Modeling of a plate with an elliptical hole under axial load considering plastic deformation

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Abstract

One of the problems in the study of rupture theory is the study of the stress field in the area of specific concentrators. From the point of view of practical application, stress concentration is mainly found, not only in the area of sharp change in stiffness, but also in the area of holes. The solution of the concentration problem is further complicated by the physical nonlinearity of the material resulting from the loads. In this article, an infinite plate with a central longitudinal hole, specifically elliptic, under axial load is discussed. The purpose of the article is to create a diagnostic model in the software complex FEMAP, the solution of which will allow us to estimate the concentration zone (spreading area).

Keywords: *stress, concentrator, stiffness, finite element.*

Main part

Consider a plate with an elliptical hole on which a tensile force acts along the axis (Fig. 1), where l and b the semi-axes are equal to 50 and 25 mm, respectively, if the semi-axes of the hole are several times smaller of the width of the plate, then we can consider that we have an infinite plate that is stretched.

Analytical solution field see Fig. 2, and Fig. 3 where represents the plate according to the Kolosov-Ingles theory of the average stress without a hole, it was found that the most dangerous peak stresses are determined by the curvature of the hole, and at the vertices A.

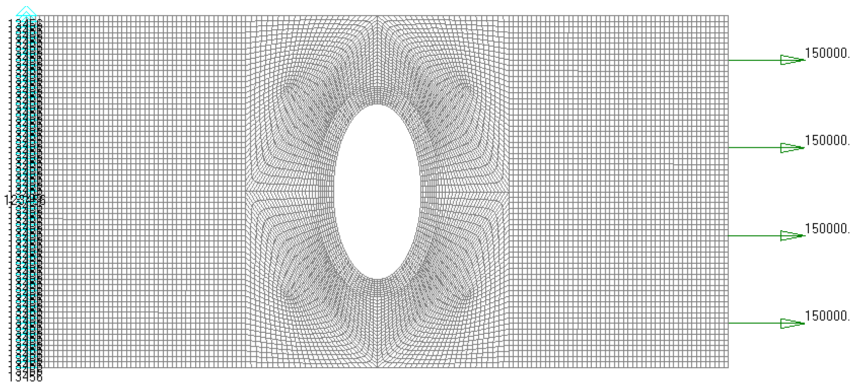


Fig. 1. The geometry of the plate to be constraint, load and mesh

Where the curvature is maximum, they can reach values that are many times higher than stress values in a solid plate: $\sigma_y = \sigma_0\left(1+\frac{2l}{b}\right)$. According to the given formula, the stress at the vertices of a narrow ellipse (l / b – is large) can become very large. If we enter the quantity ρ in the formula, which is called the radius of curvature at the vertex of the section, we get

$$\sigma_y = \sigma_0 \left(1 + 2\sqrt{\frac{l}{\rho}}\right).$$

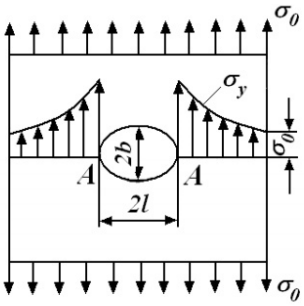


Fig. 2 stress distribution

Solution was found that the calculation of stress concentration by this formula is used not only for elliptical holes, but also for holes of any shape, on the contour of which there are points with a small radius of curvature. Of course, in real materials the stresses may increase to certain limits and the above formula cannot be used without further analysis. Stress concentrations must be carefully considered in strength calculations.

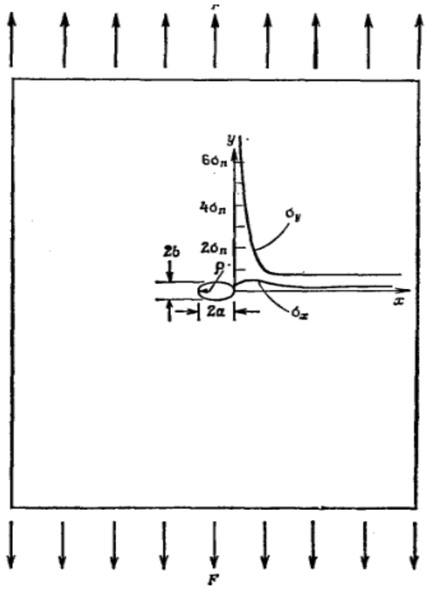


Fig. 3 Analytical solution

Stress concentrations must be carefully considered in strength calculations. Professor K. Thanks to England, the concept of "stress concentration" was introduced. The number that shows how many times the local voltages exceed the nominal is called the voltage concentration factor. Consider an example:

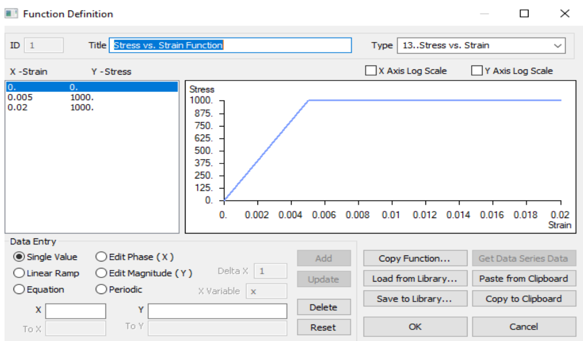
Given a steel plate with an elliptical hole at the center of $400 \times 200 \times 2$ mm, whose semi-axes are 50 mm and 25 mm, is subjected to a tensile force of 150 KN. (See Fig. 1.) Mechanical characteristics of the material: modulus of elasticity is equal to $E = 200000$ MGP. Poisson's ratio is $\mu = 0.3$ and the relationship between deformation and stress for a given material is given by the following formula:

$$\sigma = \begin{cases} 200000\varepsilon, & \varepsilon \in [0; 0.005] \\ 1000, & \varepsilon \in (0.005; 0.02] \end{cases}$$

FEMAP, an engineering calculation program created on the basis of finite elements, build a plate of appropriate geometric dimensions (see Fig. 1). Let's model it with a 4-node quadrilateral finite element. Make an ellipse around the elliptical hole with semi-axes of 65 mm and 35 mm, divide the created area into the smallest possible rectangles, where the ratio of the sides will be less than 2, and increase the grid on the remaining area (Fig. 1).

Material and property assignment

Create a functional relationship to describe the characteristics and properties of the material. To describe the stress and deformation relationship, enter the graph coordinates (0;0), (0.005;1000), (0.02;1000). During the calculation, if the deformation exceeds 0.02, extrapolation is required to calculate the remaining points. Also, we indicate that the material is nonlinearly elastic, does not obey Hooke's law.



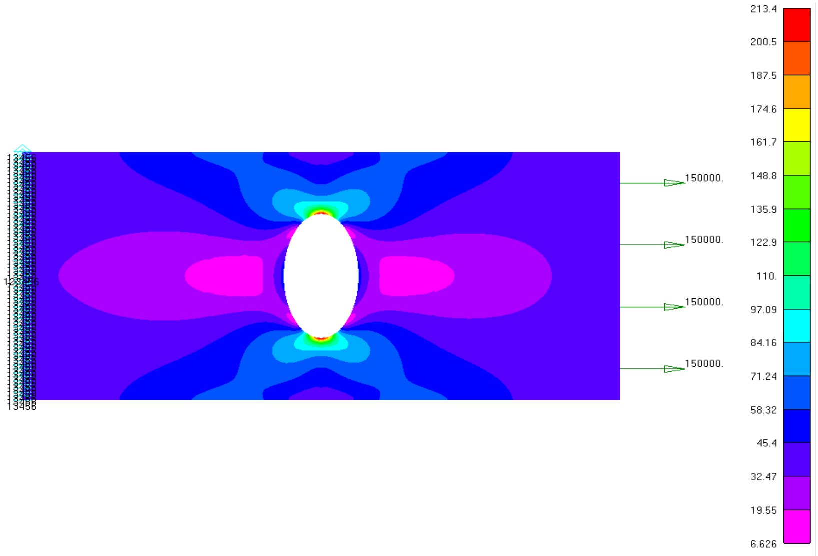
Constraints and loads

Fix the plate in such a way that its nodes on the left side are restricted from moving along the X-axis, and at the same time cannot rotate. All but one of the nodes will be able to move relative to the Y axis, which means that the plate can bend, during stretching, it will be possible to compress the plate in width. FEMAP has the ability to apply force to the line with a total load of 150,000 N, and the program itself will distribute it to the nodes.

Solution

Software results of nonlinear analysis of the given problem:

Case 1 Time 0.1 0.1*150=15KN load deformation is 0.099 mm and Mises stress is 213.4 MGP.



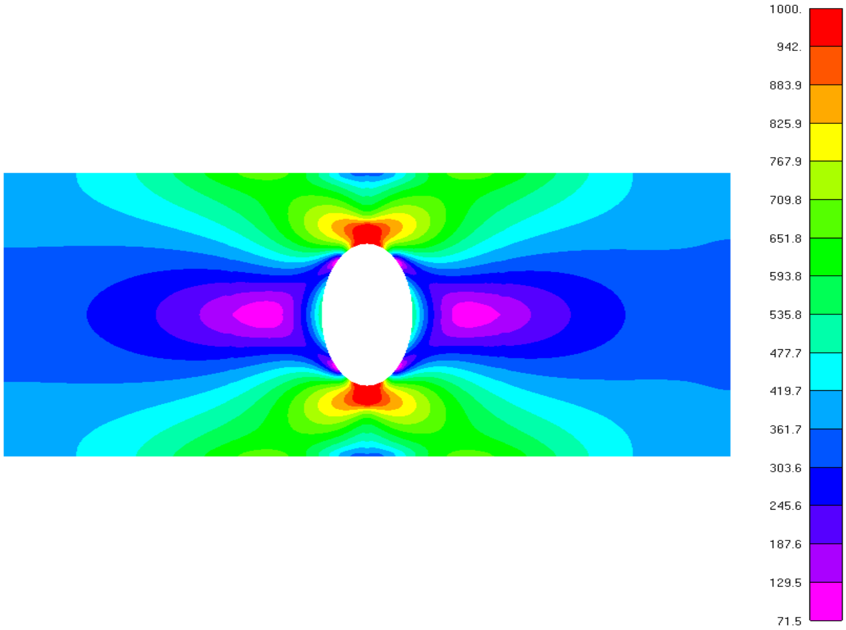
A single element in the concentration area includes no more than two colors, which indicates that the Se grid is well constructed. Also, it can be seen that there are different widths of bars in different elements, this means that we have a non-linear distribution picture.

Case 2 Time 0.2 0.2*150=30KN load did not change the picture, the voltage increased to 426.6 MGP. And the deformation will be 0.199 mm.

Case 3 Time 0.3. The load is equal to 0.3*150=45KN, the picture is the same, only the value of voltage 639.7 MGP has changed. And the deformation will be 0.298 mm. until the equivalent Mises voltage exceeds 1000 MPa. This image will not change.

Case 4 Time 0.4 0.4*150=60 KN, and the equivalent Mises stress is equal to 852.6 MPa. After that, the image will change qualitatively.

Case 5 Time 0.5, 0.5*150=75 KN. The equivalent Mises voltage on the load is exactly 1000 MPa. The deformation is equal to 0.496 mm. The image will change qualitatively and on all subsequent cycles the image will change and the voltage will be unchanged at 1000 MPG. The deformations will increase on the tenth stage (at the final stage) and I can see the picture visually:



The deformation is equal to 1.026 mm. As can be seen from the picture, plastic flow of the material took place.

Summary

Based on the numerical experiment, we can make the following conclusion, if we approximate the surface of the plate with 4-node quadrilateral elements of different sizes (it is not necessary to use parametric e.g. 8-node quadrilateral elements), the error with respect to the analytical solution is practically equal to 0, and also if the ratio of the semi-axes of the hole is equal to two, then The voltage value at the vertices of the parabola increases seven times.

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ელიფსური ნახვრეტის მქონე ფირფიტის მოდელირება ღერძული დატვირთვის შემთხვევაში პლასტიკური დეფორმაციის გათვალისწინებით

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რღვევის თეორიის შესწავლის ერთ-ერთი პრობლემაა დაძაბულობის ველის შესწავლა კონკრეტული კონცენტრატორების არეში. პრაქტიკული გამოყენების თვალსაზრისით, დაძაბულობის კონცენტრაცია ძირითადად გვხვდება არა მხოლოდ სიხისტის მკვეთრი ცვლილების არეში, არამედ ხვრელების მიდამოშიც. კონცენტრაციის პრობლემის გადაწყვეტას კიდევ უფრო ართულებს დატვირთვის შედეგად მიღებული მასალის ფიზიკური არაწრფივობა. ამ სტატიაში განხილულია უსასრულო ფირფიტა ცენტრალური გრძივი ხვრელით, კონკრეტულად ელიფსური, ღერძული დატვირთვის ქვეშ. სტატიის მიზანია პროგრამულ კომპლექსში FEMAP-ში სადიაგნოსტიკო მოდელის შექმნა, რომლის გადაწყვეტა მოგვცემს კონცენტრაციის ზონის (გავრცელების არეალის) შეფასებას.

რიცხვითი ექსპერიმენტიდან გამომდინარე შეიძლება გავაკეთოთ შემდეგი დასკვნა, თუ ფირფიტის ზედაპირის აპროქსიმაციას მოვახდენთ სხვადასხვა ზომის 4 - კვანძიანი ოთხკუთხა ელემენტებით (არაა საჭირო იზოპარამეტრული მაგ. 8 კვანძიანი ოთკუთხა ელემენტების გამოყენება) ცდომილება ანალიზურ ამონახსნთან მიმართ პრაქტიკულად 0-ის ტოლია და ასევე თუ ნახვრეტის ნახევარღერძების შეფარდება ორის ტოლია მაშინ ძაბვის მნიშვნელობა პარაბოლის წვეროებზე იზრდება შვიდჯერ.

საკვანძო სიტყვები: *დატვირთვა, კონცენტრატორი, სიმტკიცე, სასრული ელემენტი.*