Software for generation and analysis of photoelastic fringes in plates with a single hole subjected to in-plane loads

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ABSTRACT: A software package for generating and analyzing photoelastic images on infinite rectangular plates, subjected to in-plane loads, is being presented. It allows the user to generate photoelastic images as produced in a polariscope fed by monochromatic light. Both circular and plane polariscopes in conditions of dark or light field can be selected. Tools for obtaining light intensity distributions along horizontal and vertical lines and for extracting darkest regions of photoelastic fringes are also available. The extraction of such regions can be done by digital image processing (DIP). This process produces thin lines, from which main stresses and intensity factor used in the Fracture Mechanics can be obtained. The software was developed for running on *DOS* environment in SuperVGA mode. The synthetic photoelastic images are generated in 64 gray levels. This software is a very useful tool for teaching the fundamentals of photoelasticity and will help the researchers in the development of photoelastic experiments.

1 INTRODUCTION

In this paper an improved version of the FOTOEL software (Soares & Andrade 1994) is presented. This version includes infinite rectangular plates, having a single hole, and subjected to three kinds of loads distributed along its boundaries. It is part of a digital image processing system dedicated to the determination of the stress intensity factor KI of the Fracture Mechanics. The software allows generating and analyzing photoelastic images (isochromatics and isoclinics) in 64 gray levels, simulating a photoelastic experiment carried out with monochromatic light. Facilities for selecting the polariscope configuration (circular or plane, dark or light) are available. The software has options for extracting integer or even some non-integer order fringes from photoelastic images by thinning algorithms used in digital image processing. Light intensity distribution along horizontal and vertical lines and zoom effects on critical regions in terms of stress concentrations can be easily obtained. Fundamentals of photoelasticity are described in the next item.

2 FUNDAMENTALS OF PHOTOELASTICITY

The photoelasticity is a very old known technique (Frocht 1948), which makes use of birrefringent materials and the properties of light polarization. The photoelastic experiment is done with an equipment called polariscope, composed of a light source and polarizing elements (Analyzer, Polarizer and Quarter-wave plates). The light used can be white or monochromatic. Colored images are generated if white light is used. If the light is monochromatic the images are in gray levels. If the arrangement of polariscope elements includes quarter-wave plates, the polariscope is called plane. If not, it is named circular. The circular and the plane polariscopes can be also classified as dark or light, depending on the angle between the Polarizer and the Analyzer. The photoelasticity technique is based on a relationship between the main stresses in the loaded material and on the light intensity in the photoelastic image (Dally & Riley 1991).

In all computations involving photoelastic experiment the main stresses σ_1 and σ_2 are always present. They are the maximum stresses in a point of a loaded structure and reference values used by engineers for dimensioning structural components.

The photoelastic experiment is carried out with the help of birrefringent materials. They are non-crystalline materials with a single refraction index when not stressed. When stressed, however, they present two refraction indexes. When such materials are illuminated with polarized light, the emergent light beam is decomposed into two directions that has the same orientation as the directions of the main stresses.

Isochromatics are the images generated in a circular polariscope. In a plane polariscope there is a superposition of isochromatics with isoclinics.

For the same value of light intensity in an isochromatic, the same difference $(\sigma_1 - \sigma_2)$ is found. For each value of such difference only a single value of intensity light can be assigned. Based on these relationships, and with the help of some mathematical procedures, the separation of σ_1 and σ_2 can be done. In the case of monochromatic light (image in gray level) this relationship is accomplished in points where the light intensity reaches a local minimum (integer fringes). Isochromatics of integer order are generated in a circular polariscope in dark field condition.

It is possible to get information about the orientation of the main stresses, in relation to a selected reference direction, with the isoclinics. In these images, for the same light intensity level, the same inclination of the stresses σ_1 or σ_2 is found. The isoclinics are generated together with the isochromatics in a plane polariscope. For obtaining the isolated isoclinics some arrangements have to be done to eliminate the isochromatics.

3 FRINGE EXTRACTION

The fringe extraction consists in finding the central lines that composes the darkest regions in a photoelastic image. Two steps have to be followed for this purpose: skeletonization and thinning. In the first step wide lines containing the mentioned darkest region are produced. This can be performed using a binarization process or using special algorithms (Yatagai 1982) that preserve the gray level of the image inside the skeleton.

Following this step, a thinning approach (Hussain 1991) can be used for determining the central lines.

4 SOFTWARE DESCRIPTION

The FOTOEL software package was developed using *DOS* environment and Borland "C" language. It can be used in two modes of high screen resolutions: 640x480x256 and 800x600x256. For this purpose a SuperVGA driver was used (Davis 1987).The control options are selected via fixed mouse menu (bottom and left) as illustrated in Figure 1.
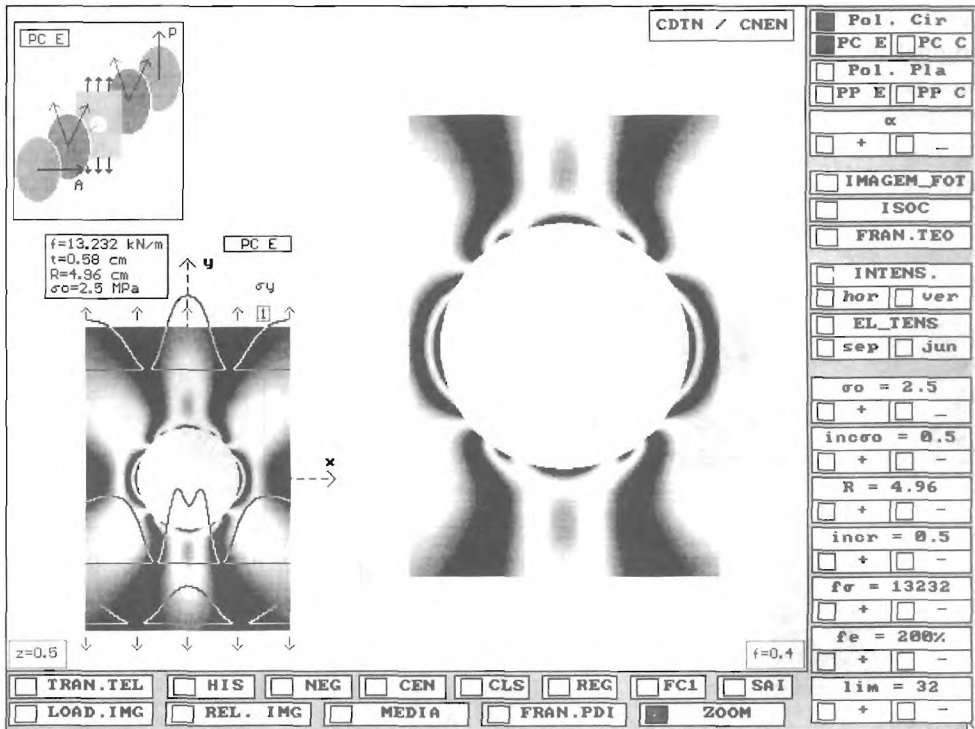

Figure 1. Work screen for the FOTOEL software with menu and some results.

The options available are: (1) type of polariscope - circular (Pol. Cir) and plane (Pol. Pla); (2) type of polariscope field - dark (PC E, PP E) and light (PC C , PP C); (3) alpha angle for generating the isoclinic; (4) generation of photoelastic image IMAGEM_FOT); (5) isolated isoclinic (ISOC); (6) intensity level along horizontal or vertical lines (INTENS), (7) main stress values and related angles (EL_TENS); (8) selection of applied stresses on the plate boundaries (σ_0); (9) radius value selection (R); (10) stress fringe value (f_σ); (11) scale factor for amplifying the image (fe) and (12) structural model (FC1, FC2, FC3).

Some other auxiliary options, related to DPI, can be also selected from the bottom menu. They are: (1) loading of a PCX image (LOAD IMG); (2) showing a loaded image

or a generated synthetic image in another part of the screen (REL. IMG , TRAN. TEL); (3) image histogram (HIS); (4) image negative (NEG); (5) media on four neighbors (MEDIA); (6) electronic rule (REG); (7) fringe extraction (FRAN_PDI) and (8) zoom function (ZOOM).

5 RESULTS

A global view of the work screen, given in Figure 1, illustrates isochromatic (left bottom) from the selected polariscope arrangement (left top) , zoom function (central) in the hole region of the isochromatic on the left, and vertical and horizontal menus. More details are presented in the zoomed image, in the hole region, when compared to the original isochromatic. Illustration of light intensity distributions along two horizontal lines is also presented in Figure 1.

Figure 2 presents the available structural plate models (infinite plate with a single circular hole). The loads are applied on the infinite boundaries. The possible polariscope arrangements are shown in Figure 3, where PC represents Circular Polariscope and PP Plane Polariscope. The final letters E end C means Dark and Light, respectively.
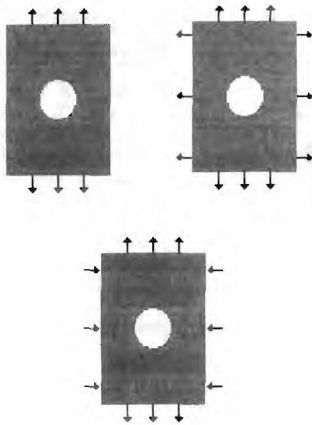

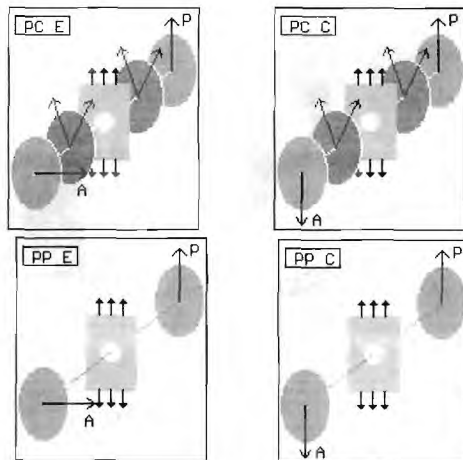Figure 2. Available structural plate models.

Figure 3. Polariscope arrangements.

Photoelastic images corresponding to the polariscope arrangements in Figure 3 are shown in Figure 4. For the circular case (PC), the left image (dark field) are integer fringes and the right (light field) are non-integer fringes multiples of 1/2. For the plane case (PP), the images are a superposition of the images in the top (circular case) with the corresponding 30 degree isoclinic shown in Figure 5.

Isochromatic images for the three available load combinations are shown in Figure 6. An isochromatic image generated with zoom function on the hole region of isochromatic

from Figure 1 is shown in Figure 7, where a greater number of fringes can be then observed. In the left side of Figure 7, results of integer fringe extraction are illustrated.
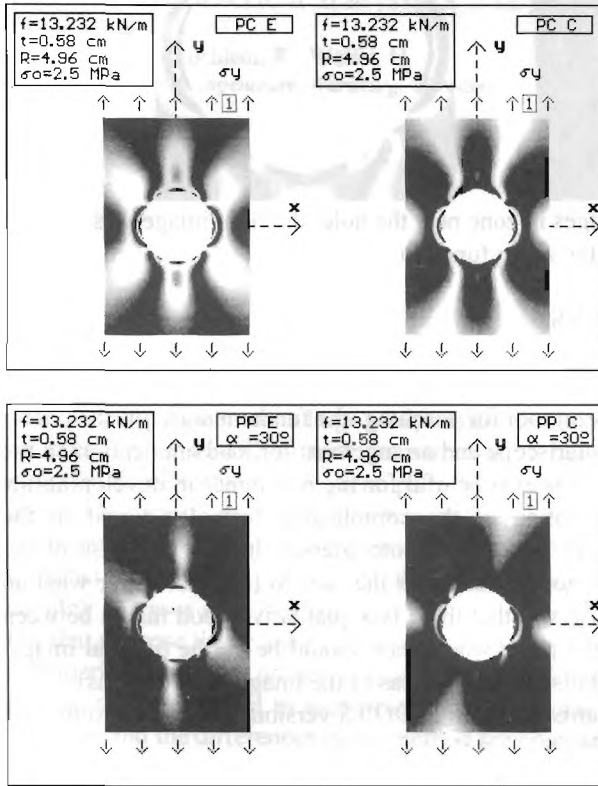

Figure 4 Photoelastic images corresponding to the polariscope arrangement in Figure 3.
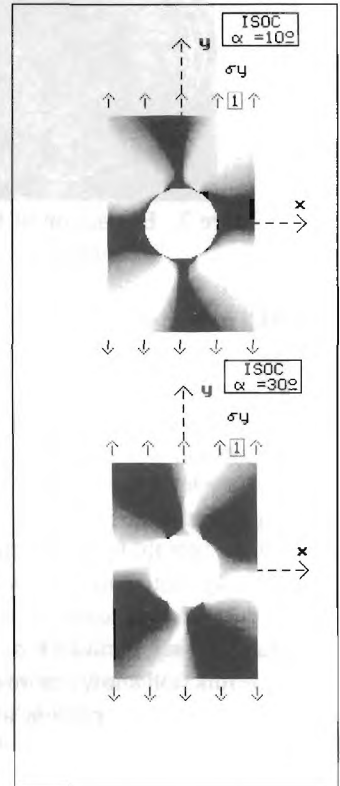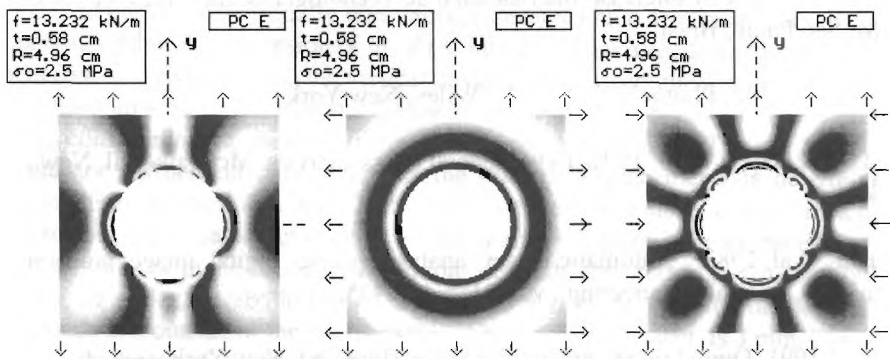
Figure 5. Examples of isolated isoclinics.

Figure 6. Isochromatics for the available structural plate models with circular polariscope in dark field conditions.
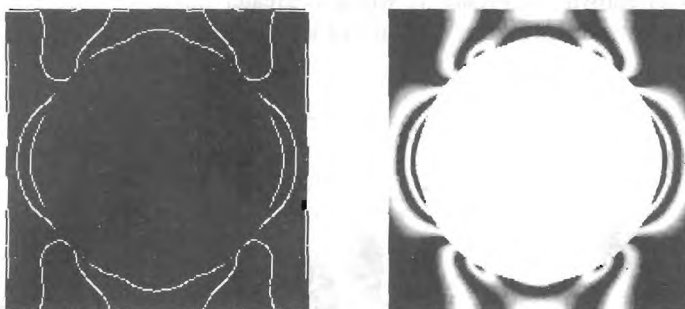
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Figure 7. Extraction of fringes in zone near the hole; the right image was generated using the zoom function.

6 CONCLUSIONS AND REMARKS

This software package is a very useful tool for teaching the fundamentals of the photo-elasticiy technique, even when a polariscope and arrangement for load application on the structural model are not available. It is also helpful for the researcher in developing the photoelastic analysis. The interpretation of the complicated formulas found in the photoelastic literature can be rapidly transformed into friendly images. The use of the light intensity distribution on a horizontal line helps the user to interpret better what an integer order fringe means. It is observed that there is a qualitative good match between the extracted fringes via DIP and the place where they should be on the original image. The zoom function shows more details in critical areas of the image (hole regions) .

Implementation is at present towards a *DOS/WINDOWS* version,including also on-line theory help.

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