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LIFE CYCLE ENGINEERING AND MANAGEMENT

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June 25-26, 2026, Prijevor, Serbia

Conference Topics:

Plenary Lectures
Quality Engineering
Reliability Engineering
Industrial Engineering
Systems Engineering
Military Engineering
Energy Efficiency
Lean Production

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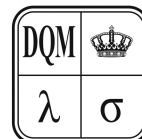
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About the Proceedings Editor

LJUBISA PAPIC

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**DISTRIBUTION OF MAIN NORMAL STRESSES IN AXIALLY
TENSIONED PLATES WITH RECTANGULAR OPENINGS****Mladen Radojković**

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Summary: When constructing mechanical structures, the main goal is their shaping. In order for construction to be efficient and functional, it is necessary to form the basis of a modern organization of the process of developing machine systems and construction work. Among the engineering tasks, the most important are certainly those related to the dimensioning of machine parts that are part of machine structures. In order to carry out dimensioning, it is necessary to determine the appropriate stresses and compare them with the permitted stresses. Therefore, the determination of value stress values and their distribution in machine parts represent one of the tasks in the construction process. Therefore, the aim of this study was to determine the distribution of the minimum main normal stress in axially tensioned plate-type elements with a rectangular opening. The finite element method (FEM) and the ANSYS software were used to obtain the results on the distribution of the minimum main normal stress, and they were compared with the theoretical results. For the plate material, steel was used as an isotropic material.

Key words: FEM, minimum main normal stress, rectangular opening, rectangular plate.

1. INTRODUCTION

It is known that when constructing machine parts that are part of machine constructions, different geometric discontinuities must often be foreseen [1]. One of those discontinuities is certainly openings that are foreseen in machine parts for

many reasons. Machine parts are exposed to various loads and can be made of various materials. Therefore, when constructing machine parts, special attention must be paid to constructing parts with geometric discontinuities, loads and type of material. Therefore, in this paper, attention is paid to the distribution of the main normal stresses in parts with a rectangular opening, exposed to the effect of biaxial axial load.

The concept of sustainable development is considered a turning point in the global approach to environmental protection and development [2]. One of the goals of sustainable development is responsible production and consumption. In production, machine parts with various geometric discontinuities are often encountered, the most common of which are openings. Openings in machine parts are sources of stress concentration, and therefore they should be given special attention. The stress distribution in a plane anisotropic field weakened by an elliptical opening was studied by Nikolić et al. [3], and the application of numerical methods in solving the theory of thin plates was dealt with by Radojković et al. [4]. In this study, Šarkoćević et al. [5] provide a brief description of the Pipeline Defect Assessment Manual (PDAM) as a joint industry project sponsored by fifteen international oil and gas companies. Radojković et al. studied the influence of rectangular and square openings in isotropic plates on stress distribution during uniaxial and biaxial tensioning of plates. [6,7]. In their study, Joksić et al. [8] deal with stress state analysis and gearbox fork optimization. To obtain results on stress distribution in uniaxially tensioned rectangular steel plates weakened by an elliptical opening, Radojković et al. [9] use numerical methods and FEM. In their study, Li et al. [10] deal with stress concentration caused by corrosion in aluminum alloy 7005, i.e. mechanical degradation and analysis of corrosion parameters, and Jordan et al. [11] by estimating the stress concentration factor in shaft grooves using finite element analysis.

2. DISPLAY OF THE ANALYTICAL RESULTS OF THE DISTRIBUTION OF THE MAIN NORMAL STRESSES

In the following text, only the analytical results of the distribution of the main normal stresses, obtained by the method of the complex variable function in uniaxial and biaxial tension of the isotropic field with a rectangular opening, will be presented, while the procedure for determining the components of the main normal stresses can be found in [1]. The results of the distribution of the main normal stresses will be illustrated graphically, i.e. figures.

According to [1], Figure 1 shows the distribution of the maximum main normal stress $\sigma_{\max}$ (upper half of the image) and the minimum main normal stress $\sigma_{\min}$ (lower half of the image), during uniaxial tensioning of an isotropic field with a rectangular opening of aspect ratio $a/b = 5$ and radius of rounding of the corners of the rectangular opening $r = 0.06a$. The tightening is done by surface forces of intensity p in the direction of the y axis, where the lines of attack of the forces are perpendicular to the longer side of the opening ($\alpha = 90^\circ$).

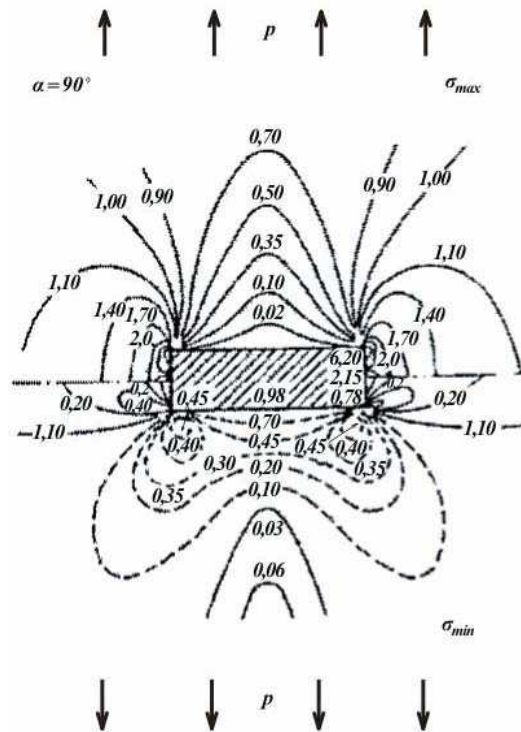


Figure 1. Lines of main normal stresses in uniaxial tension of an isotropic field with a rectangular opening of aspect ratio $a/b = 5$ and $\alpha = 90^\circ$

Figure 2 shows the distribution of the maximum main normal stress $\sigma_{\max}$ (upper half of the figure) and the minimum main normal stress $\sigma_{\min}$ (lower half of the figure) during biaxial tensioning of an isotropic field with a rectangular opening of aspect ratio $a/b = 3/2$ and radius of rounding of the corners of the rectangular opening $r = 0.06a$. Tensioning is done by surface forces of intensity p in the direction of the y axis and $0.25p$ in the direction of the x axis.

3. DISPLAY OF THE NUMERICAL RESULTS OF THE MINIMUM MAIN NORMAL STRESS DISTRIBUTION

In this paper, the numerical results of the distribution of the minimum main normal stress $\sigma_{\min}$ in rectangular plates with a central rectangular opening were obtained. FEM and ANSYS software [12] were used to obtain the results. Two cases were considered and in both cases the dimensions of the rectangular plates are $2 \text{ m} \times 5 \text{ m} \times 0.1 \text{ m}$. The position of the plates in both cases is such that their shorter side is parallel to the direction of the x axis, and the longer side is parallel to the direction of the y axis.

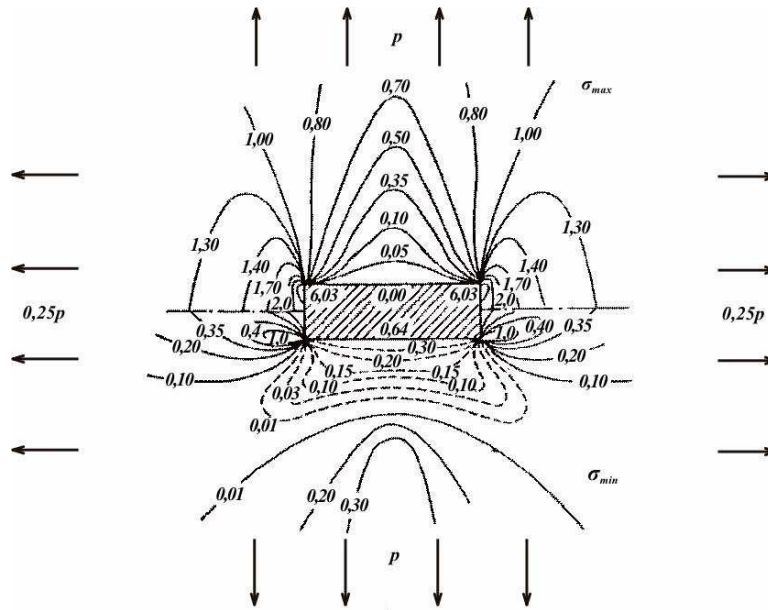


Figure 2. Lines of main normal stresses in biaxial tension isotonic field with a rectangular opening of aspect ratio $a/b = 3/2$

In the first case, the lengths of the sides of the rectangular opening are $a = 100$ mm and $b = 20$ mm ($a/b = 5$), the position of the opening is such that its longer side coincides with the direction of the x axis, and the shorter side with the direction of the y axis, the radius of rounding of the corners of the opening is $r = 6$ mm, the tension is uniaxial and is carried out by surface forces of intensity $p = 1$ N/m² in the direction of the y axis. In the second case, the lengths of the sides of the rectangular opening are $a = 100$ mm and $b = 66.67$ mm ($a/b = 3/2$), the position and radius of rounding of the corners of the opening are the same as in the first case, the tension is biaxial and is performed by surface forces of intensity $p = 1$ N/m² in the direction of the y axis and $q = 0.25$ N/m² in the direction of the x axis. Tests were performed on plates made of isotropic materials, and for these tests, steel was chosen for which the modulus of elasticity of the material is $E = 2.1 \times 10^{11}$ N/m², and Poisson's coefficient $\mu = 0.33$. Discretization of the plates in both cases was performed with 2D triangular solid finite elements with six nodes.

Figure 3 shows the distribution of the minimum main normal stress $\sigma_{\min}$ in a uniaxially tensioned steel plate with a central rectangular opening of sides $a = 100$ mm and $b = 20$ mm ($a/b = 5$), the radius of rounding of the corners of the opening $r = 6$ mm, where the tension is performed by surface forces of intensity $p = 1$ N/m² in the y direction. From Figure 3, the highest value of the minimum main normal stress can be read and it amounts to $\sigma_{\min} = -1.008$ N/m².

Figure 4 illustrates the distribution of the minimum main normal stress $\sigma_{\min}$ in a biaxially tensioned steel plate with a central rectangular opening of sides $a = 100$ mm and $b = 66.67$ mm ($a/b = 3/2$), radius of rounding of the corners of the

opening $r = 6$ mm, when tensioned by surface forces of intensity $p = 1$ N/m² in the direction y and $q = 0.25$ N/m² in the direction of the x axis. From the same figure, the highest obtained value of the minimum main normal stress can be read, and it is $\sigma_{\min} = -0.526$ N/m².

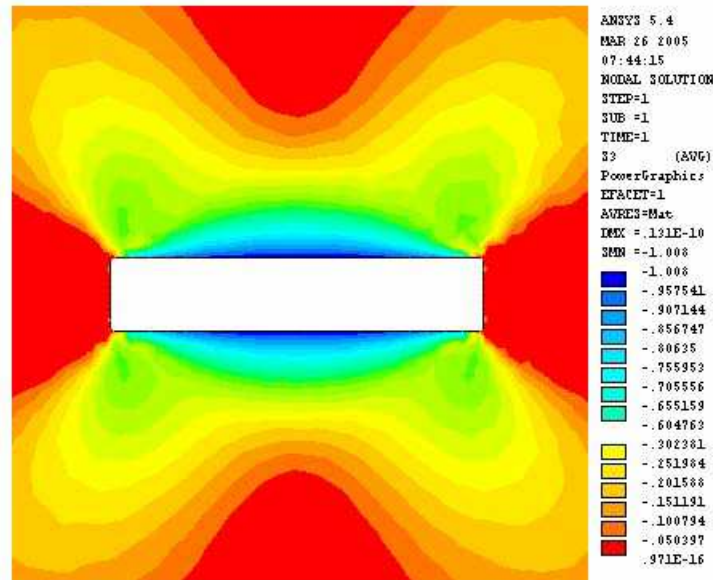


Figure 3. Distribution of the minimum main normal stress $\sigma_{\min}$ in a uniaxially tensioned plate with a rectangular opening of sides $a = 100$ mm and $b = 20$ mm

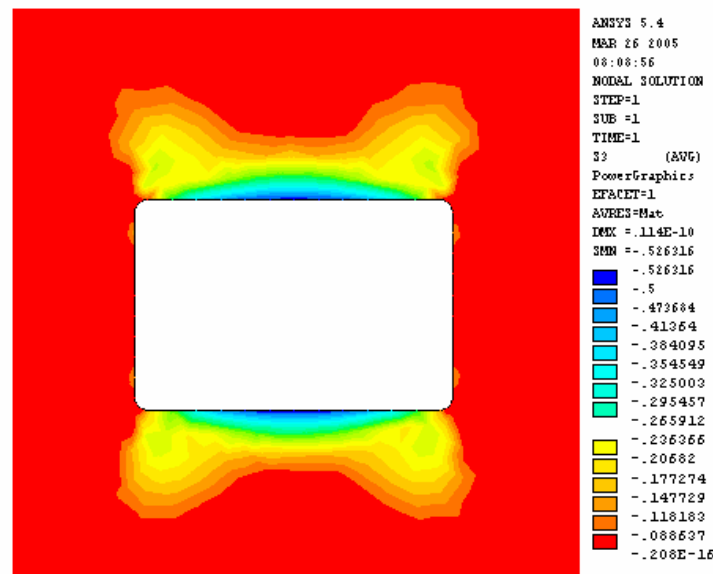


Figure 4. Distribution of the minimum main normal stress $\sigma_{\min}$ in a biaxially tensioned plate with a rectangular opening of sides $a = 100$ mm and $b = 66.67$ mm

4. ANALYSIS OF ANALYTICAL RESULTS AND RESULTS OBTAINED BY FEM

In this study, FEM and ANSYS software were used to obtain results on the distribution of the minimum main normal stress $\sigma_{\min}$. The essence of these investigations was to arrive at results on the distribution of the minimum main normal stress $\sigma_{\min}$, and then to compare them with the results from theory [1] in order to confirm them. Table 1 shows the values of the minimum main normal stress $\sigma_{\min}$, which were arrived at analytically (ANAL) and by the finite element method (FEM). The results shown in Table 1 refer to uniaxially and biaxially stressed rectangular steel plates with a rectangular opening, whose geometry and method of stressing is described in the previous chapter.

Table 1. Stress values $\sigma_{\min}$

Method	$\sigma_{\min}, \text{N/m}^2$	
	Uniaxial tension	Biaxial tension
ANAL	-0.980	-0.640
MKE	-1.008	-0.526

Based on the results from Table 1, it can be seen that the highest values for the minimum main normal stress $\sigma_{\min}$ are obtained at the intersection of the contour of the rectangular opening and the y axis (blue color of the stress field in Figure 3 and Figure 4). In addition, it can be seen from Table 1 that by applying the analytical method and MKE, approximately the same values are obtained [1].

5. CONCLUSION

The aim of the research in this paper was to reach results on the distribution of the minimum main normal stress $\sigma_{\min}$ using FEM, to examine the influence of uniaxial and biaxial tensioning of rectangular plates with a central rectangular opening on the distribution of this stress, and to show that results on stress distribution can be obtained by applying FEM.

Analyzing the influence of axial tension, in this paper it was concluded that the case of uniaxial tension of steel rectangular plates with a rectangular opening is less favorable in terms of the value of the minimum main normal stress $\sigma_{\min}$ compared to biaxial tension of the same. Also, based on the obtained values of the minimum main normal stress $\sigma_{\min}$, it can be seen that in the case of biaxial tension, significantly lower values of this stress are obtained, which is a consequence of the effect of the load in the other perpendicular direction. From Table 1, it can be seen that the deviations of the values of the MKE obtained in relation to the values obtained analytically are not large, so it can be concluded that the applied MKE gives satisfactory results and can be used to solve such problems.

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