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EXPERIMENTAL VERIFICATION OF NUMERICAL TEST RESULTS FOR A DOUBLE MULTI- LEAF SPRING

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Abstract

A double spring used in the vehicle suspension, as a combination of spring elements of characteristics close to linear ones, actually provides non-linear suspension characteristics. Due to requirements for the truck suspension being designed, the spring characteristics in the whole range of load changes should meet the vehicle motion smoothness related to keeping the frequency of own suspension vibrations within a range of 1-2 Hz [8, 10].

A prototype double spring made of a four-leaf main spring and two- leaf auxiliary spring (Fig. 1) makes a subject of considerations. Characteristic features of that structural solution includes a clearance between the main spring and the auxiliary spring.

This work presents the results of numerical tests for three models of MES double spring [23] that were compared with experimental test results. An evaluation of usability of individual numerical models was made for representation of a double spring characteristics, contact between individual leaves and regular stress in the main leaf (the so-called safety leaf). The smallest differences between the stress results obtained from numerical tests compared to the laboratory tests, for the beam and shell models, have been obtained only for one extreme main (longest) leaf.

Keywords: *experimental verification, FEM, numerical models, double multi-leaf spring, suspension of a motor truck*

1. Introduction

The work makes a continuation of the double spring tests described in works [1-4, 14, 22, 23] especially including a comparison of numerical test results with the results obtained during the experimental tests. A usability of various discreet models (beam, shell and solid ones) described in the work [23] has been evaluated for various needs, i.e. estimation of deformations (stresses) of the main leaf, evaluation of spring characteristic compatibility, clearance changes (s) in the normal load process (P) of two multi-leaf springs (the main and the auxiliary ones), and due to their structure (various component leaf bending radii of five component leaves) there is a clearance between the shortest leaf of the main spring and the longest leaf of the auxiliary spring (Fig. 1, 2).

A variable vertical load (P) affecting the double spring also results in a variation of the existing clearance, and as a consequence a variation of the spring characteristics of the suspension [3, 7, 8, 10, 16]. Presented connection of spring elements makes one of typical structural solutions of a rear dependent suspension [23] used in modern trucks of a total weight up to 3.5 tons.

Advanced modelling and analysis techniques were applied in the numerical tests including contact issues possible for evaluation by means of a set of applications for engineering calculations provided by MSC.Software [11, 12].

2. Laboratory tests of a double multi-leaf spring

The experimental tests were performed at the testing station described in [16]. The experimental test results were presented for normal load $0 \leq P \leq P_{max}$ and P = 5.0 and 10 kN. The image presented on Fig. 3 illustrating a double string deformation for maximum strength load P = 14kN.

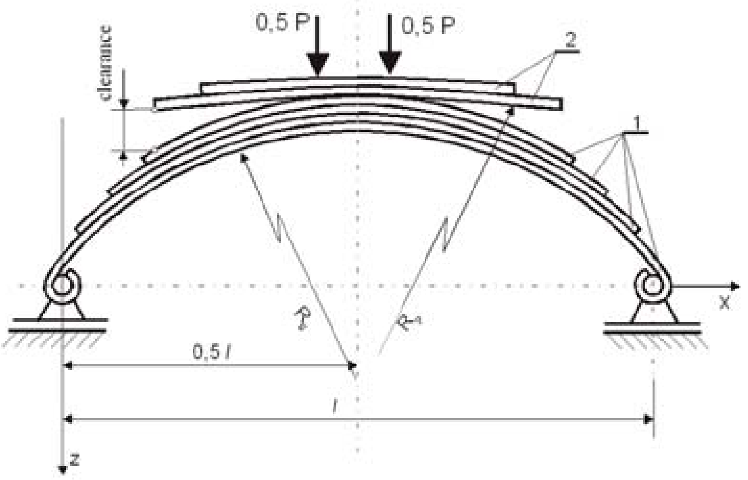
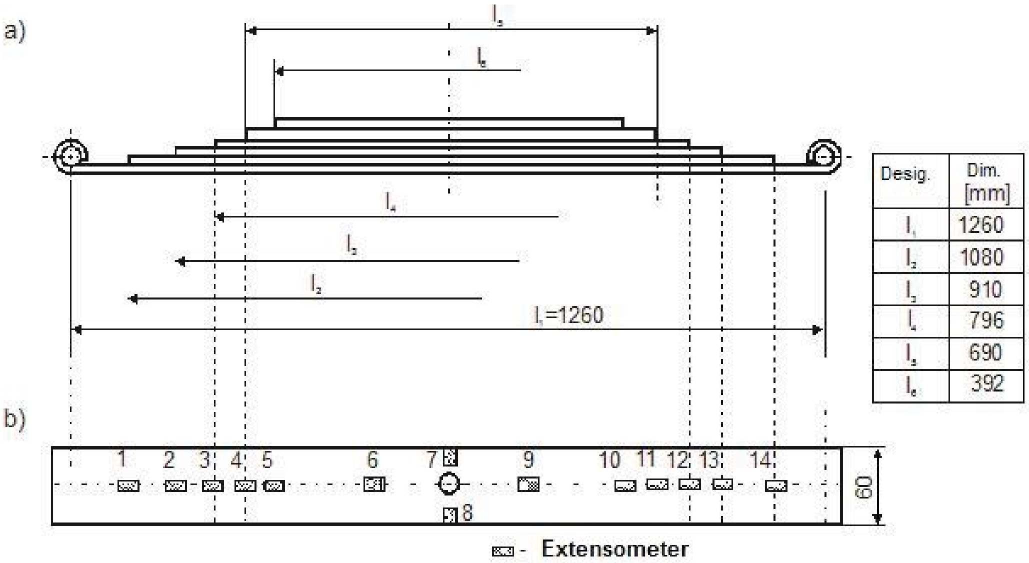


Fig. 1. Double spring diagram: clearance = s ,1- main spring leaves, 2- auxiliary spring leaves [23]



Desig.	Dim. [mm]
l_1	1260
l_2	1080
l_3	910
l_4	796
l_5	690
l_6	392

Fig. 2. Double spring diagram: a) in the straight condition, b) a diagram of extensometer arrangement on the main plate surface where numbers 1,...14 – stand for numbers of following extensometers placed on the extreme sections of the support of component leaf ends.

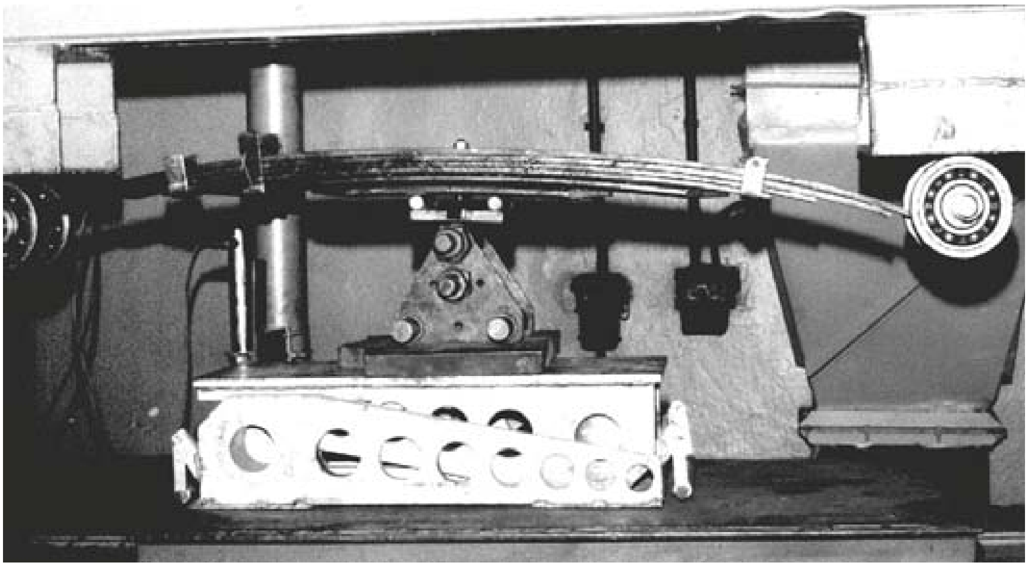


Fig. 3. A view of a double spring in the final phase of a vertical force load P=14kN

3. Spring characteristic tests

The Fig. 4 compiles vertical force load diagrams in the spring bending function obtained in the beam, coat and solid numerical model and a curve obtained on the basis of the tests of a prototype spring at the laboratory station (Fig. 3). The results obtained in the beam and coat models are slightly different.

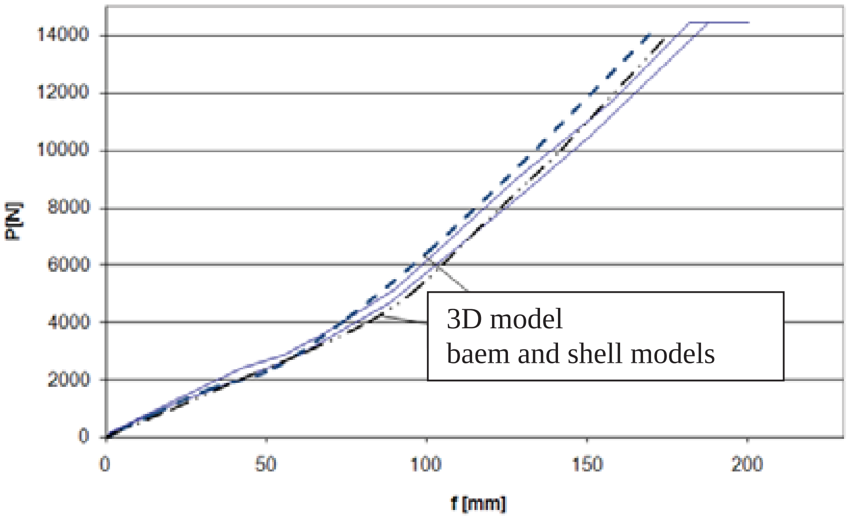


Fig. 4. Comparison of load force diagrams in the spring bending function obtained in the beam, shell and solid 3D models [23]

On these diagrams, the curves registered at the laboratory station are marked with a full line and the curves obtained on the basis of numerical simulation results in various MES models are marked with a broken line. Maximum spring bending values obtained in the simulation tests by means of various numerical models differ by less than 5%.

4. Testing the clearance between the main and auxiliary spring plates in the loading process.

In the considered spring individual component leaves are formed with various individually selected radii. After assembling them in one complete double spring, by means of a tightening screw, considered in this work, a separation of the main spring unit consisting of four leaves and the auxiliary spring unit can be clearly noticed (Fig. 1, 5). When the spring is not loaded, there is a gap of variable opening between the adjacent leaves of both spring units. Values of the clearance between the adjacent leaves of the main and auxiliary spring units vary during the spring loading process. This section of the work presents a numerical analysis of clearance variations between the main spring and auxiliary spring leaves in the loading process. For that purpose, numerical models of a double spring of various level of structural is detail representation. The beam double spring models and spatial shell models are discussed in details in the works [22, 23]. A modified 3D model of a double spring was also used for the clearance variation test, where the conditions of the station tests, described in p. 2, were represented in details. In that model, the main and auxiliary spring leaves were represented by means of 11310 eight-node solid HEX type elements spread on a net of 91204 nodes. The tightening screws (detail 2 on Fig. 5) were represented by means of the beam elements of properly selected substitute characteristics. They were spread on the nodes of terminal elements that model individual leaves in the spring symmetry plane.

The contact between individual spring leaves were modelled by defining an expected contact area of the walls of individual spring plates and assigning them proper physical parameters (e.g. friction) by means of a ‘master-slave’ function [19]. So a continuous description of a contact phenomenon was introduced in the 3D model, contrary to a discreet representation of

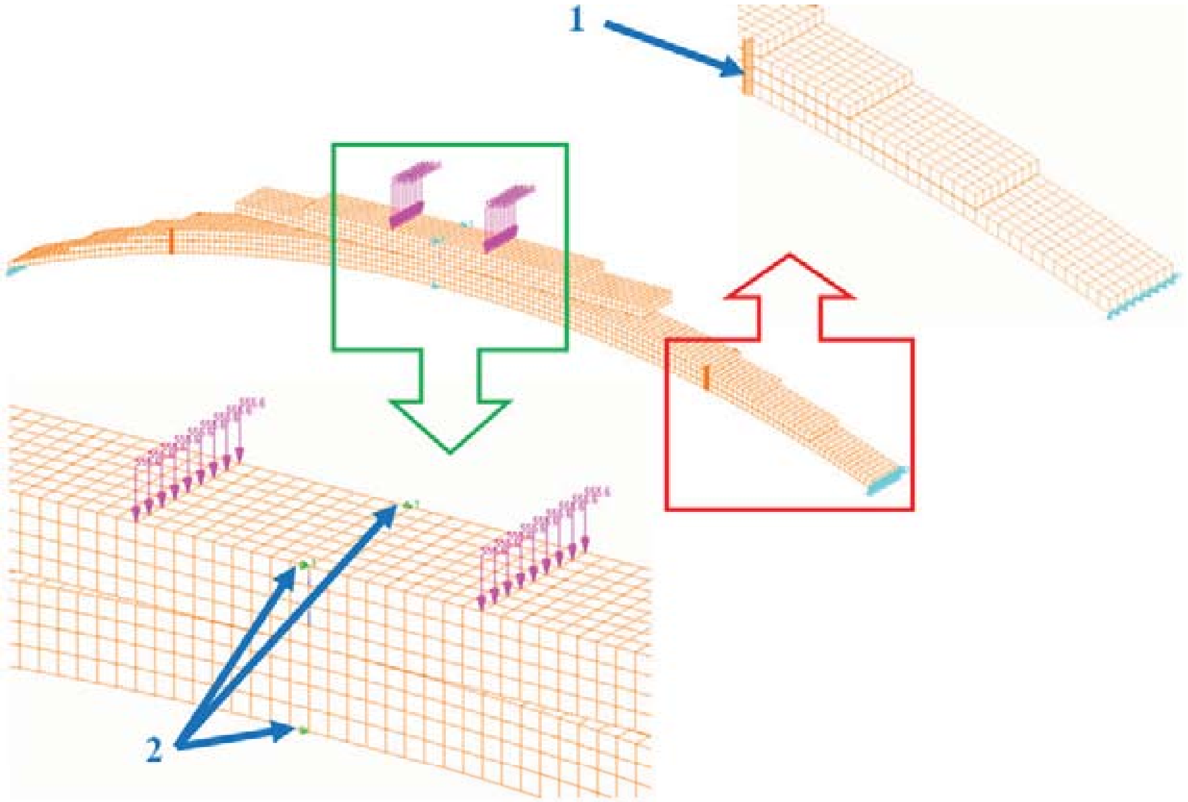


Fig. 5. Solid spring model; 1 - shackle, 2 - clamping screws [23]

a contact used in the beam and shell models [22, 23]. In a discussed beam model of the spring (Fig. 5), in order to provide a continuous contact between the nodes of adjacent leaves, resulting from a preliminary spring stress in the plate installation process, the 3D spring models includes additional yokes tightening the main spring leaves in the section marked with number 1 on Fig. 4. Additional yokes were modelled with beam elements (1), and their terminal nodes have been shared with corresponding nodes of the shortest and the longest main leaf. The load in the model was replaced with a reduced vertical force expenditure applied to two edges connecting the elements in the upper leaf of the auxiliary spring, corresponding to the position of two shafts, visible on the laboratory station photo presented on Fig. 3, where the spring was loaded during the experimental tests. The analysis of such 3D spring model was carried out by means of the MSC.Dytran software [19].

The characteristics of clearance variation between the ends of the auxiliary spring leaf and the surface of adjacent main spring leaf indicated in the coat model [22, 23] and 3D one are presented on Fig. 6. The diagrams marked with a broken line were obtained on the basis of numerical analysis and were drawn with reference to a curve obtained in the experiment P = f (s), marked with a full line (Fig. 6), describing the P force variation and **s** clearance values in the spring load process. The curve obtained on the basis of results of the numerical analysis in the 3D model, adjusted to station test conditions (Fig. 6b), provides better representation of the clearance variation in the spring deformation process. Better adjustment of the curve indicated numerically for the experimentally registered diagram corresponds to the initial spring operation stage (only the main spring operates) and the stage of selecting the clearance between the adjacent plates of the main and the auxiliary springs (a stage of involving two leaves of the both springs – Fig. 1).

5. Stresses in the main (safety) leaf of the main spring

The analysis of a double multi-leaf spring effort has been also carried out. The numerical analysis of stresses in the spring leaves in the beam and shell models has been carried out within a scope of non-linear statics by means of MSC.Nastran software [12, 18]. The load in the flat beam model and in the spatial shell model was defined as a single force or in a form of two identical focused forces applied to the nodes of the transverse symmetry plane of the spring [23]. The analyzed numeric models were loaded with resultant force equalling 14 kN (Fig. 3). The such maximum force was also applied to the spring during the laboratory station tests (Fig. 3). The boundary conditions corresponding to the spring attachment at the testing station are shown on Fig. 2, 3. In the model nodes corresponding to the edges of the main spring (the longest) leaf a possibility of linear displacement along the Y and Z axes was taken.

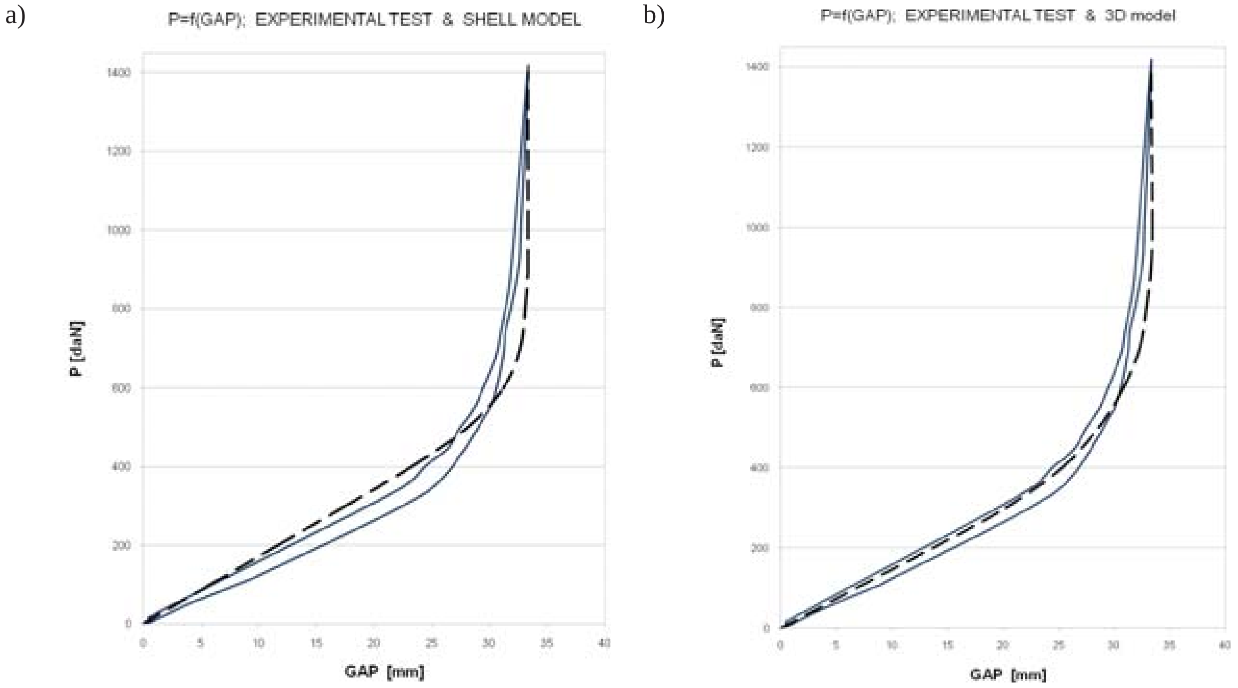


Fig. 6. A comparison of clearance variation between the main spring and the auxiliary spring leaves in the loading simulation with the results obtained in the experimental tests: a) shell model, b) 3D spatial model

The numerical analysis made within a presented scope of loads and conditions of structure attachment allows for comparison of stress values obtained by numerical method and during the station tests. The table 1 includes the stress values specified numerically for two load levels that equals 5kN and 10kN in the beam and shell models in three sections of the longest main spring leaf. These sections correspond the locations of extensometers no. 8, 11 and 14, (Fig. 2). The stress maps in the main (longest) leaf of a double spring obtained in the shell model for aforementioned load levels are presented on Fig. 7.

Tab. 1. Stresses in selected main spring sections caused by normal load [MPa]

Normal load P [kN]	Selected main leaf sections according Fig. 2b		
	Extensometer no. 8	Extensometer no. 11	Extensometer no. 14
	Beam model		
5	518	379	206
10	703	608	370
	Shell model		
5	606	323	202
10	798	596	394

The stresses indicated numerically in the beam and shell models for 5 kN and 10 kN forces in indicated sections. Fig. 8a, 8b, 8c presents the loads in the spring bending function obtained in the experimental tests and proper discrete stress values corresponding the locations of extensometers no. 8, 11, 14 – points marked with a square and triangular marker. The numerical stress values and the ones registered during the experimental tests differ from the most by app. 25% in case of a measurement section with extensometer no. 8 (Fig. 8) i.e. in the section corresponding the half of the leaf length (Fig. 2).

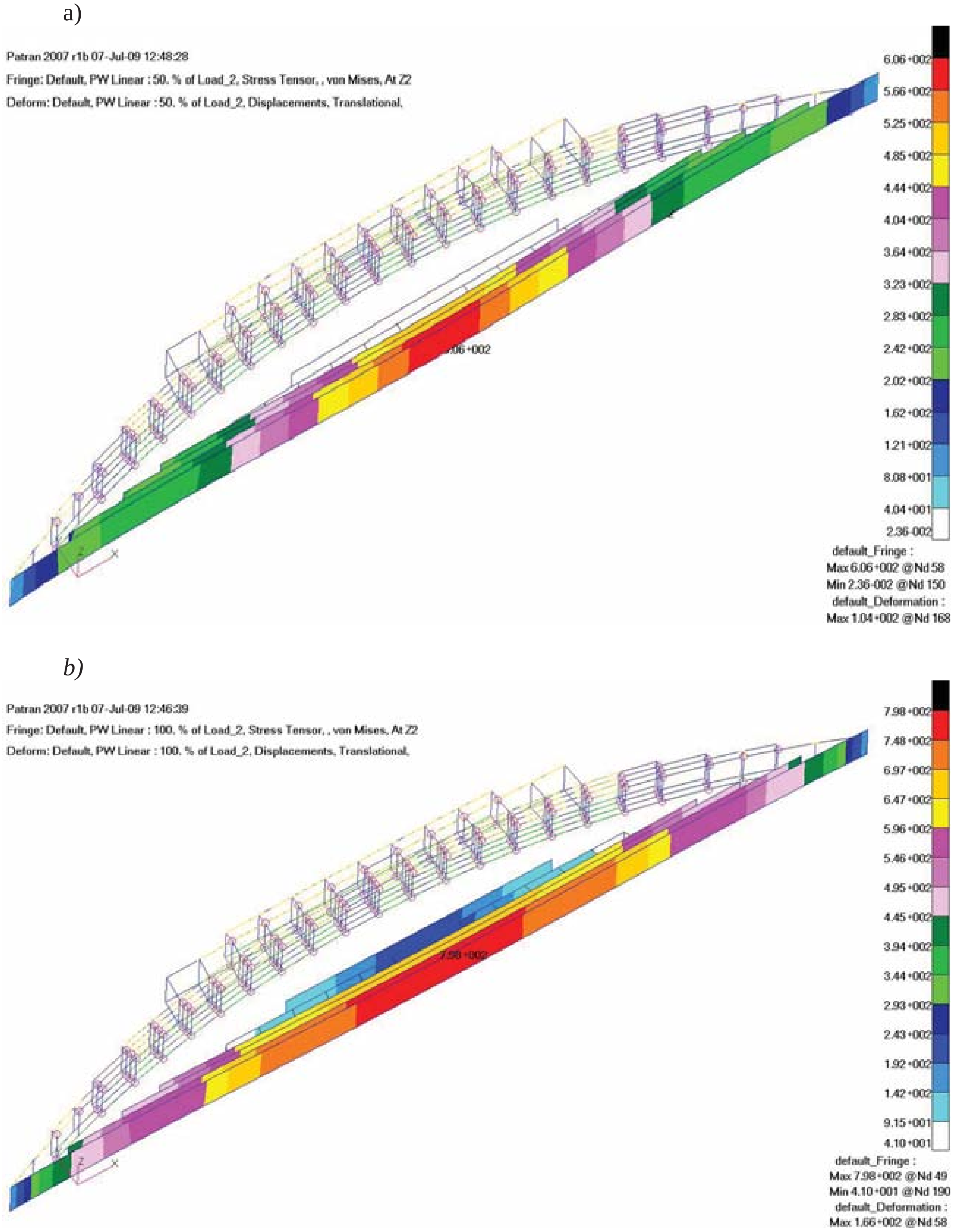


Fig. 7 A map of stresses reduced in the main leaf obtained for the spatial shell model, a) P = 5 kN , b)P = 10 kN

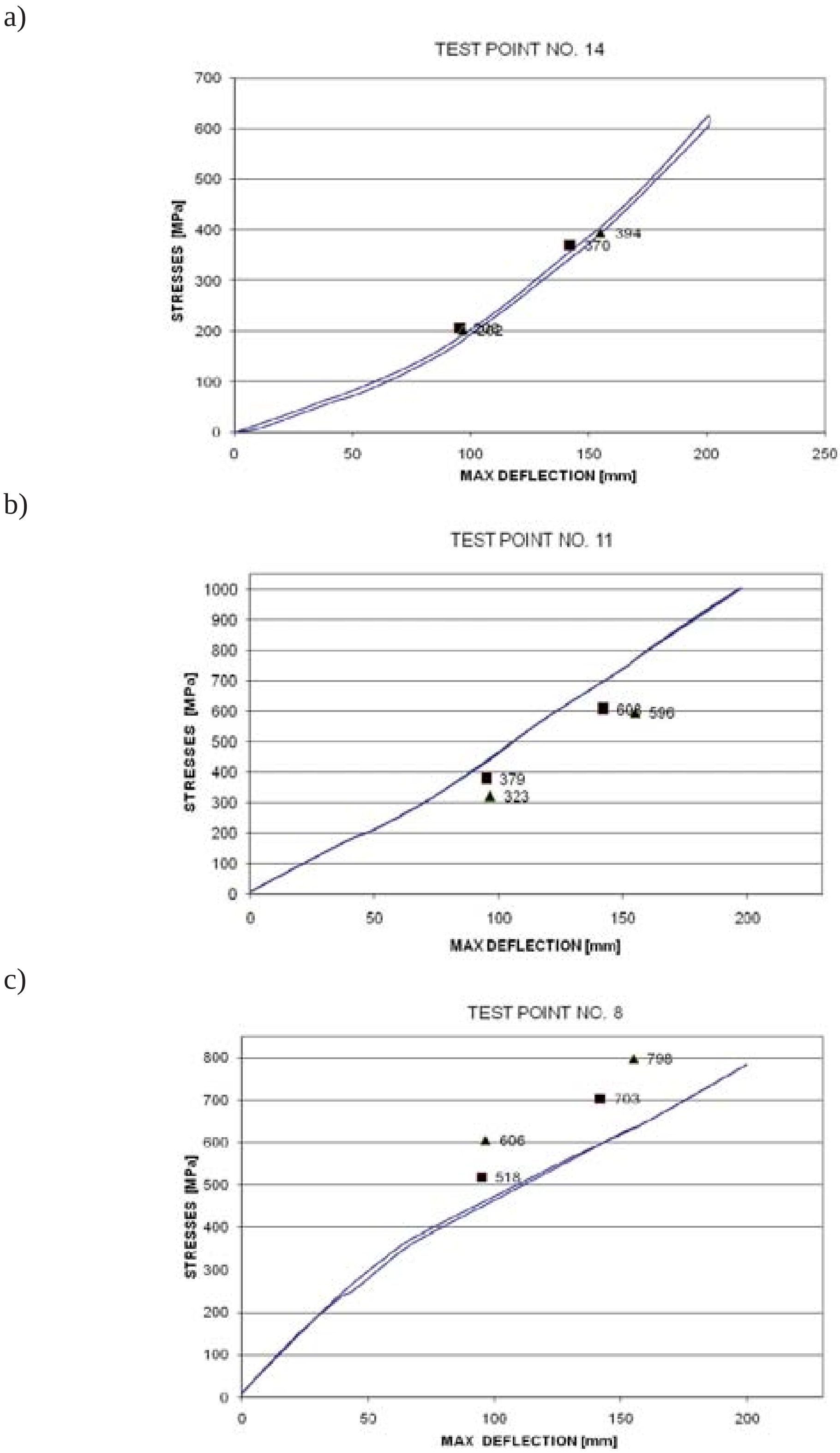


Fig. 8. The stress results obtained in the laboratory tests (full line) and discrete stress values from numerical analysis; a) measurement point no. 14, b) measurement point no.11, c) measurement point no. 8

6. Summary

Even the use of the most simple beam models of the spring, requiring the lowest workload at the stage of creation leads to obtaining satisfactory results within a scope of structure stiffness. The solid models provide better conformity of measurement results within a scope of stiffness characteristics specified numerically and experimentally, in their bending sections i.e. in the interval corresponding the operation of a double spring, when mutual reaction of component springs takes place (Fig. 1).

Analogical conclusions should be formulated in reference to the tests of clearance variation between the ends of the auxiliary spring leaves and the surface of the adjacent main spring leaves in the structure loading process. More detailed numerical representation of the clearance variation and structure deformation process has been obtained in case of the 3D model.

The use of beam and shell models with simplified representation of cooperation of the double spring leaves is not sufficient for the effort analysis. The smallest differences between the stress results obtained from numerical tests compared to the laboratory tests, for the beam and shell models, have been obtained only for one extreme main (longest) leaf. So the effort analysis requires the use of the most detailed 3D models of the double spring with precise representation of cooperation between individual component spring leaves (the main and the auxiliary ones).

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