Investigation of Stress State in Plane Truss Nodes

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Abstract. Stress state in a plane truss node was studied in two ways: numerically using the finite element method and experimentally using the photoelasticity method. The finite element method was used to calculate plane truss model. Photoelasticity or polarization-optical method was used to research stresses of piezo-optical materials. The picture of interference fringe patterns in the model of a plane truss was obtained by the method of photoelasticity. Stresses were calculated with their help. The purpose of the work was to compare both methods. Fields of maximum tangent stresses were obtained in the sample plane using both methods. This work is a continuation of [1]. So, we obtained picture of interference fringe patterns and isocline fields in the node of the farm model, using the photoelasticity method. The field of maximum tangent stresses in the truss node was obtained by the photoelasticity method. The stress fields in the truss node were obtained by the finite element method in the software package “SCAD”. A comparative analysis of the numerical and physical experiments results was carried out and it was found that the nature of the stress distribution in both numerical and physical experiments coincides.

1. Introduction

The complexity of building structures, the use of nodes in a complex configuration entails difficulties associated with obtaining stress fields in these nodes. In some cases, experimental verification of numerical solutions and experimental studies was required. A truss is a structure consisting of perfectly straight rods connected at the nodes by cylindrical hinges and working for the perception of nodal loads [2-13].

Numerical and physical experiments were used for the study. The solution obtained in the SCAD software package was tested using a physical experiment. There were a number of experimental methods for studying stresses [14-16]. In this work, the polarization-optical method of stress investigation, namely the photoelasticity method [17-19], was applied.

2. Materials and methods

The sample was illuminated by a beam of coherent light, studying plane models with the use of a polarizing optical method. As a result, double refraction occurs and a picture of interference fringe patterns, or an isochromic field, was observed on the screen when a beam of light passes through the loaded model (Figure 1).

In the case of obtaining an isochromic field in white light, interference fringes with strictly defined color alternation was observed. Special points or areas with zero optical path difference were characterized by color; uniformity of care was determined by dark color. There was the same color of the entire field, corresponding to the wavelength of light, isochromes were observed as alternating...
dark and light lines against it, in order to obtain isochromes in monochromatic light. If we talk about the relationship between picture of interference fringe patterns and stress-strain state of model, then isochromes considered as lines that are the geometric location of points with the same difference in the main stresses.

![Figure 1. The picture of interference fringe patterns farm.](image)

We can observe isoclines, which are geometric places of points with the same angle of the main stresses inclination coinciding with the plane of polarization in addition to the isochrome field, in the photoelasticity studies, (Figure2)

Isoclines field could be obtained either in “white” or monochromatic light. They were observed as dark lights passing against the color picture background of interference fringe patterns, receiving isochromes in white light. They were observed as dark lights passing over an isochromatic fringe pattern consisting of alternating dark and light lines, receiving isoclines in monochromatic light. Therefore lines of isoclines in monochromatic light were difficult distinguish from isochromes. When the angle of the polarization planes inclination changed the isochromatic fringe patterns remains unchanged and
stationary and isoclines were moved relative to isochromes. Only with synchronous rotation of the polarization planes can one family of lines be distinguished from others. The isolines family represented isoclines field in the sample plane.

Isoclines in the stressed model are observed in plane-polarized light with the cross position of the polarization plane of the polarizer and analyzer. Thus, you need to get the picture of interference fringe pattern sand isocline field to study stress-strain state model.

3. Polarization-optical experiment

The model was studied made from polarizing–optical material - epoxy resin (E = 3000 MPa; ν = 0. 38. σ₀₁₀ = 1. 4MPa*sm, sample thickness = 0.5sm)

![Figure 3. Farm model.](image)

The farm is construction with rigid nodes, supported by a hinge at the edges. The load was concentrated force in the central node of the upper belt of the farm. The model was tested on polarizing unit PPU-7, loaded with force of 0.4 kN in the node of farm and highlighted with white light. As the result, a picture of interference fringe patterns farm was obtained.

On figure 4 the isochrome field was enlarged in the node which was noted on a figure 3. Numbers (1, 2, 3…) indicate the order of the interference fringe patterns.

The fringe pattern order was related with difference of the main stresses by the formula (1) where n is order of the fringe, σ₁, σ₂ are main stresses in the sample plane, h is thickness of the model and σ₀ is value of the material fringe. The band value is a difference between the main stresses that cause a single fringe to appear in a model with a thickness of h = 1cm and it is usually determined by calibration tests. In our case we consider a strip for material with a thickness of 0.5 cm

\[
n = \frac{h(\sigma_1 - \sigma_2)}{\sigma_0}
\]

![Figure 4. The picture of interference fringe patterns in the node.](image)
Then we determine the maximum tangent stresses $\tau_{\text{max}}$ based on the known dependences of the materials resistance.

$$\tau_{\text{max}} = \frac{\sigma_{y}^{0.1\alpha}}{2h},$$

As a result we got fields of maximum tangent stresses, presented on Figure 5.

4. Results
The finite element method (FEM), using the SCAD software package, was used to study a flat truss with rigid nodes, which rods were set by plate elements. The loading scheme of model was shown in figure 6. The characteristics of the calculated model correspond to the epoxy resin from the polarization-optical experiment. In the node, in the upper belt on the axis of truss symmetry, the node load $F = 0.4 \text{ kN}$ was set. The model was divided into cells that have a square base grid with a size of 1x1 mm. The x-axis was oriented along the rods.

As a result of calculating the model by the finite element method, stress fields $\sigma_x, \sigma_y$, and $\tau_{xy}$ were obtained in its plane (Figure 7). For figure 8 showed the stress fields in the truss node marked in figure 6, analyzing which, we can conclude that the maximum stresses were located in the center of the truss node. At the junction of the rods, there was a concentrator in the form of an acute angle, where extreme stresses were marked.

Comparing the stress fields in the numerical and optical polarization methods, we can note a qualitative coincidence of the results.

![Figure 5. Fields of maximum tangent stresses (MPa).](image)

![Figure 6. The loading scheme of model.](image)
Figure 7. Stress fields in the truss node.
Based on the work results, conclusions can be drawn:

1) we obtained picture of interference fringe patterns and isocline fields in the node of the farm model, using the photoelasticity method;

2) the field of maximum tangent stresses in the truss node was obtained by the photoelasticity method;
3) stress fields in the truss node were obtained by the finite element method in the software package “SCAD”;
4) a comparative analysis of the numerical and physical experiments results was carried out and it was found that the nature of the stress distribution in both numerical and physical experiments coincides.

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