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Experimental Study, Using Strain Gauge Technique, for Stress Measurement on 45^0 Angular Tubular Branched Structures

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Abstract

Tubular branched structures are a widespread alternative for technological paths. Due to geometrical discontinuities, under specific loads, they show strong mechanical stress concentrations. In order to reduce the unacceptable technical risk in service is necessary to establish an efficient method to quantify the effects produced by the internal pressure load, the most commonly encountered case in practice. Quantifying the effects of stress concentrator by classical analytical methods, it is very difficult because of reduced mathematical modeling opportunities. However, numerical modeling by finite element method can be used to simulate the behavior of structures with complex geometry. In order to validate the results obtained using finite element analysis is necessary to compare the results of numerical analysis and experimental results obtained from analytical calculation. For this purpose it was designed and built an experimental structure, designed to highlight the effects of concentrators produced by geometric discontinuities. The experimental structure allows determination of stresses in 33 points, on tree axes.

Key words: *Tubular brached structures, stress concetrators, mechanic stress, strain gauge.*

Overview

Tubular branched structures are a common alternative for technological pipe systems. Under specific loads, due to geometrical discontinuities, they show strong concentration of mechanical stresses.

The mechanical stress concentrator means any source or abnormality such as design, metallurgy and so on, causing increases in intensity of mechanical stress at its location and in its immediate vicinity.

Is necessary to establish an efficient method to quantify the effects of stress concentration in order to eliminate unacceptable risk and allow a predictable technical exploit for such structures.

Usually, the mechanical stress concentration factors are directly determined, based on numerical results, which were obtained by analytical solutions, by experiment or by numerical computer simulation [1, 2].

Fundamental formulas of strength of materials, commonly used in engineering practice, are correct and truly applicable only for elements which have constant or smoothly changeable section, elements considered simple, typical or standard.

Such conditions are uncommon for the high stressed areas of real structures. The presence of holes, grooves, protrusions, threads, rays of joints and other drastic changes, structural geometrical configuration (inclusions, holes, welding etc.) involves a more complicated distribution of mechanical stress, compared with the corresponding distribution for the typical elements. Therefore, there is inevitable the presence of zones with local increases of stress level and this effect denotes the mechanical stress concentration.

Analysis of the mechanical stresses and deformations of elements of structures/systems in general and the determination of concentration coefficients, in particular, is made by analytical methods (elasticity theory problems), numerical (finite element method) and experimental (photoelasticity, strain gages technique, holographic interferometry, brittle lacquer method etc.). Because the exact analytical solutions are known only for a small number of cases, the vast majority of studies are being carried out by numerical methods or experimental. Numerical calculation methods alone can only lead to inaccurate results and this is due to mismatch of the input conditions and the actual data or the errors of computerization. On the other hand, using only experimental methods involve difficulties, specific features are limited and often not allowing full resolution of the problem. It follows a major interest to use in combination analytical methods, numerical and experimental that allows analysis of stress concentrators effects, determining the contour area data - experimental – stress and strain conditions, based on these conditions it is studied - analytically or numerically - the distribution of mechanical stress in the area.

Experimental Structure

To get experimental results that can be used as reference it was undertaken an experimental analysis of the mechanical stress concentration at the intersection of a cylindrical tubular junction field, inclined at 45^0, DN200 nominal diameter, made by welded pipes.

The tubular junction, shown in Figure 1 was build by welding two 45K3 cylindrical pipes, Φ219x8 mm, hot-rolled low-alloy steel.

To pressurize the structure, the end of the pipes had to be closed, this was done by welding ellipsoidal caps. Ellipsoidal shape of the cap was chosen to reduce the effect of stress induced by sections of the tube end, tensions that could had been superimposed on the state of stress in the geometric discontinuity, distorting the results.

The structure has been provided with threaded connections at each cover, which is used in the hydraulic assembly to achieve the necessary internal pressurization.

The hydraulic installation consists of a hydraulic gear pump used to achieve internal pressure, a valve needed to remove air from the tubing and drain fluid from the end of the experiment and high precision pressure gauge used to read internal pressure.

Because it was intended to highlight and quantify the effects of concentration caused by the geometric discontinuity, strain gauge transducers were positioned so as to determine the strains and tensions both in the vicinity of the welded line and in more remote areas to capture local and global effects.

To achieve the strain gauges layout, areas of interest has been defined, thus defining areas called “calibration”, in the remote areas of the line of intersection of two cylindrical pipes, where the state of stress is not influenced by geometrical discontinuities of the structure.

In the geometric discontinuity areas were defined several areas of interest, an area that includes the vicinity of the weld along its full length, two areas located at the intersection of the two shells, the sharp angle, obtuse angle respectively of the intersection, another area is the median at the intersection of two tubes arranged on the circumference of the base pipe. Areas where the concentration is favored by the geometry of surface tensions were set symmetrically to check the results.

Figures 2 and 3 show the layout of these areas as well as the arrangement and orientation of strain gauge transducers [3].

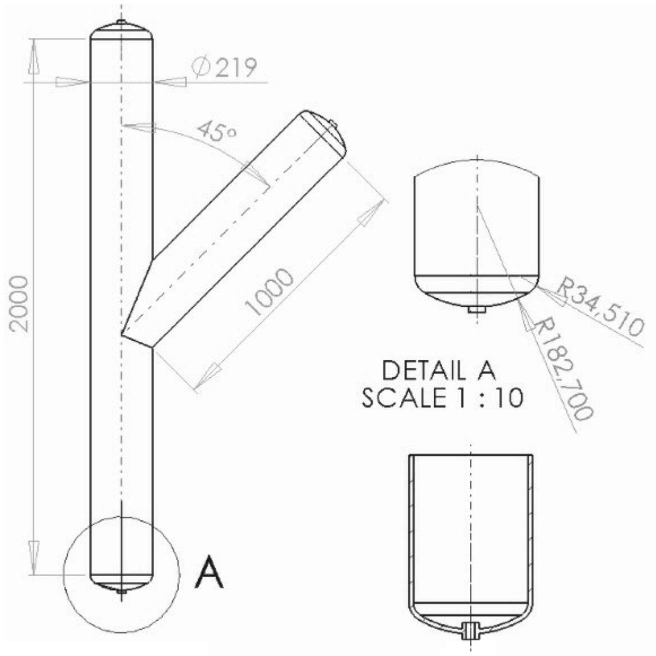

Fig. 1. The design of the experimental structure

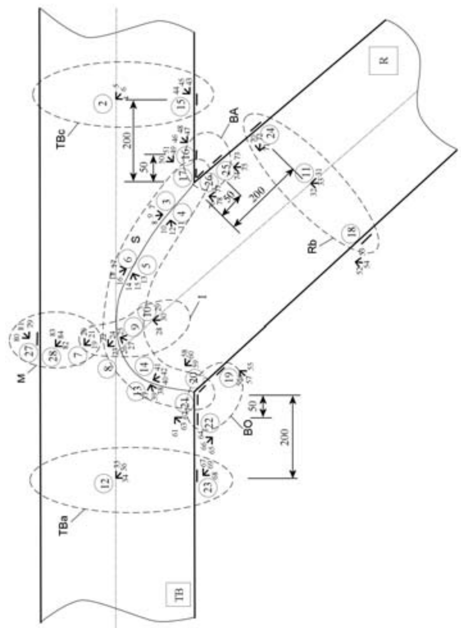

Fig. 2. The layout of the strain gauges, top view

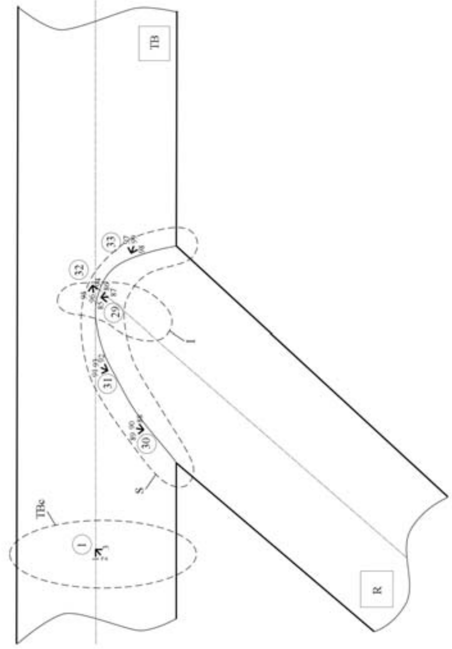

Fig. 3. The layout of the strain gauges, bottom view

Description of the areas of interest:

TBa - A calibration area located on the TB element, near the obtuse branch, located at 200mm from the intersection of the two tubular elements.

TBc - C calibration area located on the TB element, near the sharp branch, located at 200mm from the intersection of the two tubular elements.

Rb - B calibration area located on the R element, located at 200mm from the intersection of the two tubular elements.

BO - the junction between TB and R near the obtuse branch.

BA - the junction between TB and sharp R near the sharp branch.

S - the contour determined by the intersection of R and TB represented by weld line.

M - middle area, near the intersection of the axes of the two tubular elements.

I, I '- areas with maximum stress concentrator.

It were used 99 Hottinger transducers consisting in 33 strain gauge rosettes (1-RY33X-6/120, producer HBM), with three directions of measurement (0^0, 45^0, 90^0) and were grouped in 33 measuring data points (PMT).

Strain gauge rosettes choice was justified by the need to determine the main directions of stress and deformation in the weld area.

Strain gauge rosettes were attached to the pipe surface using special adhesive Z70 manufacturer (HBM). The surface was initially prepared by removing irregularities to ensure the best possible contact surface, and was subsequently defatted for determining the adhesive to achieve the best conditions. To preserve the strain gauge glued and to avoid oxidation and soldering the terminal contacts to use insulated protective grout ABM75 aluminum foil manufacturer (HBM).

In order to support the structure in horizontal position, the two ends of the TB element had been leaned on two supports provided with clamps; and one plain bearing, which allows sliding horizontally on the free end of R. Their position was determined as a result of simulations by finite element method aiming to eliminate the effect of deflection caused by the weight of the structure and the liquid used for pressurization.

In order to determine the stress concentrator for the structure it was defined an experiments plan, this it included two pressurization schemes, both with maximum pressure of 24.5 bar.

Pressurization schemes have been defined as the step hydraulic pressure test (IPH-T) in steps defined by the following steps (expressed in bar): 0, 4.9, 9.8, 14.7, 19.6, 24.5, used for compresion and decompression, and direct hydraulic pressure test (IPH-D) using direct pressurization and depressurization stages to a maximum pressure of 24.5 bar expressed (fig. 4).

Determination of stress and strain states has been achieved in terms of hydraulic internal pressurization, at standard normal temperature conditions, $t = 20^0$. To achieve the measurements it was used a electronic analogue bridge type Wheatstone produced by Hottinger, reading precision of 5μm/m.

The bridge used permit the use of a simple cable layout with a single wire to each terminal of the strain gauge transducers, however, was necessary to use thermal compensation using plates made of the same material as the structure with strain gauges attached (1-LY11X-6/120, producer HBM).

To ensure precise measurements, special attention was given to the zero readings, both at the beginning of measurements and at the transition from the step by step loading regime to the straight loading regime.

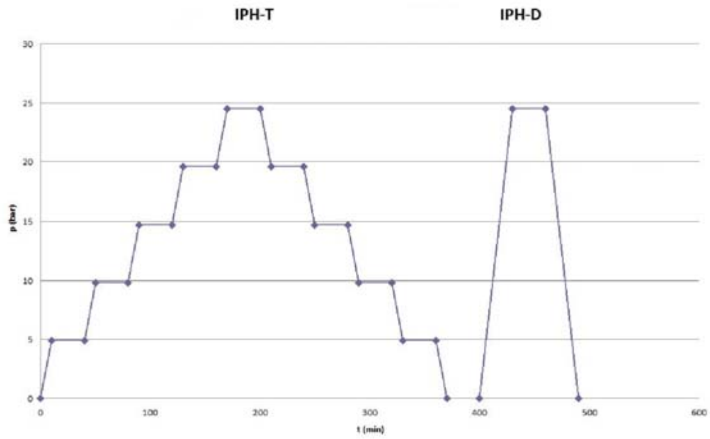

Fig. 4. The two pressurization schemes

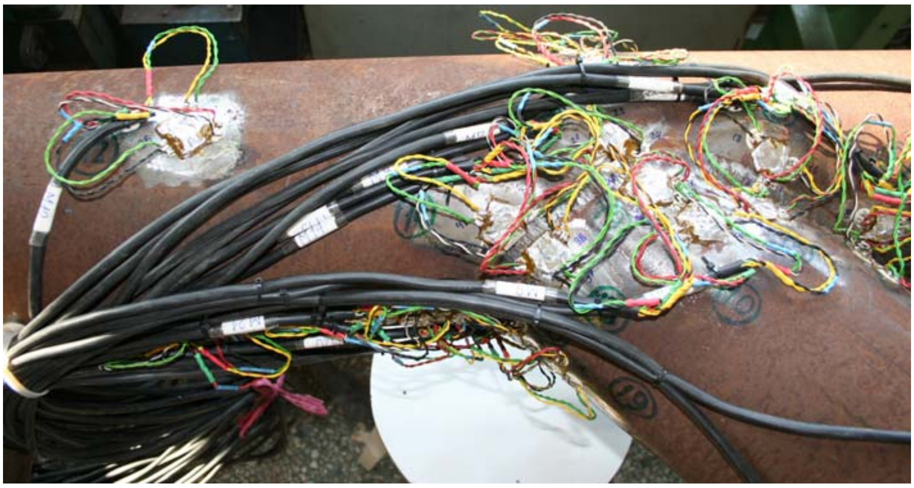

Fig. 5. Detail of the strain gauges layout, top view

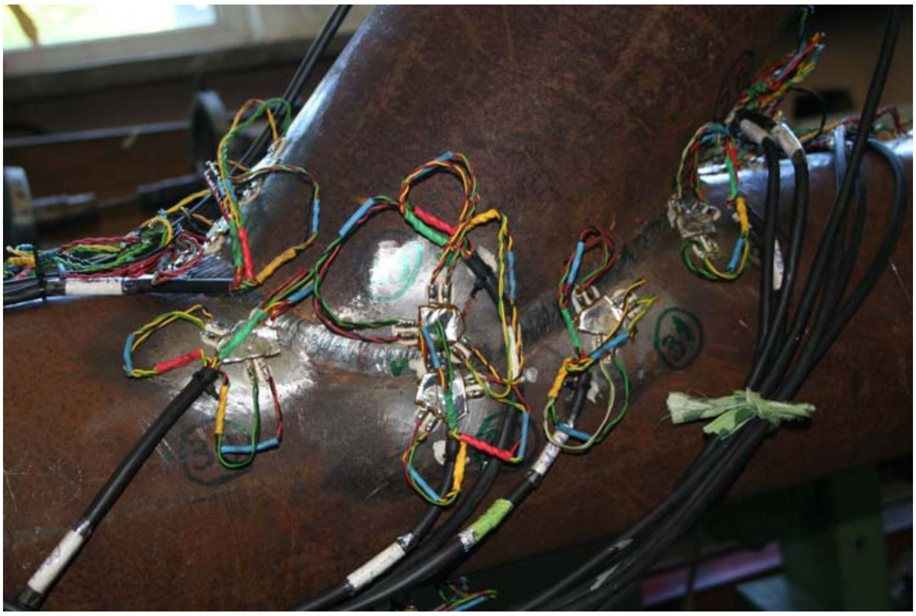

Fig. 6. Detail of the strain gauges layout, bottom view

Results

The experiment led to the values of strains recorded by each transducer as a result of internal pressure action. Their values expressed in μm/m were then processed to determine the main directions of deformation, main stress values, maximum stress, the Tresca and von Mises equivalent stress.

Analyzing the experimental results for each measuring point following clarifications are required on the quality of the results obtained:

- It can be observed, during IPH-T pressurization phase, a higher level of stress level than the one recorded for the same step, during depressurization. This is due to the more extensive first phase of pressurization due to irregular operation of hydraulic equipment,

- Due to the same fact on some of the measuring points occurred transducers slides, slides that have distorted in some cases the results,

- For some measuring points there are deviations from the linear dependence of the gauge. The causes of these deviations from linearity are the slides produced in the first stage of pressurization of the structure and the reading errors for small values of internal pressure or improper operation of the transducer.

Analyzing the relative deviations according to the stress values recorded and position transducers with improper operation, we can say that these deviations are not likely to affect substantially the results of the experiment.

The mechanical stress concentration coefficient defined in the format [3]:

$$K = \sigma_{max\_exp} / \sigma_{nom}, \quad (1)$$

where:
σ_{max_exp} – maximum recorded stress;
σ_{nom} – nominal stress, in this case is the maximum stress recorded at the calibration areas.

Analyzing the results provided by the transducers placed on the calibration areas, the transducer placed on PMT1 have been chosen as a reference, having a linear behavior throughout the experiment (fig. 7).

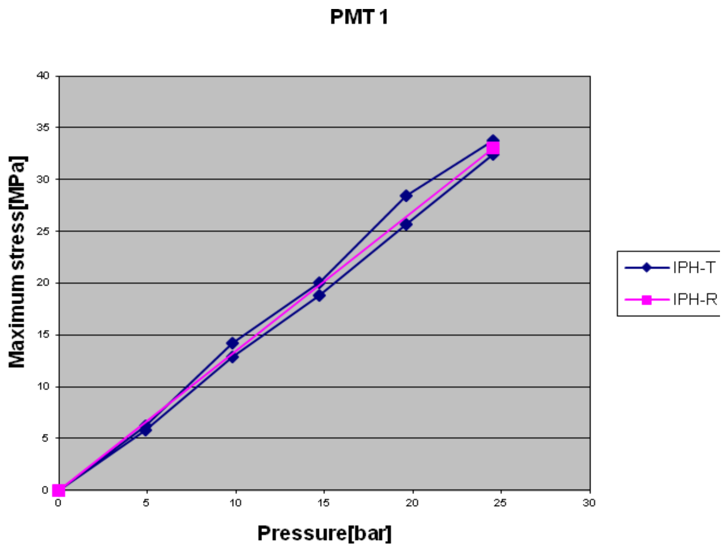

Fig. 7. Experimental data provided by the PMT1 transducer

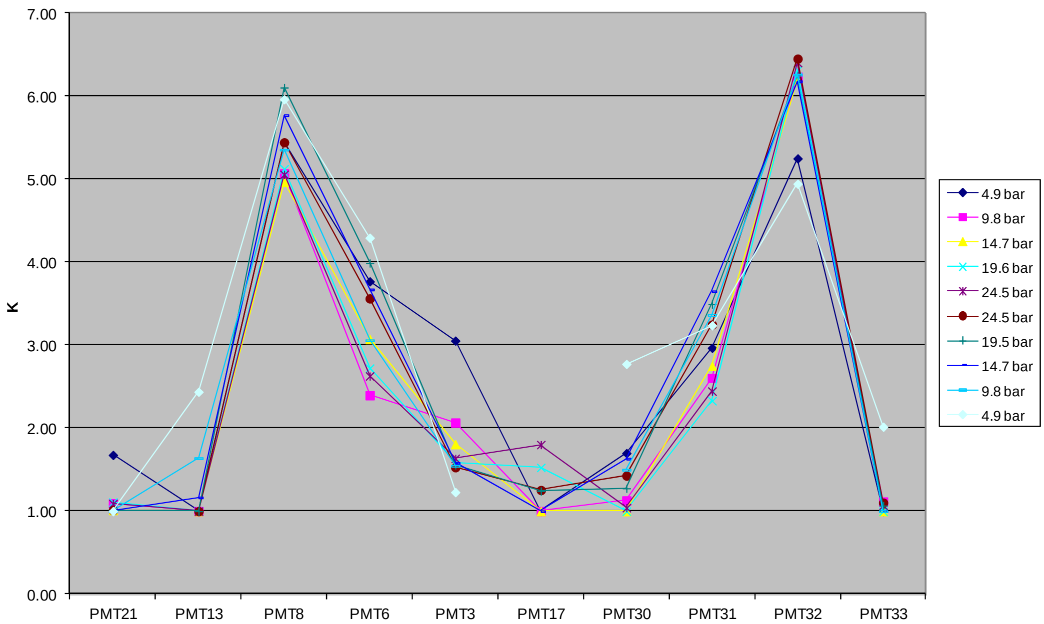

Fig. 8. Distribution of the stress concentrator values arround the welded line for the measing points placed on the TB element

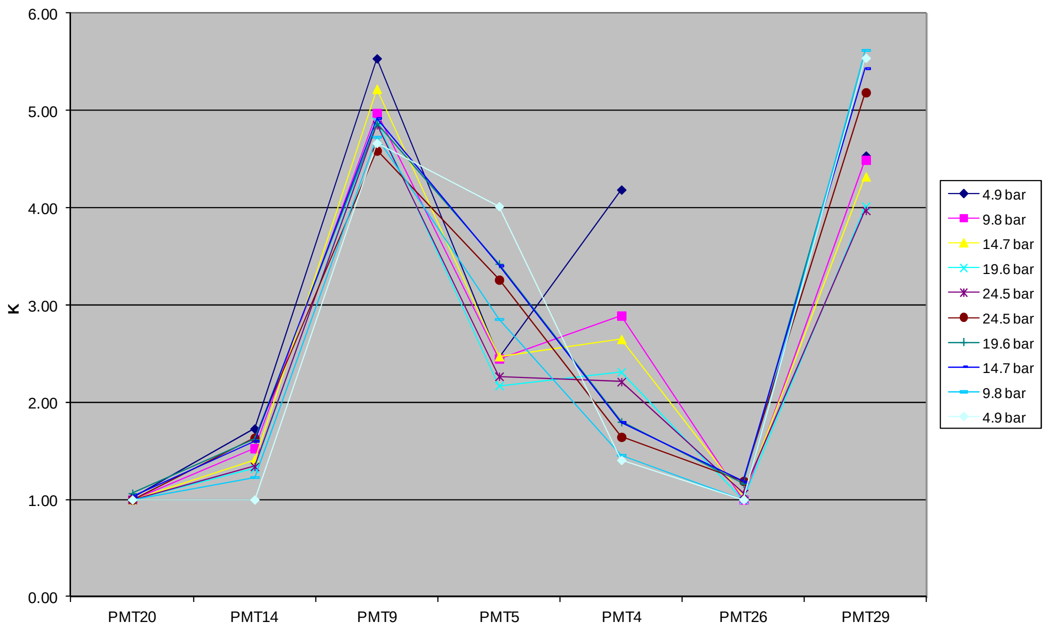

Fig. 9. Distribution of the stress concentrator values arround the welded line for the measing points placed on the R element

The values of the stress concentrator on the calibration areas TBa, TBc and Rb, recorded away from the geometric discontinuity influence, has the average value K=1, this validates the quality of the measurements.

Stress concentration coefficient values determined to the exterior surface of the angular areas, BA and BO, have low level, below 2. The experimental results obtained by means of strain gauge technique indicates maximum stress concentration coefficient in the I and I' areas, with a maximum value of 6.45, on PMT 32.

The purpose of this study is to get a reliable set of experimental results for such a structure, results meaning the values of stress and the value of the stress concentrators. This set of results is to be used for further research, looking to find a valid numerical model, using the finite element method. The numerical model can be validated only by comparing the results recorded during this experiment with the ones achieved by simulation for the same structure, in the same conditions, using the same pressurization schemes.

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Studiu experimental, utilizând tehnica tensometriei electrorezistive, pentru determinarea tensiunilor mecanice prezente la structurile tubulare ramificate la 45^0

Rezumat

Joncţiunile unghiulare ale elementelor tubulare cilindrice în construcţie sudată, neconsolidată, sunt o alternativă larg răspândită în realizarea traseelor tehnologice tubulare. Datorită discontinuităţilor geometrice, în condiţiile acţiunii solicitărilor specifice, acestea prezintă puternice concentrări ale tensiunilor mecanice. În vederea eliminării riscului tehnic previzibil şi inacceptabil în exploatare, a structurilor de acest tip, este necesară stabilirea unei metode eficiente pentru cuantificarea efectelor concentratoare. Este foarte dificilă cuantificarea efectelor concentratorilor de tensiuni utilizând metodele analitice casice datorită posibilităţilor reduse de modelare. Însă, modelarea numerică utilizând metoda elementelor finite, poate fi utilizată pentru simularea comportamentului structurilor cu geometrie complexă. Pentru a valida rezultatele obţinute utilizând un model numeric este necesară compararea acestora cu date experimentale, obţinute prin tehnici consacrate. De aceea a fost proiectată şi construită o structură experimentală, cu scopul evidenţierii efectelor concentratorilor de tensiuni mecanice produse de discontinuităţile geometrice. Structura experimentală permite determinarea tensiunilor mecanice pe trei axe în 33 de puncte tensometrice.