280^2\right]}{(2\cdot 445)^2 - 280^2} = 71,6MPa \qquad (2)$$

The stress value in the cross-section A_2 - B_2 can be calculated as follows (tensile stress, cross-section weakened by the opening):

$$\sigma_{A2-B2} = \frac{Q}{(2R-d)\cdot s} = 27,0MPa \qquad (3)$$

It can be seen that these values are much lower than the yield strength of the material (σ_Y = 210 MPa). However, due to the stress concentration caused by the opening, the stress state is analysed in more detail, along both of the mentioned cross sections, using the finite element method. Another motivation for the use of numerical analysis is the contact loading, which makes the stress analysis much more difficult because the contact is in the weakened spot of the structure (at the surface of the opening).

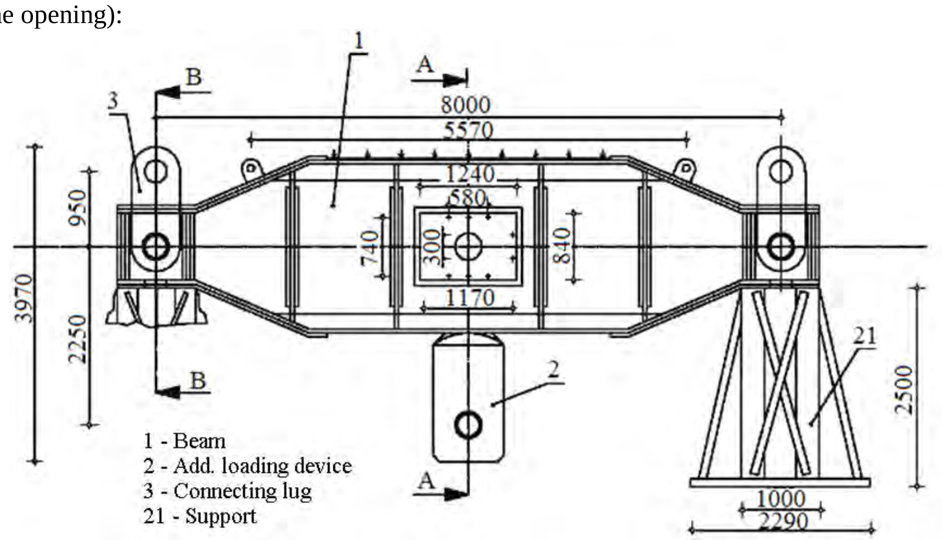

Figure 2. A part of the bridge crane for weights of up to 500t

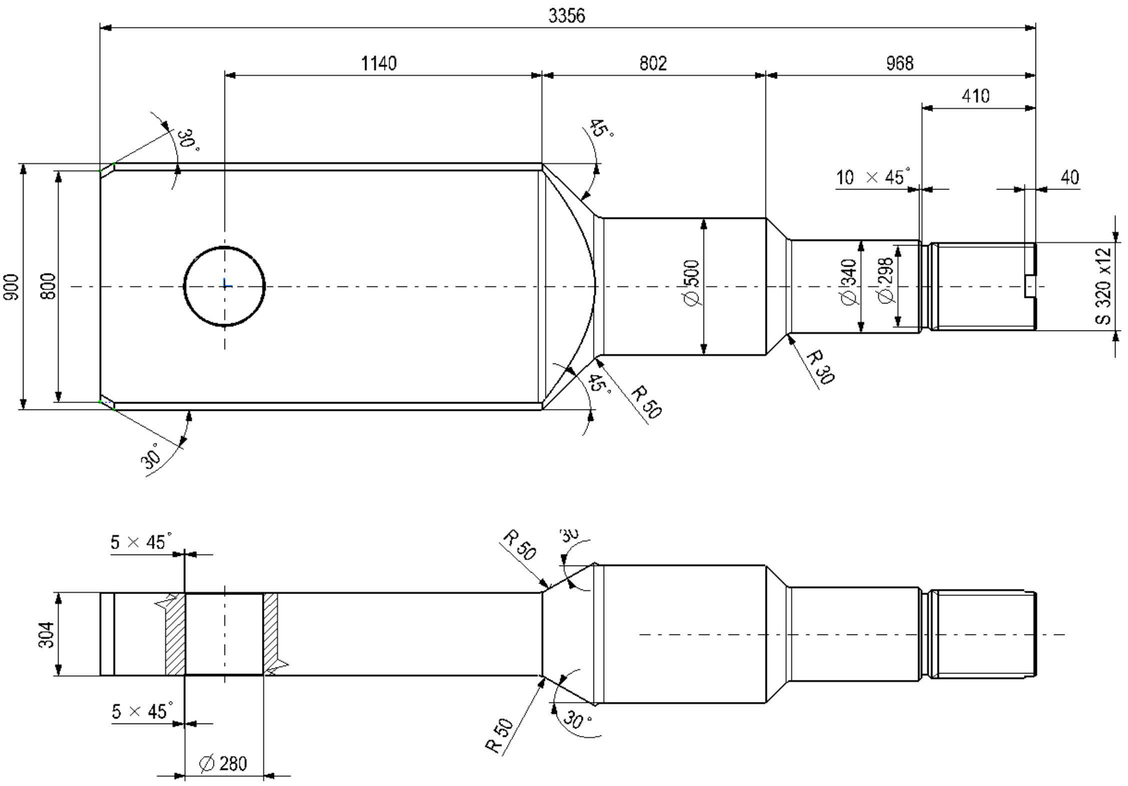

Figure 3. Detail drawing of the additional loading device of the bridge crane for weights of up to 500t

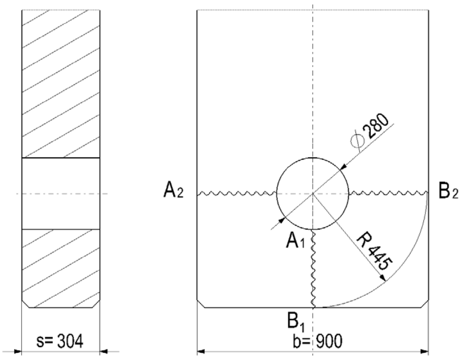

Figure 4. Cross-sections for stress analysis

4. NUMERICAL ANALYSIS

The three-dimensional finite element model is formed using two symmetry planes and appropriate boundary conditions, having in mind the geometry of the loading device. The loading is defined by contact with the rigid body - pin for attaching the weight. Linear-elastic description of material behaviour is used; elasticity modulus E=210 GPa, Poisson's ratio ν=0.3. Yield strength of the material is σ_Y=210 MPa; however, numerical calculations were not performed in the plastic regime, and this value is used only to check whether the calculated stress values are in the elastic zone.

The finite element mesh (Fig. 5) is formed from tetrahedral elements with quadratic interpolation functions. The loading, which acts on the pin, represents a quarter of the exploitation load - having in mind the symmetry conditions.

The connection of the loading device with the traverse of the crane (threaded connection) is modelled using a simplified approach in the model - all displacement components at the cylindrical joining surface are constrained. Numerical analysis is performed using the software package Abaqus (www.simulia.com).

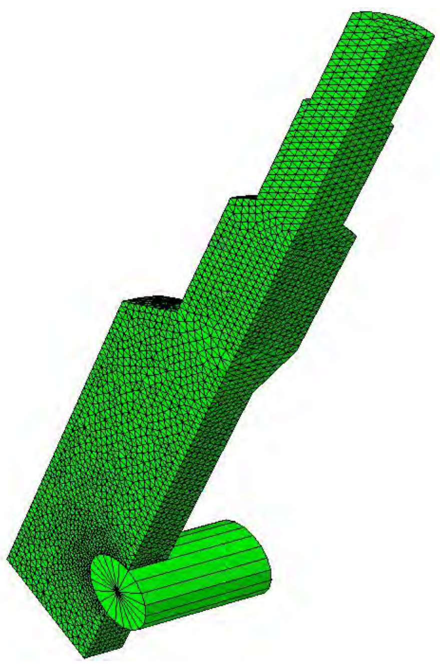

Figure 5. Finite element mesh

5. RESULTS AND DISCUSSION

Longitudinal (axial) stress distribution around the opening is given in Fig. 6. The zone with negative values is pronounced, due to the contact with the loading pin (i.e. due to the load transfer across the contact surface). In order to present the stress state more clearly, the loading pin is not shown in this figure.

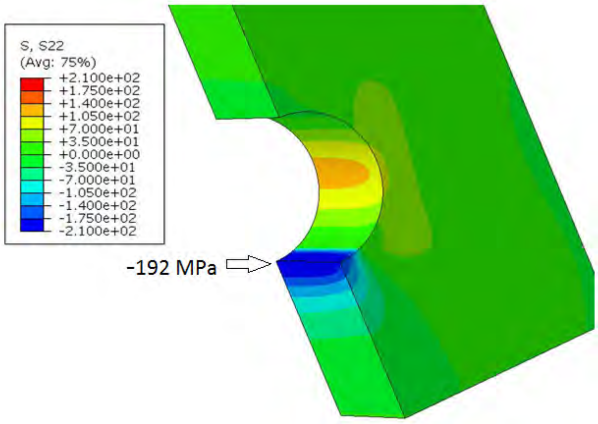

Figure 6. Axial stress distribution in the zone around the opening

Figures 7 and 8 show the variation of stress values along the defined paths A-B and C-D; these paths are used for tracking the stress values, in order to determine the stress state around the opening as accurate as possible. In both figures, both axial stress and equivalent von Mises stress are given. It can be seen that equivalent von Mises stress has higher values along the first path (A-B), which can be attributed to the high negative values in the axial direction.

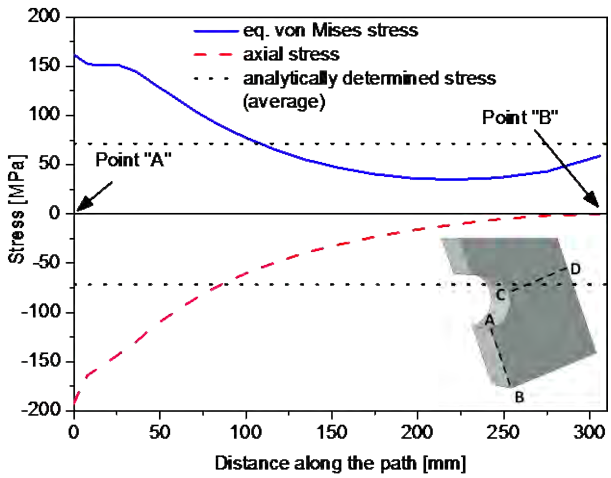

Figure 7. Variation of stress values along the path A-B

Together with numerical results, analytical solutions are also shown in Figs. 7 and 8; they actually represent the average values across the corresponding paths (calculated in Chapter 3). A significant stress concentration is obtained in the surface of the opening using the numerical analysis. Of course, stress concentration for some geometries and loadings can be determined using the expressions from the literature. However, in this case, it was estimated that numerical analysis is needed, due to the complex local loading conditions caused by the contact between the loading pin and the opening surface. These conditions prevent us from considering this geometry as a simple thick plate with a hole loaded by tensile stresses.

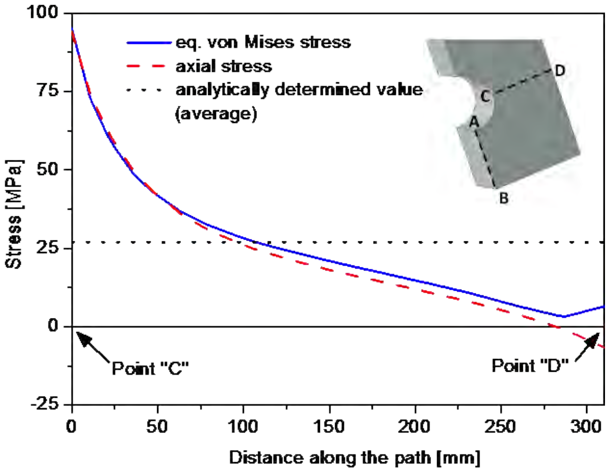

Figure 8. Variation of stress values along the path C-D

In order to assess the stress state in the screw connection zone in more details, current and future work includes analysis of 2D axisymmetrical model which resembles the exact shape of the screw profile.

Axisymmetrical model of the loading device and the threaded connection is shown in Fig. 9. The loading is defined by prescribing the displacement at the bottom part of the model. This displacement is determined by the previously described 3D calculation; the maximum displacement corresponds to the maximum loading.

The loading is transmitted by modelling the contact between the inner and outer thread, which can also be seen in Fig. 9.

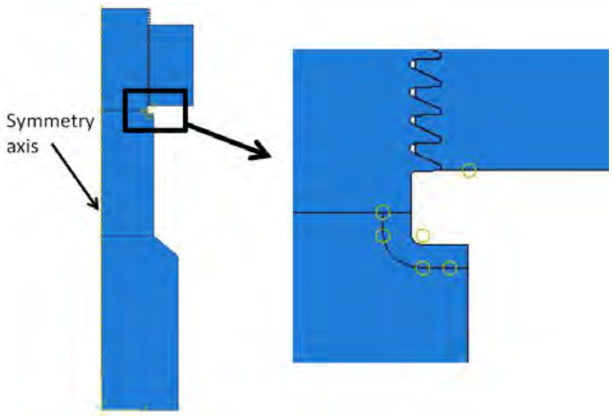

Figure 9. Axisymmetrical 2D model with enlarged zone around the threaded connection

The highest stress values are obtained in the roots of the first few threads, as expected. However, it should be noted that the thread zone, and especially its root, is thermo-mechanically treated during the fabrication of the thread; hence, it often has better properties than the rest of the structure. A more detailed future analysis will therefore include all these aspects, along with a detailed consideration of exploitation loads, [7]. A nice example of the threaded connection analysis can be seen in [8].

6. CONCLUSIONS

Based on the results of the examination of the additional loading device of the bridge crane for loads up to 500t, following conclusions can be drawn:

- Visual examination revealed certain amount of corrosion products and negligible local defects.
- Ultrasonic examinations lead to discovery of some lamellar defects in the material, rather typical for the forged elements with large dimensions.
- Analytical calculations have shown that the factors of safety in the critical locations have sufficient values for the design loading (weight of 500 t).
- Due to the complex loading in the zone weakened by the circular opening (contact with the pin), 3D numerical analysis is applied to determine the stress state. Local stress values in the critical regions do not reach the yield strength of the material.
- Current work includes analysis of 2D numerical model of the threaded connection; this part of the structure will be considered in detail in the future work.

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