# ANALYSIS OF THE STRESS FIELD IN A MODEL OF PIPE BRANCHES

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**Abstract**

*The aim of this paper is to analyze the stress field of a complex geometry model of pipe branches loaded with internal pressure of 10 bar. The analysis will be done by comparing method of strain gauges and a new one (state-of-the-art) 3D optical method to finite element method, as a numerical method. Finite element method is used to determine critical points (places of expected stress concentration) in the branch. In these places (or at least close to them) strain gauges are placed. The main limitation of the method of strain gauges is that it is not possible to place them anywhere. Whole stress field can be obtained using a system for 3D optical stress measurement based on the method of digital image correlation (Aramis system). Comparing the results of strain gauges and Aramis-system the advantages and disadvantages of modern and classical experimental methods are shown.*

**Keywords:** strain gauges, digital image correlation, finite element method

## 1. Introduction

Use of pipe branches is very wide, which requires diversity to shape and function, as well as the use of different materials [1].

Just because of their wide application they could be exposed to various loads. During operation due to extreme stress values occurring in places of geometric discontinuity can occur fracture or structural failure. Based on previous research can be concluded that to fractures (cracks) of branches comes just in places of the greatest stress concentration [2-4].

Analysis of stress field of complex structures is usually performed by analytical calculations, numerical calculations and experimental methods. The most commonly used method for stress measurement on the real structures and a physical models is a method of strain gauges that gives a value of stress in a small area. One of the goals of this paper is to demonstrate the advantages of 3D digital image correlation method for testing complex geometry structures. This system is used to test all types of materials and has a very wide application [5-9].

In this paper numerically (FEM) are determined critical zones of the branch, i.e. the expected locations of stress concentration. Then experimental testing using the method of strain gauges and DIC is carried out. Finally, the numerical and experimental results are compared. For these testing, the load was the internal pressure of 10 bar. It is concluded that the pressure of this value would not cause initial plastic deformation in the branch model.

## 2. The Finite Element Method

The subject of these testing is a model of pipe branches made of steel S355J2+N, loaded with internal pressure. Dimensions and thicknesses are shown in Fig. 1.

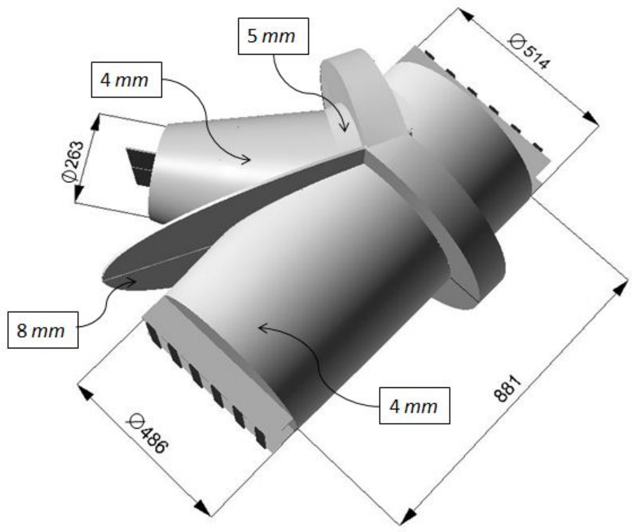


Figure 1 Model of pipe branches, dimensions and thicknesses

Three-dimensional model of branches was developed for the FEM analysis. Considering the symmetry of model, regarding the geometry and load, only half of the model is analyzed (Fig. 2). The grid is denser in places of geometrical discontinuities, i.e. in areas where stress concentration is expected (Fig. 2). The structure is loaded with internal pressure of 10 bar.

The results of FEM analysis (von Misses stress) are shown in Fig. 3.

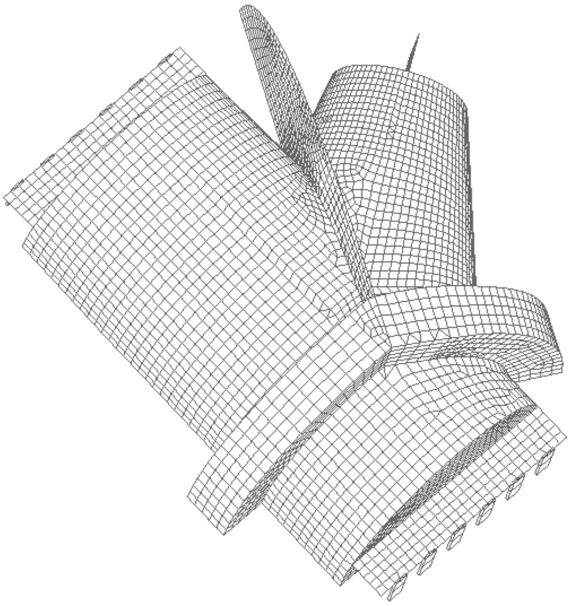

Figure 2 FEM model

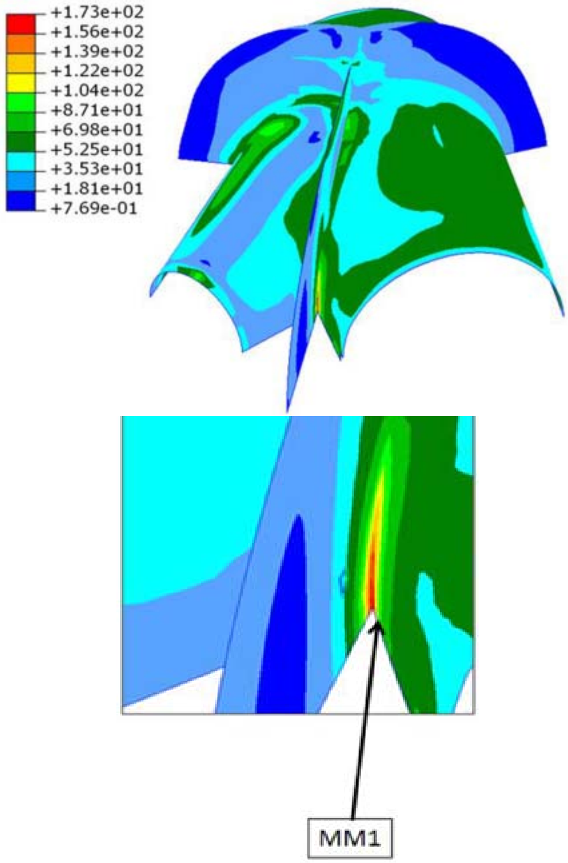


*Figure 3 Von Misses stress [MPa], internal pressure 10 bar*

The greatest stresses occur in places of geometric discontinuity, as can be seen in Fig. 3. In addition, since the value of stress (even in places of concentrations) is lower than the value of the yield strength of the material (S355J2+N), it can be concluded that pressure of 10 bar would not cause initial plastic deformation.

## 2. The Experimental Testing

The experimental installation in the Laboratory for Strength of Materials, Faculty of Mechanical Engineering, University of Belgrade is shown in Fig. 4.

*Figure 4 Experimental installation*

Strain gauges are placed in characteristic points (identified on the basis of FEM calculation). Eight measuring spots are defined. The highest measured value of the stress is obtained in measuring spot MM1 (as estimated on the basis of FEM calculation). Location of MM1 is shown in Fig. 5. The diagram of stresses as a function of pressure value is shown in Fig. 6.


*Figure 5 The strain gauge in measuring spot MM*

A method of 3D optical stress analysis is based on digital image correlation. This technique involves the digitization of prepared measuring surfaces of painted object before and after loading. Equipment for experimental analysis consists of an optical system for 3D stress analysis, i.e. special sets of stereo cameras and lenses, software package Aramis, a stand that allows the security and stability of sensors, devices to control the supply and image capture, PC systems and additional lighting (Fig. 4). Measured surface has to be sprayed (Fig. 7). Spray creates visible dots in a way of contrast in order to perform more accurate measurement. Aramis system partitions the pixels within the image into a small units - facets, calculating the displacement by tracking the relative movement between facets.

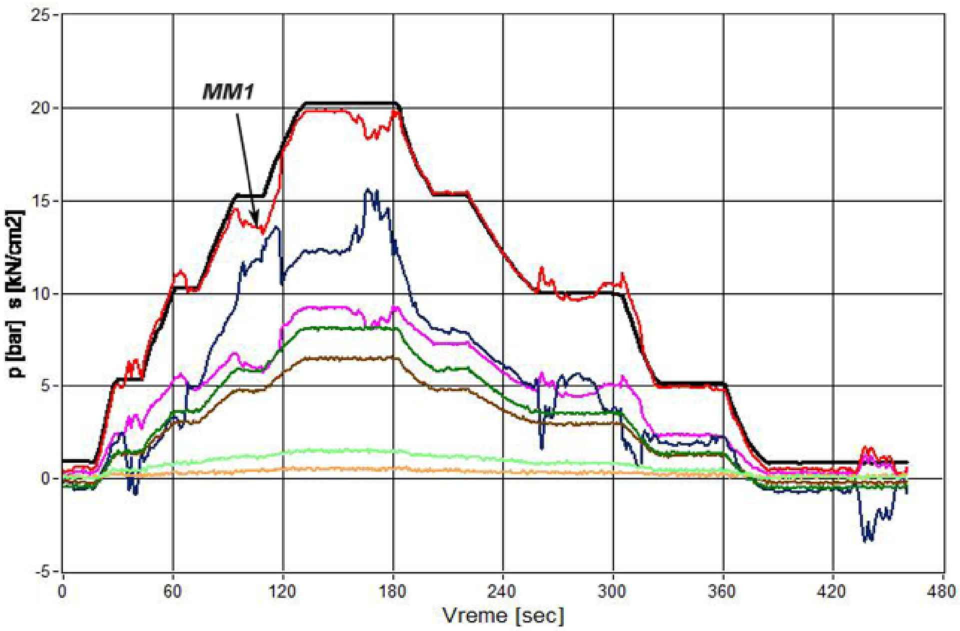


Figure 6 Diagram of stresses as a function of pressure

After performing the experiment, the Aramis software computes the displacement of the every point on the measured surface, and it shows stresses in each direction and is able to calculate Von Misses stress as well.

The measuring results obtained by the Aramis-system in measuring spot MM1 are shown in Fig.7.

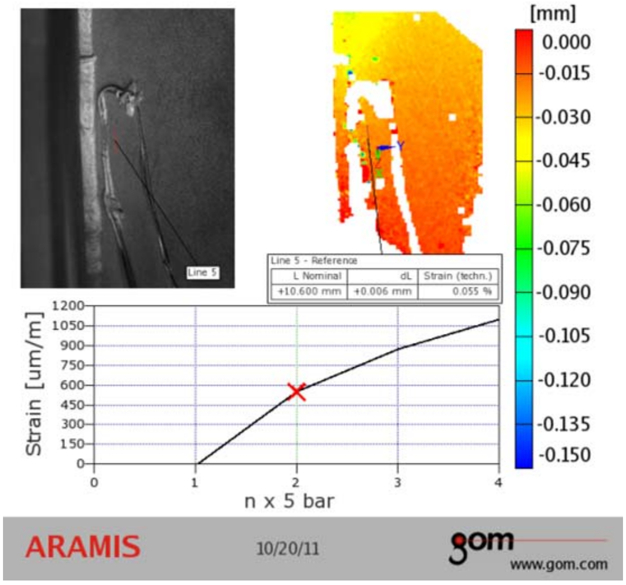


Figure 7 Measuring spot MM1, the Aramis-system, internal pressure 10 bar

The value of the stress at MM1 is

$$\sigma = 580 \cdot 10^{-6} \cdot 21000 = 12.2 \frac{kN}{cm^2} = 122 MPa$$

(Aramis-system internal pressure of 10 bar). This measurement indicates the presence of concentrations of the deformation around the middle horizontal plane of symmetry and closer to the welded joint of the cylinder and the stiffener.

In addition to the field around the MM1, and welded joint of the cylinder and the stiffener is taken. Measurements of 3D deformations in this place (the place of largest stress concentration) had for a goal to determine the degree of stress increase versus stress in MM1. In measuring spot MM1 was possible to place strain gauge (nearest possible to welded joint, about 15mm).

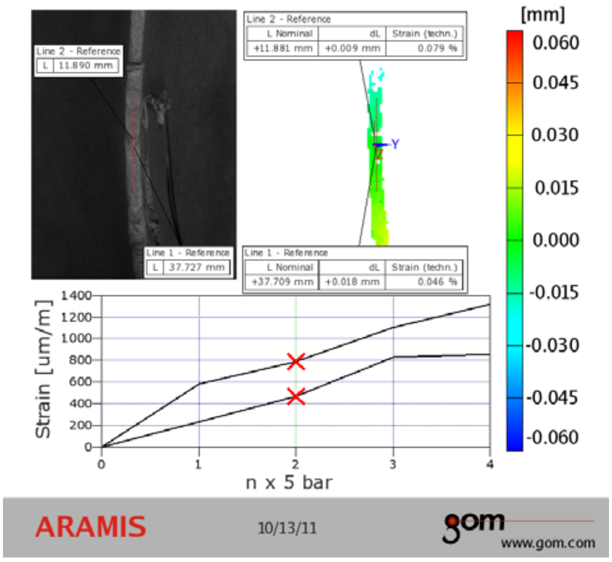


Figure 8 Welded joint near MM1, the Aramis-system, internal pressure 10 bar

The value of the stress in welded joint near the MM1 measured by the Aramis-system is $\sigma = 600 \cdot 10^{-6} \cdot 21000 = 12.6 \frac{kN}{cm^2} = 126\ MPa$ (load is internal pressure of 10 bar).

## 3. The analysis of the results

In Table 1 the results of measurements and numerical calculations for measuring spot MM1 are shown. Load is internal pressure of 10 bar.

*Table 1 Comparison of numerical and experimental results, measuring spot MM1, internal pressure 10 bar*

| The stress value [MPa] | | |
|---|---|---|
| The Finite Element Method | Experimental method of strain gauges | Experimental method of 3D Digital Image Correlation, the Aramis-system |
| 115 | 100 | 122 |

Comparing the results obtained experimentally with the results of numerical calculations can be seen that the values are similar, so the numerical model of pipe branches is verified.

Using strain gauges was not possible to obtain the stress value in welded joint, i.e. was not possible to place the strain gauge at welded joint. Using the Aramis-system the value of stress in welded joint is obtained. Measured value of stress in welded joint is 126 MPa, which proves that stress concentration is present.

## 4. Conclusion

The goal of this paper was not just to analyze behavior of pipe branches loaded with internal pressure, but to demonstrate advantages of the method of digital image correlation comparing to classical measuring techniques. Strain gauges still represent reliable method for stress and strain measurement. In the other hand, Aramis-system (based on DIC) is able not only to deliver precise results but also to illustrate full stress field. Analyzing obtained results can be concluded that:

- The highest stress concentration occurs in welded joint near measuring spot MM1;
- The results obtained by experimental measurements confirmed results obtained numerically;
- Using the method of digital image correlation can be obtained the stress values in welded joint;
- Internal pressure of 10 bar would not cause the model of pipe branches to plastically deform.

## 5. Acknowledgement

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