

DISTRIBUTION OF MINIMUM MAIN NORMAL STRESS IN UNIAXIAL TENSION PLATE WITH CIRCULAR OPENING

Mladen Radojković^{1*}, Saša Milojević², Snežana Joksić¹, Aleksandra Kokić Arsić³, Blaža Stojanović²

¹University of Pristina, Faculty of Technical Sciences, Kosovska Mitrovica, Knjaza Miloša 7, 38220 Kosovska Mitrovica, Serbia, mladen.radojkovic@pr.ac.rs, snezana29joksic@gmail.com

² University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, blaza@kg.ac.rs, sasa.milojevic@kg.ac.rs

³ Kosovo and Metohija Academy of Applied Studies, Department Zvecan, Nušićeva 6, 38227 Zvečan, Serbia, akokicster@gmail.com

ABSTRACT

The growth of production is largely related to the increase in the volume of scientific and technical information used in the process of constructing. The collection, processing, transmission and analysis of technical information can greatly affect the process of constructing. By having such information, constructors come up with ideas more easily and carry out processes of constructing more easily. In the process of constructing, constructors perform various calculations and analyses. Analysis of the state of stress is one of the main analyzes in the process of constructing of machine parts. Therefore, the aim of this paper was to analyze the distribution of the minimum main normal stress during axial tension of isotropic rectangular plates with a central circular opening. For this analysis, the finite element method (FEM) and the ANSYS software package were used, and steel as one of the most well-known isotropic materials was used for the plate material.

Keywords: circular opening, minimum main normal stress, rectangular plate, ANSYS software package.

INTRODUCTION

During the intensive scientific development, many theoretical and practical models were created for the analysis, synthesis and testing of constructions. Structural analysis methods are research methods that seek answers about construction properties. Based on the created physical form of the mechanical construction, simplified models are formed, and then a mathematical model is selected for calculation and analysis. The analysis is performed using the chosen theoretical-analytical, numerical or experimental method and the construction is improved step by step until the desired goals are achieved. Practically, the analysis collects data that enables the correction of constructive solutions, i.e. the evolution of existing or the improvement of newly developed constructions. In addition, analysis methods are used to collect data and knowledge on which the development of future mechanical constructions will be based. Depending on the speed of the analysis, the features of the construction can be identified very early, that is, more constructive variants can be developed and the most favorable solution can be chosen (Nikolić, 1999).

It is known that the mechanical construction is composed of many parts that make up a functional whole. Machine parts in most cases have a complex geometric shape. To assess the reliability and safety of parts and construction, it is necessary to know the values and distribution of stress (Radojković, 2005).

Openings in machine parts are sources of stress concentration. Analytical methods can be used to determine the distribution and concentration of stress around openings in machine parts, whereby the basic division of these methods can be made into exact and approximate. An important place among approximate methods is occupied by the method of the function of complex

variables and it can be used to determine the distribution and concentration of stress both in isotropic and anisotropic homogeneous fields with openings (Savin, 1968).

Differential equations that describe the state of stress of more complex structures and geometric shapes, as well as complicated contour conditions, usually cannot be solved by analytical methods, so the search for approximate particular solutions is resorted to using numerical methods. By applying numerical methods and the FEM as one of the most used numerical methods, results were obtained on the stress distribution in plates with circular (Mekalke at al., 2012), rectangular (Rahman, 2018), elliptical (Patel, & Desai, 2020) and a square hole (Radojković at al., 2023), whereby the obtained results confirmed the justification of the application of the mentioned method.

REVIEW OF THE ANALYTICAL RESULTS OF THE DISTRIBUTION OF THE MAIN NORMAL STRESSES IN A PLATE WITH A CIRCULAR OPENING

In this chapter, the procedure and results obtained using analytical methods will only be briefly presented (Savin, 1968; Radojković, 2005). They refer to an isotropic field with a central circular opening, and the complex variable function method was used as an analytical method.

Stress functions during uniaxial tension of an isotropic field with a central circular opening of radius R (Savin, 1968; Radojković, 2005) have the form:

$$\begin{aligned}\varphi(\zeta) &= \frac{pR}{4} \left[\frac{1}{\zeta} + 2\zeta \right], \\ \psi(\zeta) &= -\frac{pR}{4} \left(\frac{1}{\zeta} + \zeta - \zeta^3 \right),\end{aligned}\tag{1}$$

where: ζ – independent variable, p – intensity of tensioning surface forces.

Expressions for calculating stress components in the polar coordinate system (Savin, 1968; Radojković, 2005) are:

$$\begin{aligned}\sigma_\rho &= \frac{p}{2} \left[(1 - \rho^2) + (1 - 4\rho^2 + 3\rho^4) \cos 2\theta \right], \\ \sigma_\theta &= \frac{p}{2} \left[(1 + \rho^2) - (1 + 3\rho^4) \cos 2\theta \right], \\ \tau_{\rho\theta} &= \frac{p}{2} (1 + 2\rho^2 - 3\rho^4) \sin 2\theta,\end{aligned}\tag{2}$$

where: ρ – radius vector, θ – angle between the normal at a point on the contour of the opening and the x axis and is measured while going around the contour in the positive mathematical direction.

When $\rho = 1$ is put in the expression for σ_θ (2) (Savin, 1968; Radojković, 2005), the expression for calculating the stress on the opening contour is arrived at in the form:

$$\sigma_\theta = p(1 - 2 \cos 2\theta).\tag{3}$$

From the expression (3), it can be seen that the maximum stress values σ_θ are obtained at $\theta = \pm\pi/2$, i.e. is obtained by:

$$(\sigma_\theta)_{\max} = 3p.\tag{4}$$

Based on the expressions for σ_p , σ_θ and $\tau_{p\theta}$ (2) (Savin, 1968; Radojković, 2005), the values of the main stresses σ_{\max} , σ_{\min} and τ_{\max} can be calculated. Figure 1 shows the distribution of the main normal stresses during uniaxial tension of an isotropic field with a circular opening, surface forces of intensity p . These results were used for comparison with the numerical results obtained in this paper.

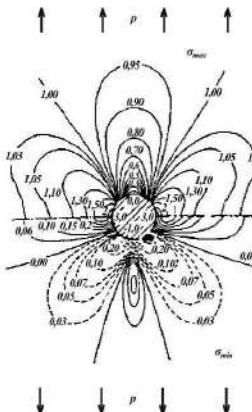


Figure 1. Lines of maximum σ_{\max} (upper half of the figure) and minimum main normal stress σ_{\min} (lower half of the figure) in uniaxial tension isotropic field with a circular opening.

REVIEW OF THE NUMERICAL RESULTS OF THE DISTRIBUTION OF THE MINIMUM MAIN NORMAL STRESS IN A PLATE WITH A CIRCULAR OPENING

In order to obtain numerical results on the distribution of the minimum main normal stress σ_{\min} , the FEM and the ANSYS software package were used in this work. The tests were performed on uniaxially tensioned rectangular plate-type elements, dimensions $2 \text{ m} \times 5 \text{ m} \times 0.1 \text{ m}$. The position of the plate is such that its shorter side is parallel to the direction of the x axis, and the longer side is parallel to the direction of the y axis. The rectangular plate is weakened by a central circular opening, diameter $d = 100 \text{ mm}$, and tensioning is performed by surface forces of intensity $p = 1 \text{ N/m}^2$ in the direction of the y axis. The plate on which the tests are performed is made of isotropic material, and steel was chosen for it, for which the modulus of elasticity of the material is $E = 2.1 \times 10^5 \text{ N/m}^2$, and Poisson's coefficient $\mu = 0.33$. Discretization of the model (plate) was performed with 2D triangular solid finite elements with six nodes.

Figure 2 shows only the detail of the finite element mesh around the circular opening, created in the ANSYS software package, and Figure 3 shows the distribution of the minimum main normal stress σ_{\min} in a uniaxially tensioned steel plate with a central circular opening of diameter $d = 100 \text{ mm}$, where the tensioning is done by surface forces of intensity $p = 1 \text{ N/m}^2$, whose attack lines are perpendicular to the shorter side of the rectangular plate. From Figure 3, it can be seen that the highest value of this stress is obtained at the points of intersection of the contour of the opening and the y axis and is $\sigma_{\min} = -0.994 \text{ N/m}^2$.

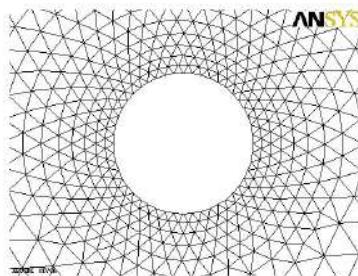


Figure 2. Finite element mesh detail of a uniaxially tensioned plate weakened with a circular opening with a diameter of $d = 100 \text{ mm}$.

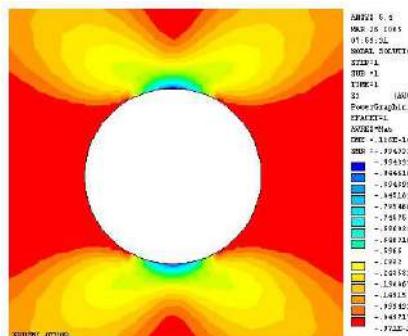


Figure 3. Distribution of the minimum main normal stress σ_{min} in a uniaxially tensioned plate weakened by a circular opening with a diameter of $d = 100$ mm.

ANALYSIS OF ANALYTICAL AND NUMERICAL RESULTS OF MINIMUM MAIN NORMAL STRESS DISTRIBUTION

In this paper, the results on the distribution of the minimum main normal stress σ_{\min} were obtained numerically, using FEM and the ANSYS software package. They were compared with the results from theory (Savin, 1968; Radojković, 2005), in order to determine the accuracy of the applied numerical method and the obtained results. Table 1 shows the values of the minimum main normal stress σ_{\min} , which were arrived at by the analytical method (ANAL) and the finite element method (FEM). The obtained results refer to uniaxially tensioned steel plates with a circular opening of diameter $d = 100$ mm.

Table1. Stress values σ_{\min}

Method	σ_{\min}, N/m²
ANAL	-1.000
FEM	-0.994

Analyzing the results from Table 1, which were obtained by uniaxial tensioning of a steel plate with a circular opening, it can be concluded that the highest values for the minimum main normal stress σ_{\min} are obtained at the intersection of the contour of the opening and the y axis (blue color of the stress field in Figure 3). Also, from the same table, it can be seen that by applying FEM and the ANSYS program package, approximately the same values as the theoretical values are obtained (Savin, 1968; Radojković, 2005).

CONCLUSIONS

The aim of these researches was to reach results on the distribution of the minimum main normal stress σ_{min} , to examine the influence of the circular opening on the distribution of this stress and to verify the numerical results obtained in this paper.

Numerical results on the distribution of the minimum main normal stress σ_{\min} were obtained in the paper. The FEM and the ANSYS software package were used to obtain the results, and the results of the distribution of this stress are illustrated in Figure 3. When it comes to the influence of the circular opening on the distribution of the minimum main normal stress σ_{\min} , based on the results obtained in this work, the results from the theory and the results obtained for other shapes of the opening, conclude that this shape of the opening has no significant influence, because small values are obtained for this stress. Regarding the application of numerical methods, and the FEM as the chosen method for obtaining results in this paper, it can be said that it confirmed the justification of the application, because the obtained results are close to the analytical results from the theory. Also, the applied software package proved to be reliable for solving such and similar problems.

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ISSN 2303-498X

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ISSN 2303-498X



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Publisher:

University PIM, Banja Luka, Republic of Srpska, Bosnia and Herzegovina

For publisher

Ilijा Džombić, PhD, General Manager

Editorial board:

Dejan Kojić, PhD, Vice-Rector for Science

Darjana Sredić, MSc.

Design and Computer processing:

Ljubica Janjetović, PhD

Print:

„Vilux“ Banja Luka

Circulation:

20 Copies

СИР - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

33:005(082)
62(082)
0/9(082)

МЕЂУНАРОДНА конференција о друштвеном и
технолошком развоју (12 ; 2023 ; Требиње)

Zbornik radova / XII Međunarodna konferencija
o društvenom i tehnološkom razvoju, Trebinje, 15-18.
juni 2023. godine = Proceedings / XII International
conference on social and technological development,
Trebinje, June, 15-18, 2023 ; [editorial board Dejan
Kojić, Darjana Sredić]. - Banja Luka : Univerzitet za
poslovni inženjeringu i menadžment =University PIM,
2023 (Banja Luka : Vilux). - 631 str. : илустр. ; 25 cm.
- (Međunarodna konferencija o društvenom i
tehnološkom razvoju = International conference on
social and technological development, ISSN 2303-
498X)

На насл. стр.: 20 godina univerziteta PIM. - Радови
на срп. и енгл. језику. - Тираж 20. - Напомене и
библиографске референце уз текст. -
Библиографија уз сваки рад. - Сажеци на енгл. и
срп. језику уз сваки рад.

ISBN 978-99955-40-70-8

COBISS.RS-ID 139321089

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