Investigation of the stressed state of a cut-out plate

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Abstract. The results of the numerical and physical experiments aimed at studying of the flat element's stress state with an oval cut and ten crack - simulating cuts are presented in the article. It was estimated the influence of the cuts inclination angle on the stress values. The stress concentration coefficients at the cracks' vertices were obtained.

1. Purpose and objectives of the study

The aim of this work is to study the flat element's stress state having an oval cutout and stress concentrators in the cracks form. Objectives of the study are to assess the influence of cracks inclination angle on the element's stressed state; calculate the stress concentration coefficients near the cracks; to study expediency of the decision application of the program complex SCAD tasks. In order to achieve the intended goal, the finite element method implemented in the SCAD software complex was used, and the photoelasticity method as the experimental method of stress study.

The problems of stress concentration using numerical and experimental methods were investigated in [1-8]. A model of a polarization-optical material - E2 Plexiglas (modulus of elasticity E=3500 MPa, Puasson's ratio ν=0.4, band price for voltages $\sigma_0^{1,0}$ = 1650 kPa sm) with overall dimensions 93mm × 84mm × 6mm was studied in both cases. An oval cutout at the intersection of the symmetry axes weakened the element. To the port's contour at different angles, cuts simulating cracks were made in the number of ten pieces. The model is shown in Figure 1, the numbers 1 - 10 are the number of cracks-cuts.

2. A numerical experiment

Using finite element method (FEM) with the software complex "SCAD" use, the above planar model was calculated in two versions. In the first case, the fracture-cutting axes are rectilinear, in the second, some cracks have deviations from the rectilinear axis. The finite element scheme of the calculation model and the loading scheme are shown in Figure 2. The model is loaded with a compressive nominal load q_0=10.75 kN/m in the vertical direction. Vertical axis of symmetry is fixed from horizontal displacements, and horizontal is fixed from vertical ones. The models had a square basic grid with a cell size of 1x1 mm. In the area of the cracks' peaks, the grid cells were reduced to 0.25x0.25 mm.

Figure 3 shows the stress fields of the main σ_1, σ_2, and tangential stresses τ_{xy} in two models with straight and broken fracture-propyl axes. In order to analyze the obtained results, we should note that a slight slope of the crack axis does not affect the stress values in the model at a distance from the crack peaks. The situation is different near the peaks of the cuts. The greatest difference in the stress values was noted at the crack tip № 5, which was 26% (the voltage of the inclined crack apex is less).
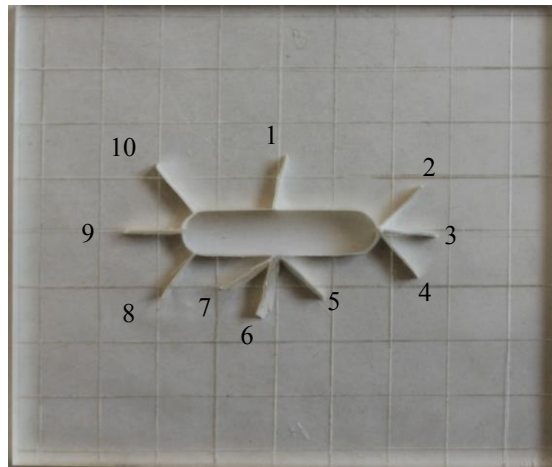
Figure 1. The model under the study.

$q = 10.75$ kN/m $q = 10.75$ kN/m
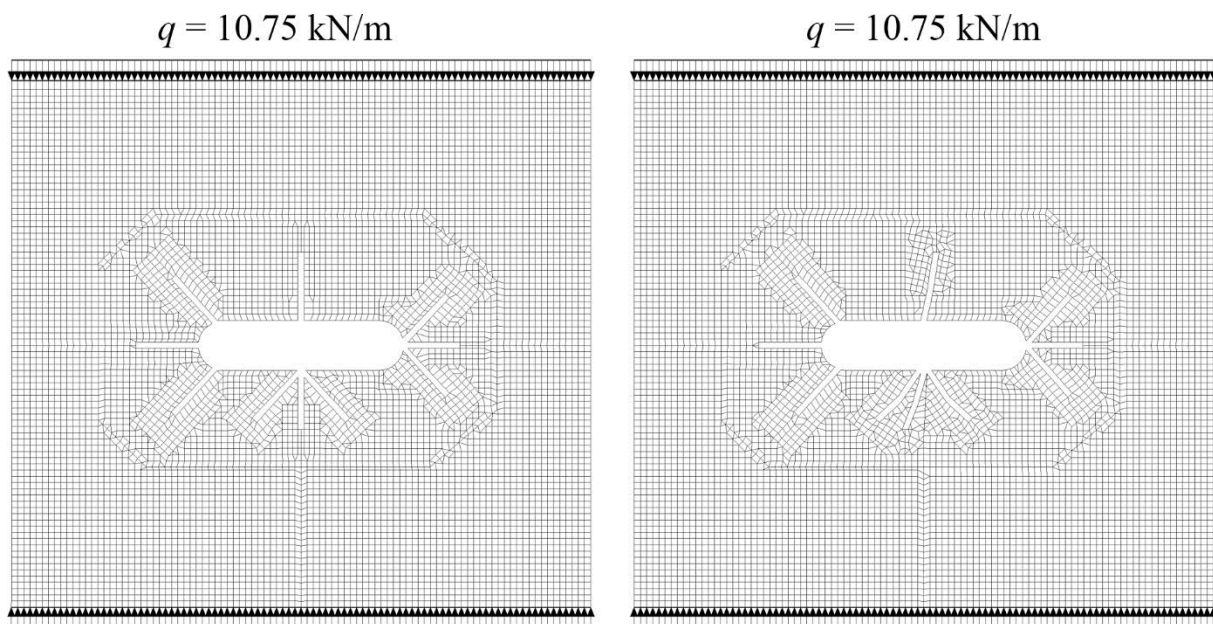
Figure 2. Loading scheme of the calculation model.

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The zone of concentrators influence is not the great one, the stresses in the model quickly equalize. At the tops of horizontal crack-cuts, the highest stresses are marked. The maximum stress is observed at the crack tip № 3 ($\sigma_{max} = 16.1$ MPa). At the vertices of inclined cracks № 2 and 4, the stresses are much higher than in cracks №10 and 8, which is apparently due to the fact that crack № 9 is single with insignificant influence of cracks № 10 and 8, and cracks № 2, 3 and 4 work as a single concentrator with redistribution of stresses in the vertex zone. The stresses at the cracks tops located

near the horizontal axis of the model are negative, while the peaks of the cracks located near the vertical axis are positive.
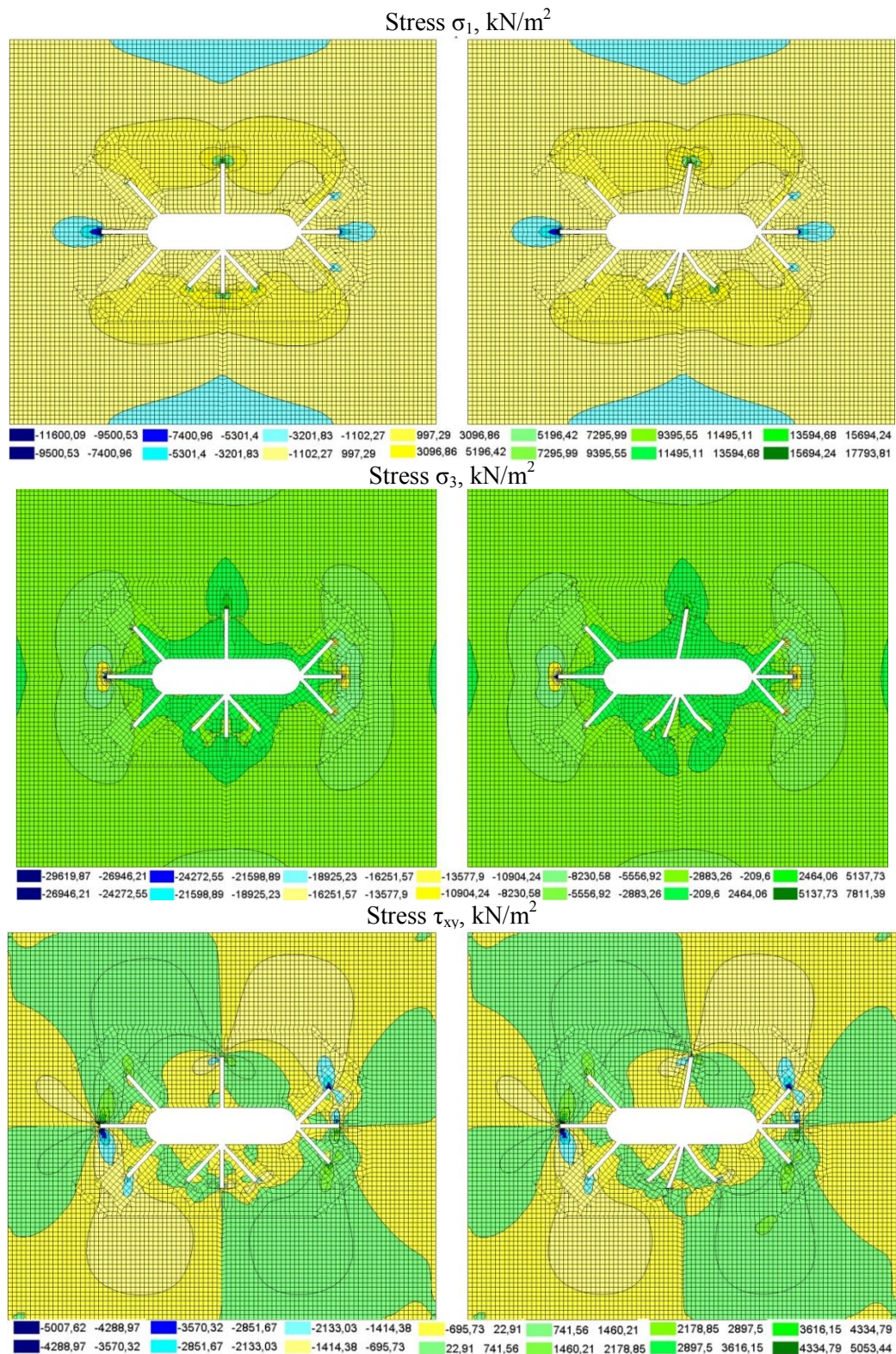
Figure 3. Stress fields obtained by the SCAD software.

3. Polarization-optical experiment

In order to verify the numerical experiment results, a photoelastic analysis of the model given in Figure 1 was performed. In a physical experiment, the cracks of № 1 and № 6 are inclined. In the case of a model direct translucence in white light, patterns of interference bands were obtained in the PPU-7 setup [9]. The interference strip connects points with the same principal difference in the stress plane. Figure 4 shows the pattern of interference bands at a load corresponding to a numerical experiment. The numbers 0 - 3 indicate the bands numbers.
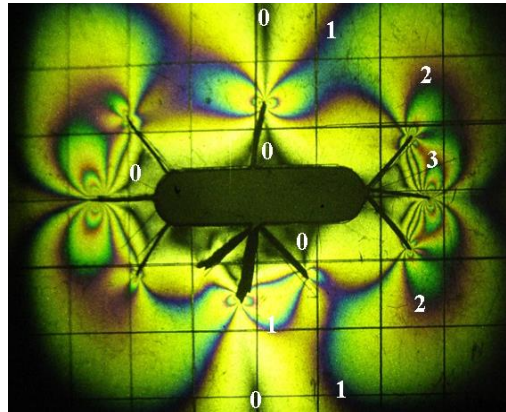
Figure 4. The pattern of interference bands.

By means of the interference bands pattern, the stresses at the peaks of the cracks-cuts are determined (the order of the interference band is multiplied by the strip price by the stresses, taking into account the model thickness). Such an approach to the determination of stress values on the port contour is described earlier in other works [10, 11, 12].

4. Kinetics of stress concentration coefficients

Based on the numerical and polarization-optical experiments results, the stress concentration coefficients at the tips of the crack-propyls is defined (1)

$$K_\sigma = \frac{\sigma_{\max}}{\sigma_0} \, , \qquad (1)$$

where $\sigma_{\max}$ and σ_0 are respectively, the maximum and nominal stresses.

The calculated maximum stresses are taken from the numerical calculation results of the FEM, and the experimental ones are obtained by means of interference bands; patterns. As far as, the stress normal is its zero on an unloaded circuit, and, consequently, a uniaxial stress state is realized, the maximum loop stress was determined from formula (2)

$$\sigma_{\max} = n \cdot \sigma_0^d \, , \qquad (2)$$

where σ_0^d is the price of the sample material strip.

The obtained concentration coefficients are shown in Table 1.

Analysis of the stress concentration coefficients, determined from the numerical experiment results, shows that their values obtained by the calculated (MCE) and experimental (polarization-optical method) results differ by a maximum of 2.3 times.

In the known reference books on the stress concentration coefficients [13, 14], the type of problems described in this article section is absent.

Table 1. Voltage Concentration Coefficients.

Number of crack	Physical experiment	Numerical experiment with inclined cracks	Numerical experiment with vertical cracks
1	6.2	6.29	6.38
2	6.9	4.73	4.80
3	4.2	8.98	9.01
4	6.9	4.69	4.67
5	3.1	2.86	3.62
6	5.4	4.86	4.38
7	0.77	3.16	2.34
8	5.4	2.41	2.37
9	4.5	8.05	7.12
10	6.2	2.72	2.43

5. Conclusions

In this paper, we simulated the cracks effect occurring along the port contour in structural elements on the stress state and concentration coefficients. The possibility of the SCAD software using for solving problems with cracks is considered.

We should note, that vertical and close to them cracks are more dangerous for the strength of the structure, since the stresses at their vertices are stretching, although they have smaller values than at the horizontal cuts' vertices.

Using the polarization-optical method, an experimental check of the stress concentration coefficients calculated based on the "SCAD" software complex was performed. This allowed us to conclude that the results of numerical methods calculations strongly depend on the cell size of the basic grid near the sharp concentrators. With a sufficiently fine grid, the stresses are much greater than in the real model. We must consider it during the structural calculations performing.

Data analysis presented in Table 1 shows that for the models with a horizontal oval cut the slopes of the first and sixth cracks lead to an insignificant change in the stress concentration near the other cracks (not more than 11%). The sixth crack is located near the seventh one, and therefore № 6 crack's slope has a greater effect on the stress change at the top of the seventh cut (26% decrease). The slope of the first and sixth cracks leads to a decrease in the stress concentration at the vertices by 1.5% and 10%, respectively. Comparing the concentration coefficients found by means of the photoelasticity method and numerical calculation, we can conclude that the numerical experiment gives understated values (except for the crack № 3, 6 and 9), the greatest discrepancy leaves more than 3 times (crack № 7). The percentage calculation is made in the relation to the physical experiment.

It should be noted the SCAD design model has been refined many times, the center grid has changed, it has been further broken near the cell cracks' vertices. All these measures did not allow us to get as close to the physical experiment as possible. Due to this fact, it can be concluded that the SCAD software complex does not allow to accurately estimating the stress state near cracks. Earlier, a similar study to assess the feasibility of SCAD software using to study the stress concentration near the corner cuts in planar elements allowed us to conclude that a decrease in the centering grid does not make it possible to achieve compliance with a physical experiment [4].

In conclusion, it can be said that in order to evaluate the stress state and concentration of stresses near such concentrators as cracks and angled notches it is necessary to consider the possibility of other software complexes using based on the finite element method with the goal of selecting a program correctly determining the voltage near the listed concentrators.

References

[1]   Pestrenin V M, Pestrenina I V and Landik L V 2013 *Vestnik of Tomsk State University. Mathematics and Mechanics* **4** 24 78–87

[2]   Stepanova L V and Dolgikh V S 2017 *University. Natural series. Mechanics* **1** 59–68

[3]   Frishter L Yu 2014 *Proceedings of Moscow State University of Civil Engineering* **5** 57–62

[4]   Pestrenin V M, Pestrenina I V and Landik L V 2014 *Vestnik of Tomsk state University. Mathematics and Mechanics* **1** 27 95–109

[5]   Darwish F, Tashtoush G and Gharaibeh M 2013 *Eur. J. Mech. A/Solids* **37** 69–78

[6]   Enab T A 2014 *Ain Shams Eng. J.* **5** 3 839–50

[7]   Jafari M and Ardalani E 2016 *Int. J. Mech. Sci.* **106** 220–30

[8]   Handa D, Dondapati R S and Usurumarti P R 2017 *Int. J. Mech. Eng. Techn.* **8** 1718–25

[9]   Alexandrov A Ya and Ahmetzyanov M H 1973 *Polarization-Optical Mechanics Methods of a Deformed Body* (Moscow: Science)

[10]   Tabanyukhova M V and Pangaev V V 2006 Photoelastic analysis of mode i stress intensity factor in beams with angular notches *Proc. 16th European Conference of Fracture* (Alexandroupolis: Greece) 447–48

[11]   Albaut G and Tabanyukhova M 2006 *News of Higher Education Institutions. Civil Engineering* **10** 107–12

[12]   Albaut G N, Pangaev V V, Tabanyukhova M V and Kharinova N V 2005 *News of Higher Education Institutions. Civil Engineering* **1** 97–102

[13]   Peterson R 1977 *Coefficients of Stress Concentration. Graphs and Formulas for Calculating Structural Elements for Strength* (M.: Mir)

[14]   Savin G N and Tulchy V I 1976 *Reference Book on Stress Concentration* (Kiev: Vishcha school)