Numerical modeling of a plate with an oval cut and cracks on the contour

A A Lazarev¹, N V Kharinova¹

¹Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Novosibirsk, Russia

E-mail: n.kharinova@sibstrin.ru

Abstract. A numerical study of a plane model with an oval cut and cracks-cuts along the contour, made at different angles, was performed. The change in the stress-strain state with the successive appearance of cracks-cuts was considered.

1. Purpose and objectives of the study

The purpose of the work was to study the stress-strain state of the model with an oval cut, depending on the appearance of cracks-cuts on its contour. Objectives of the study: to assess the effect of successive appearance of cracks in the contour cut on the stress state of the element; to calculate the stress concentration coefficients near the cracks top. The SCAD software package was used for the numerical study.

Previously, models with other concentrators were studied [1-3].

The studied model was made by the polarization-optical material – Plexiglas brands of E2 (modulus of elasticity E = 3500 MPa, Poisson's ratio ν = 0.4) with dimensions of 93mm x 84mm x 6mm. At the intersection of the axes of symmetry cut out the oval hole. At different angles to the contour of the oval cut cracks-cuts were made. A photo of the model and the sequence of cracks is shown in Figure 1.

Figure 1. The model under the study.
2. Numerical experiment

The finite element method (FEM) using the software complex "SCAD" was used to calculate a group of models with different number of cracks-cuts on the contour of the oval cutout. The order of occurrence of cracks is shown in Figure 1. Cracks № 7-10 have deviations from the straight axis, other cracks - straight. The finite element scheme of the computational model and the type of loading are shown in Figure 2. The model was loaded with a compressive rated load \( q_0 = 10.75 \text{ kN/m} \) in the vertical direction. The vertical axis of symmetry is fixed from the horizontal displacements, and the horizontal axis from the vertical ones. The models had a square base grid with a cell size of 1x1 mm.

![Figure 2. Loading scheme of the calculation model](image)

3. The results of the numerical experiment

Figure 3 shows the stress fields \( \sigma_1 \) and \( \sigma_3 \) in the models with different number of cracks-cuts. The following it was noted analysing the results. The zone of influence of concentrators was not great, the stresses in the model were quickly aligned and become uniform. At the tops of horizontal cracks-cuts marked the highest stress values. Stresses at the tops of cracks № 5 and 2 were much higher than that of cracks № 3 and 4.

Cracks № 7-10 were in the zone of positive stresses \( \sigma_1 \). On tops of inclined cracks № 2, 3, 4, 5 pass lines of change of a sign of tension \( \sigma_1 \).

With the advent of new cracks-cuts stress at the tops of existing cracks, as a rule, increased. The increase in stress was 5-20%. Most with the advent of new cuts increase stress at the top of the crack № 4 (2.2 times), at the tops of cracks № 1 and 3 maximum stress increased 1.4 times. The appearance of crack № 6 unloads the stress state at the tops of cracks № 2 and 5, and crack № 10, respectively, cracks № 8 and 9.

4. Kinetics of stress concentration coefficients

According to the results of numerical experiment, the stress concentration coefficients at the crack-propyl tops were determined by the formula (1)

\[
K_\sigma = \frac{\sigma_{\text{max}}}{\sigma_0},
\]

where \( \sigma_{\text{max}} \) and \( \sigma_0 \) - respectively the maximum and nominal stresses.

The calculated maximum stresses were taken from the results of numerical calculation of FE at the crack tops, nominal, respectively, at a distance from the concentrator.

The resulting concentration factors were listed in Table 1. Horizontal indicates the number of cracks in the model. Vertically - at the top of a crack the concentration coefficient was obtained.
The highest value of the concentration coefficient obtained from the top of the horizontal crack-cut: No. 1 $K_\sigma = 19.45$ and No. 6 $K_\sigma = 15.23$. At the same time, with the appearance of new cracks in the model, the concentration coefficients increased most strongly at the top of crack No. 4 (2.2 times). The concentration coefficients at the tops of cracks № 5 and 9 decreased by 30 %.

The concentration coefficient in the model with an oval hole without cracks along the contour was $K_\sigma = 5.2$. Thus, the appearance of the first horizontal crack increased the stress concentration in the model by 2.7 times. At the end, when there were already 10 cracks on the circuit, this value reaches 3.8 times.

In reference books on stress concentration [4, 5] the type of tasks described in this section of the article was absent.

| Cracks number | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1              | 13.74 | 15.05 | 14.99 | 15.51 | 17.14 | 17.59 | 18.47 | 19.27 | 19.28 | 19.45 |
| 2              | 13.02 | 13.20 | 13.39 | 13.55 | 8.87  | 8.72  | 9.11  | 9.81  | 10.02 |
| 3              | 4.98  | 4.61  | 4.35  | 4.49  | 5.85  | 6.48  | 6.43  | 6.60  |
| 4              | 2.99  | 4.30  | 5.95  | 6.75  | 6.80  | 6.61  | 6.58  |
| 5              | 14.22 | 8.87  | 9.86  | 9.45  | 9.43  | 9.38  |
| 6              | 14.65 | 14.70 | 14.71 | 15.18 | 15.23 |
| 7              | 7.03  | 7.69  | 7.94  | 8.07  |
| 8              | 6.95  | 7.57  | 6.35  |
| 9              | 6.79  | 4.66  |
| 10             | 8.64  |
Figure 3. Stress fields $\sigma_1$
Figure 4. Stress fields $\sigma_3$. 
5. Some of the findings of the research
In this paper, the influence of cracks arising along the contour of holes in structural elements on the stress state and concentration coefficients was investigated. Considered the change of the stress state in the model in the process of the emergence of new cracks.

It was noted that the vertical and close to them cracks have tensile stresses at the vertices, which was more dangerous for the structural strength. Although their values were significantly less than those of the horizontal ones.

Analysis of the data presented in Table 1 shows that with the appearance of new cracks, the stress concentration at the tops of existing cuts tends to increase. Cracks that appear between the slanted cuts, coming from the same point, lead to their discharge. The highest values of the concentration coefficients were at the tops of the horizontal cracks-cuts. At the tops of vertical cracks concentration coefficients were much smaller, but have a positive sign, which makes these cracks no less dangerous than horizontal.

References
[1] G. Albaut Model determination of stress levels in elements of building structures with angled notches / G.N. Albaut, M.V. Tabanjuhova // News of Higher Education Institutions. Civil Engineering. - 2006. - №10. - P. 107-112.
[2] G. Albaut To the problem of the stress intensity factors determination in the elements of building structures / G.N. Albaut, V.V. Pangaev, M.V. Tabanyukhova, N.V. Harinova // Izvestiya Vuzov. Civil Engineering. - 2005. №1. - P. 97 - 102.
[3] Tabanyukhova M.V. Photoelastic analysis of change mode I stress intensity factor in elements with angular notches / M.V. Tabanyukhova, V.V. Pangaev // In Proceedings of 16th European Conference of Fracture. Alexandroupolis, Greece, 2006. P. 447 - 448.
[4] Peterson R. Coefficients of stress concentration. Graphs and formulas for calculating structural elements for strength / R. Peterson - M.: Mir, 1977. - 450 p.
[5] Savin G.N. Reference book on stress concentration / G.N. Savin, V.I. Tulchya - Kiev: Vishcha school, 1976. - 412s