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AN APPROACH TO THE NONLINEAR LOCAL PROBLEMS IN MECHANICAL STRUCTURES

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Acest articol prezintă o comparaţie între o analiză numerică şi una experimentală pentru o structură complexă, solicitată cu presiune interioară, pentru a dovedi faptul că problemele neliniare pot fi tolerate într-o anumită măsură, în cazul în care caracterul lor este local, astfel încât problema să nu aibă influenţă asupra integrităţii structurii. Acest lucru înseamnă că tolerarea problemelor locale neliniare ajută la separarea abordării lor de cele globale, ceea ce permite economii substanţiale de materiale şi alte resurse la producerea de structuri industriale mecanice.

This article presents a comparison between a numerical analysis and an experimental one for a complex structure, loaded with internal pressure, in order to prove the fact that nonlinear problems may be tolerated to some extent, if their character is local, so the problem does not have influence on the integrity of the structure. This means that tolerating local nonlinear problems helps to separate such an approach from the global problems, allowing substantial savings of materials and other resources for manufacturing industrial mechanical structures.

Keywords: local problems, material nonlinearity, structure.

1. Introduction

In mechanical engineering there is a wide range of machinery, equipment, or devices, consisting of components with different geometries, from the simple to the complex, which provide strength, stability, safety, accuracy, durability etc. and which are called mechanical structures.

The mechanical structure is defined as a complex system, rigorously defined functionally, geometrically and mechanically, consisting of individual mechanical components [1].

Failure is a problem with an important *local character* for all types of mechanical structures, no matter how high-performance their manufacturing technologies, constructive and functional characteristics are. The failure is initiated at a point or a small region (compared with the dimensions of the

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structure) and then spreads until the structure loses its ability to fulfill its functional role. Therefore, analysis of local problems is of great importance [2]. There are situations where failure is global in nature, namely when the structure loses its stability, but this paper treats the material nonlinearity, not the geometric or mixed one.

The stress state is considered to be *local* when its intensity is relatively high in a small area in relation to the dimensions of the structure [2].

In linear analysis, response is directly proportional to load. Linearity may be a good representation of reality or may only be the inevitable result of assumptions made for analysis purposes [3].

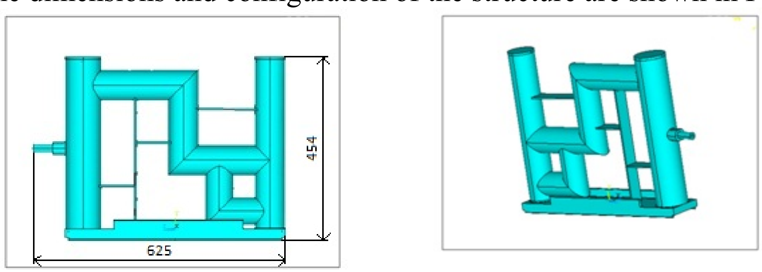
The experiment aims at proving that nonlinear problems may be tolerated within certain limits, if the character of the problem is local. The experimental analysis is done using statically applied internal pressure.

2. The designed structure and experiment description

A mechanical structure was designed, modeled and physically manufactured; then it was analyzed numerically and experimentally.

The physical model of the structure was made of steel, whose characteristic curve was determined by tensile testing of specimens taken from the material which the model was manufactured from.

The dimensions and configuration of the structure are shown in Fig. 1.



a. Front view of the structure b. Isometric view of the structure

Fig. 1. Front and isometric view of the structure

The numerical analysis of the structure was performed using the conventional curve of the material, which is nonlinear. This curve is presented in Figure 6.

For the analysis, the characteristic curve of the material was introduced in the database of the software as pairs (σ, ε) selected from the chart containing the curve.

The finite element model [4] is illustrated in Fig. 2, where it can be seen a more refined mesh in the two areas studied experimentally (see Fig. 3 for the studied areas).

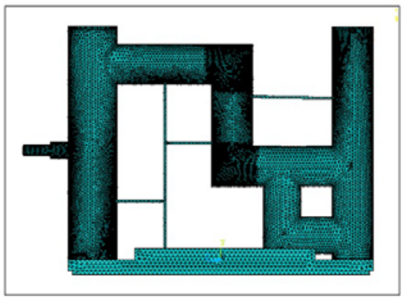


Fig. 2. Finite element model of the structure

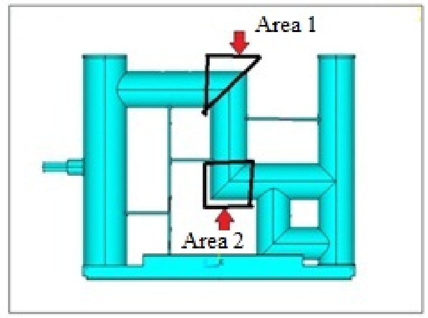


Fig. 3. Areas of the structure chosen for comparative analysis

The two areas under experimental investigation were chosen because they are among the areas with large gradients of stress, practically in the nonlinear zone of the material [5].

The finite element that was used is SOLID type with 20 nodes, with three degrees of freedom per node (three translations) [7].

The average size of the elements side used in meshing was 5 mm, with appropriate refinement in the two studied areas. The structure was considered manufactured as one piece and the welding to be made uniform, with a proper quality that does not influence the local state of stress and strain.

The structure was made of tubes with wall thickness of 3.5 mm, which communicate with each other. Also, beams with rectangular cross section were used as stiffeners for the structure. The assembly is welded on a horizontal cross, with supporting role.

Fig. 4. Manual pump

This physical model was filled with water and the internal pressure was applied via a hand pump (Fig. 4), connected to the structure through a "T" element, on whose third thread is mounted the manometer for pressure determination. The structure is shown in Fig. 5.

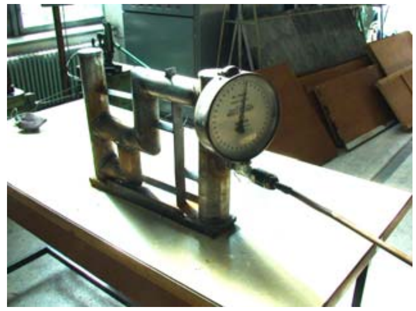


Fig. 5. The structure and the manometer

The characteristic curve of the material used, is shown in Figure 6. In Figure 6 is presented the conventional curve obtained as arithmetic average of the curves provided by the program of the testing machine.

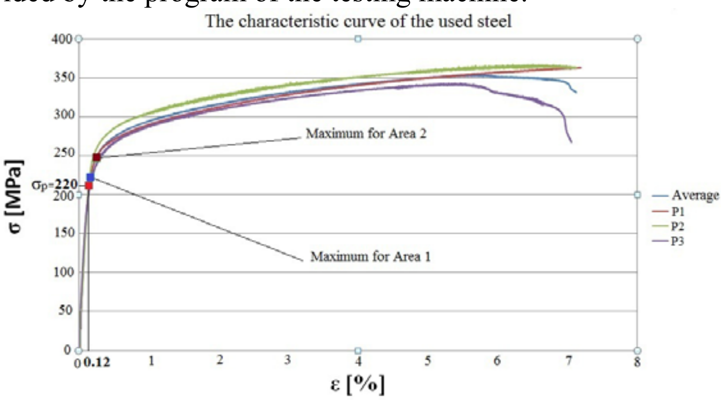


Fig. 6. The curves provided by the testing machine for the three specimens and the curve of the material obtained as average

The configuration of the tested specimens is shown in Figure 7, and their dimensions in Table 1.

The geometry of the tested specimens is nonstandardized.

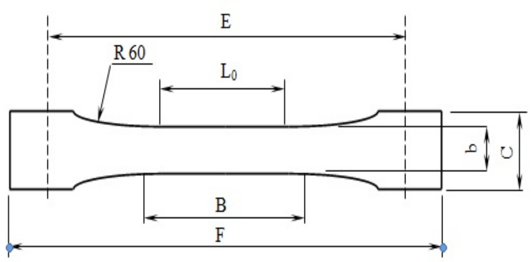


Fig. 7. Configuration of the specimens used to determine the characteristic curve of the material

Table 1

Dimensions of the specimens

Dimensions (mm)	*Symbol*	*Value*
Total length, min.	***F***	170
Width at extremities	***C***	16 ± 0,5
Total thickness	***h***	3.9
Length of the calibrated part	***B***	60 ± 0,5
Width of the calibrated part	***b***	7.5 ± 0,25
Reference length	L_0	50 ± 0,5
Distance between jaws	***E***	115 ± 5

In Table 2 are listed the material characteristics, as they were determined by the testing machine software and the size of the tested specimens.

Table 2

The results obtained by tensile testing of the specimens

	Thickness (mm)	Width (mm)	Young's Modulus in tension (MPa)
1	3.900	7.620	185716.6
2	3.900	7.250	173118.3
3	3.900	7.510	194158.8
Average	3.900	7.510	185716.6
Standard Deviation	0.000	0.190	10588.4
Coefficient of Variation	0.000	2.546	5.744

Table 2

(Continuation)

	Yield stress (MPa)	Ultimate Tensile Strength (MPa)	Ultimate Tensile strain (%)
1	260.3	365.0	8.180
2	274.9	354.9	7.826
3	250.7	323.8	6.444
Average	260.3	354.9	7.826
Standard Deviation	12.182	21.453	0.917
Coefficient of Variation	4.649	6.165	12.256

The standard deviation and the coefficient of variation were presented to observe more easily the degree of scattering of the experimental results, corresponding to the tested specimens. In this case, the values are small, so we may say the results are coherent.

For the experimental analysis, it was used it was used the ARAMIS system based on the state-of-the-art techniques for measuring optical three-dimensional deformations and specific strains.

Due to the homogeneity of the surfaces of the considered structure, the preparation was done by cleaning and painting them (Fig. 8).

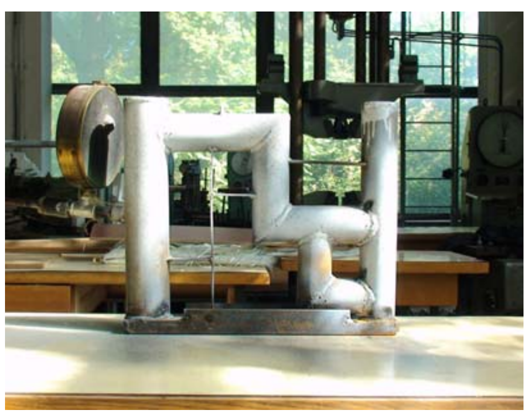


Fig. 8. Preparation of the structure's surfaces

Painting was done by spraying, applying a first coat of white paint, covering the entire surface of the structure and a second layer of black paint, applied over the white layer in the form of dots [6], thus achieving the desired contrast, as shown in Figures 9 and 10.


Fig. 9. The first area studied


Fig. 10. The second area studied

Measurements were made for two junctions of the structure.

For the first junction, the experiment was performed repeatedly by progressive loading of the structure up to the value of 129 bar in the first phase, repeating measurements from 16.5 to 16.5 bar to 91 bar value, then from 7.57 to 7.57 bar up to the value of 129 bar.

For the second junction, the experiment was performed by using the same loading sequence as for the first junction.

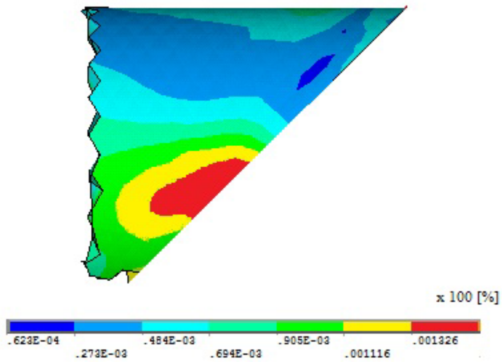
3. Numerical and experimental results

Corresponding to each load step, numerical results are compared to the experimental ones for the areas shown in Figure 3. Strains corresponding to the last load step are shown in Figure 11 and Figure 12 and the results for the remaining steps are shown in Table 3.

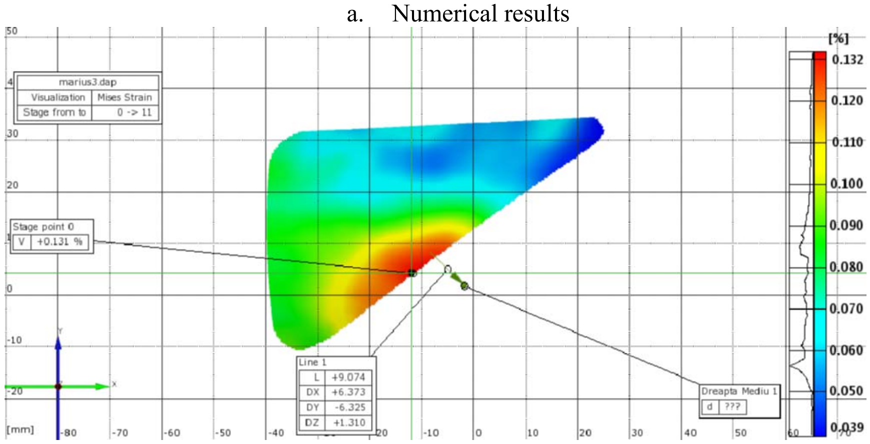
Comparing the numerical results in Figure 11,a with the experimental ones from Figure 11,b we see that the maximum local strains have almost identical values (0.132%).

Comparing the numerical results in Figure 12,a with the experimental ones from Figure 12,b we see that the maximum local strains have almost identical values (approx. 0,206%), too.

In Figure 6 is presented the conventional curve of the material used. The proportionality limit is marked on the curve with the notation σ_P. Up to this amount of stress, stress is proportional to strain (Hooke's law), so the stress-strain graph is a straight line, and the gradient will be equal to the longitudinal modulus of elasticity of the material [8]. Above this value it is considered that the material has a nonlinear behavior. σ_P is about 220 MPa and it corresponds to a strain of 0.12%. These values were extracted from the results set given by the testing machine. Even if they were exceeded in local areas, the structure maintained its integrity and reliability. This allows the formulation of the statement that areas with strains higher than the proportionality limit may be tolerated within certain limits if the problem is local.

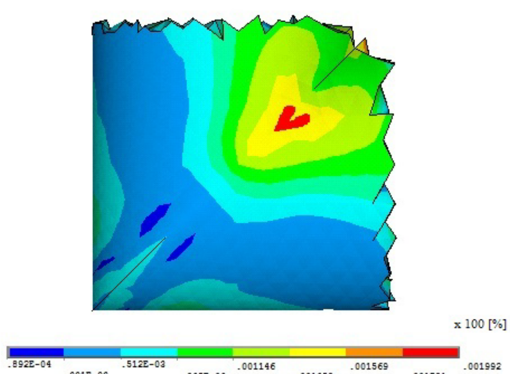


a. Numerical results

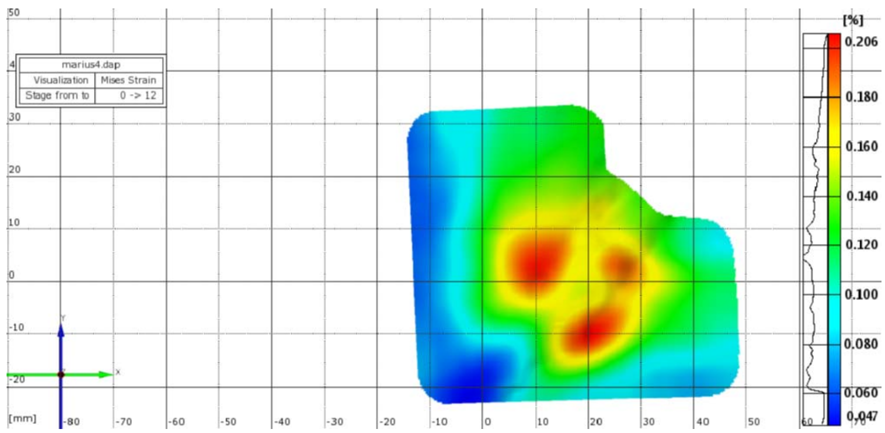


b. Experimental results

Fig. 11 Comparison between numerical and experimental results for area1 - stage 11 - 128.75 bar



a. Numerical results



b. Experimental results

Fig. 12 Comparison between numerical and experimental results for area 2 - stage 11 - 128.75 bar

Table 3

Strains obtained experimentally and numerically

Load level (bar)	Area 1 ε (%)		Area 2 ε (%)	
	Exp.	Numerically	Exp.	Numerically
30.3	0.03	0.027	0.11	0.064
45.45	0.037	0.041	0.116	0.097
60.6	0.052	0.054	0.132	0.115
75.75	0.065	0.065	0.138	0.125
90.9	0.082	0.082	0.139	0.133
98.47	0.102	0.106	0.163	0.151
106.04	0.109	0.112	0.178	0.16
113.61	0.113	0.12	0.187	0.17
121.18	0.127	0.13	0.19	0.188
128.75	0.132	0.132	0.206	0.199

Analyzing the results from Table 3 we see that the numerical and experimental ones are very close for each load step applied, excepting the first one, which will not be taken into consideration.

4. Conclusions

From the comparative analyses performed in this research, one may conclude that:

- Comparing the numerical results with the experimental ones, we see small differences for the strains values in the studied areas.
- Regions presenting nonlinear behavior in the analyzed areas are small compared to the dimensions of the structure (approx. 10 mm x 10 mm << 454

mm x 625 mm), which allows us to conclude that the nonlinear problems from those regions have a local character.

- We observe that, although the proportionality limit is a stress which is exceeded in small local areas, the physical model, remained functional and maintained the integrity in those areas, as well as the entire structure.
- We can conclude that areas with strains higher than the proportionality limit may be tolerated if the problem is local.
- The separation between the approach to the local nonlinear and global problems, allows substantial economy of material and other resources (human, energy, financial etc.) for manufacturing industrial mechanical structures.
- Areas of application of the new approach to the nonlinear local problems in mechanical engineering are many: aerospace, automotive, most branches of mechanical industry etc.

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