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ANALYSIS OF THE RESULTS OF THEORETICAL AND EXPERIMENTAL STUDIES OF FREIGHT WAGON FALS

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Abstract. *A comparative analysis based on the results from strength-deformation analysis of wagon body, series Fals, and on the results from the real wagon test was made. Calculations were carried out in the Department of Railway Engineering at Technical University of Sofia and are based on the finite elements method. Two computational models of wagon design were developed. One of them consists of shell elements (triangular), and the second one of solid elements (tetrahedral). Experimental studies on real wagon were conducted at the National Transport Research Institute. It was found that the results obtained for the stresses are similar, which proves that the models are appropriate and they can help to solve a wide range of issues, for example those related to lightweight design of railway vehicles.*

Key Words: *Railways, Freight Wagon, Strength Analysis, FEM, Tests*

1. Introduction

The paper is a comparative analysis [1, 2] of the results of the static strength obtained theoretically (FEM calculation) and the results from the real tests carried out on the supporting steel structure of freight wagon series Fals.

The goal of this comparison is to determine which of the theoretical models, that emerged in recent years in the calculation of railway structures, describes more accurately the actual test article. The first model was built up of finite elements type "Solid" and the second of "Shell" finite elements. Theoretical static strength analysis was performed by the method of finite elements [3, 4, 5, 6] in the Department of Railway Engineering of Technical University of Sofia. The tests on the wagon prototype were carried out in Bulgarian National Research Institute of Transport (NRIT). After the calculations were carried out and the points with the highest stresses were identified, the same points were proposed for the measurements in the test. Both theoretical and experimental studies have been done in full compliance with international

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requirements described in the European standard DIN EN 12663[7], Technical Specifications for Interoperability (TSI) - Rolling stock [8] and Code 577 of the International Union of Railways (UIC)[9]. According to these regulations, 13 static load cases and 8 fatigue load cases were carried out on the wagon structure.

In order to achieve a more precise comparative analysis, only the so-called "clear load cases" were selected, i.e. those in which the forces are applied only in one direction of the coordinate axes. This allows us to avoid some subjective factors arising from the improper positioning of the force producing elements (hydraulic cylinders) and strain gauges during the tests.

The results of only two of the obligatory (clear) load cases are presented in the paper: “Compressive force at buffer height 2000 kN” (provisionally marked LC-1) and “Tensile force in coupler area 1500 kN” (provisionally marked LC-2) [7, 8, 9, 10]. In the present research, the comparison was done in a limited number of zones.

2. Computational Models

For the purpose of this study, two complicated calculation models for static strength calculations were developed. The first model (Fig. 3) was built up from finite elements type 3D solids (Fig. 1) and consists of 697 047 nodes and 349 371 elements. The maximum size of the finite elements is 42,6 mm. All theoretically required ratios between the parameters of finite elements that allow modeling of the structure of the body with 3D solids were fulfilled.

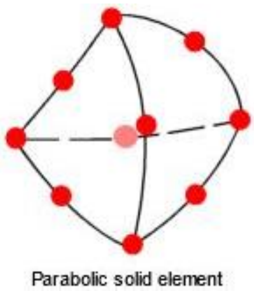

Fig. 1 Finite element type 3D solid

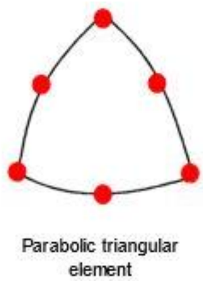

Fig. 2 Shell type finite element

In the second model the mesh was generated of finite elements type shell (Fig. 2). This mesh has following parameters: maximum size – 31,8mm; minimum size – 10,6mm; rate of increase – 1,5; number of finite elements – 401 874; number of nodes – 801 408.

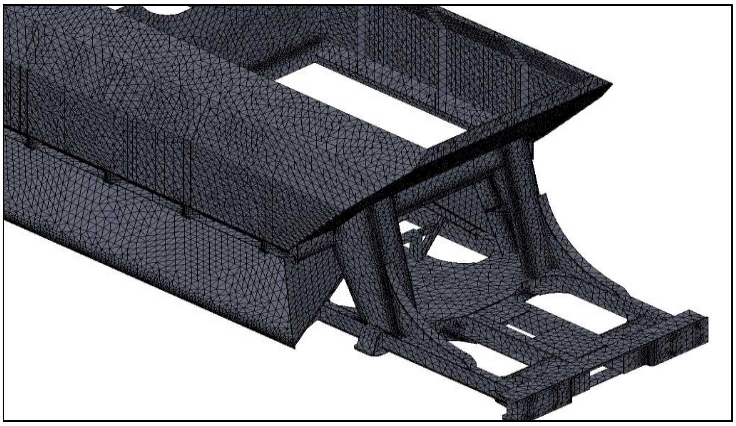

Fig. 3 FEM model built up of finite elements type 3D solid

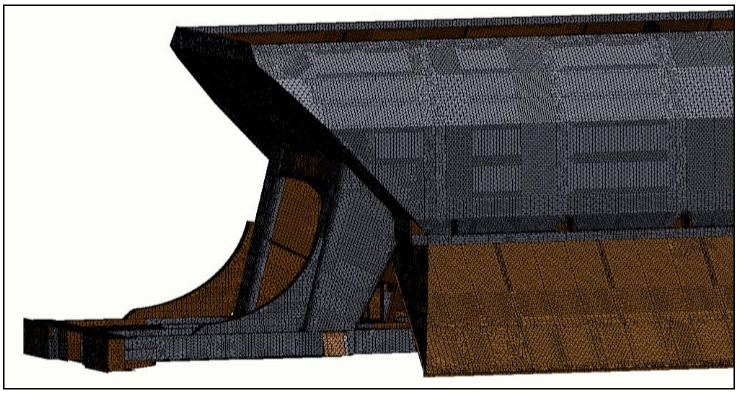

Fig. 4 FEM model built up of finite elements type shell

Fig. 4 shows the finite element mesh of the calculation model built up with elements type shell.

The models were optimized by studying the convergence of the solution [11, 12, 13, 14].

The third major component of this research is the real test of the structure [15]. Fig. 5 shows the plan and the locations of the strain gauges on the wagon prototype. The horizontal forces from load cases described above were applied by means of hydraulic cylinders acting on the buffer or draw gear.

The values of stress measured in experimental test were used in this report for comparison with stress values obtained in FEM calculation with both types of finite elements.

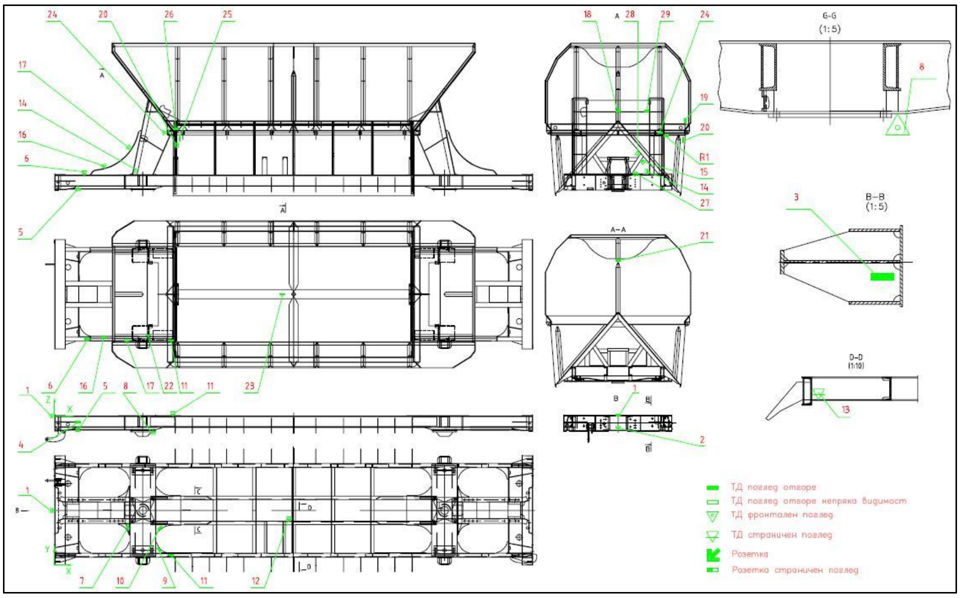

Fig. 5 Plan of measuring points on wagon prototype

3. Analysis of Results

In the analysis of the two theoretical models the forces and restrictions [16, 17, 18] were not compared in the boundary areas, as the stress values obtained there might be unrealistically high due to modeling. These stress values do not have to be taken into account in the analysis of the results [13]. It is advisable that the comparison of the results from the two computing models should be performed by elements, not by nodes. The elements cover the area where the strain gauges are located and stress value contains the information of the value of its constituent nodes. This in turn leads to a slight problem with the shell model when deploying strain gauges on the thin side of the profile. The analysis shows that it is practically impossible to make a comparison because of the way the shell model was built - with shell elements defined by the mid surface of the profile. Analysis of other problems related to modeling and FEM analysis with shell elements the authors have published in [19].

Table 1 represents the comparison of stress values in areas with the highest stresses calculated in FEM analysis with both models and stresses obtained in test of the wagon in both horizontal load cases. The analysis of the results obtained shows relatively high correlation of the stress values obtained in the two models. In most cases, the stress values in the shell model are lower than those constructed with 3D solid.

Table 1 Comparison of stress values from calculations and test

No.	LC- 1			LC- 2		
	FEM Shell	FEM Solid	Test	FEM Shell	FEM Solid	Test
1	118,6	105,7	91,4	129,8	132,1	105,3
2	86,2	89,0	80,0	98,3	160,8	149,7
4	48,6	148,4	67,9	52,5	12,4	103,5
6	127,1	139,8	283,1	70,5	51,9	67,9
8	52,1	72,6	67,5	101,9	93,8	55,9
9	64,7	53,6	77,8	133	108,7	107,5
11	138,7	249,2	205,2	107,3	126,5	151,3
12	50,2	58,3	55,1	107,1	89,5	107,3
16	32,3	29,8	69,1	8,3	4,7	25,9
19	29,9	16,5	17,1	15,1	13,8	13,5

Figs. 6 and 7 show the stress values measured in the zone of gauge No. 2 for the shell and 3D solid models respectively. Fig. 8 shows the arrangement of strain gauges on the wagon structure.

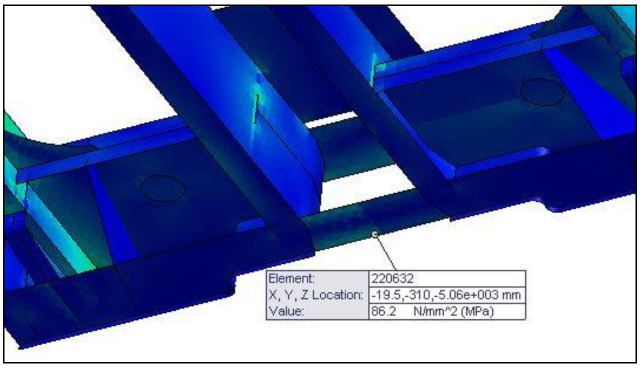

Fig. 6 Stress value in the zone of strain gauge no. 2 - shell model

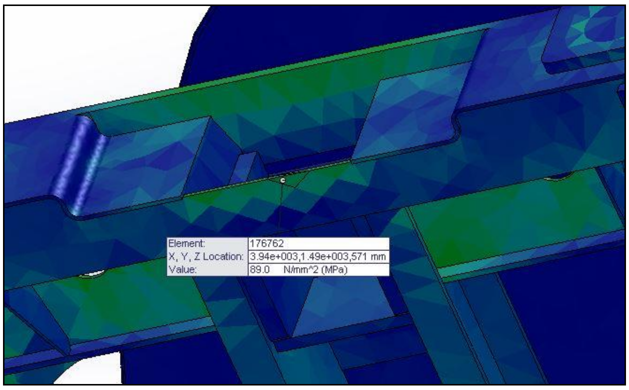

Fig. 7 Stress value in the zone of strain gauge no. 2 - solids model

Fig. 8 Strain gauge no. 2 – placement on wagon prototype during test

Figs. 6 and 7 show the stress values measured in the zone of gauge No. 2 for the shell and 3D solid models respectively. Fig. 8 shows the arrangement of strain gauge No. 2 on the wagon structure.

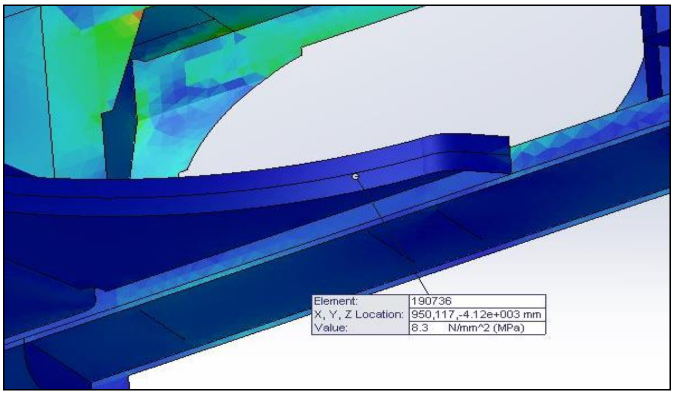

Fig. 9 Stress value in the zone of strain gauge no. 16 - shell model

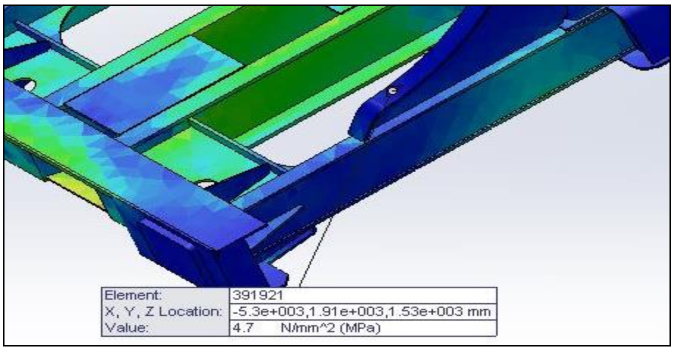

Fig. 10 Stress value in the zone of strain gauge no. 16 - shell model

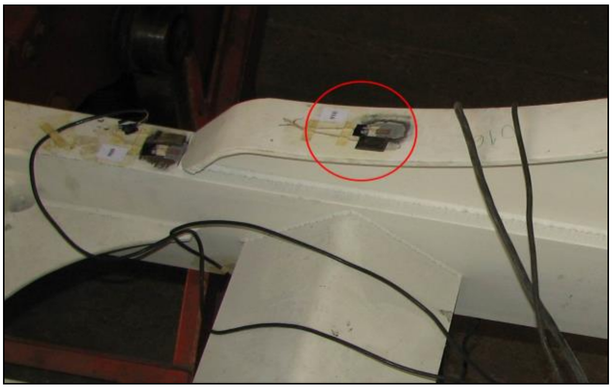

Fig. 11 Strain gauge no. 16 – placement on wagon prototype during test

All the results (two theoretical for both types of finite elements and physical measurements) show significant similarities. The analysis for all load cases shows a significant difference between the FEM values (Figs. 9 and 10) and the values measured by strain gauge No. 16 (Fig. 11). Possible reasons for the differences, in our opinion, are the defects in the welded joint located underneath the strain gauge No. 16, structural changes in the material because of bending and welding during the manufacturing of the wagon and possible inaccurate signal transmission caused by strain gauge installed in the bent part of the steel sheet.

However, the results of FEM analysis correctly reflect the general nature and distribution of stresses in the wagon structure.

4. Conclusions

Computational models for strength analysis of the structure of a specialized wagon series Fals were developed. A comparative analysis of the results obtained by calculations and those obtained in actual tests of the wagon was performed. The stress values were compared for a limited number of zones and a good correlation between the results from the theoretical models and the actual tests were found. In both theoretical models identical distribution stress values in the wagon structures were observed. This allows the developed computational models to find application in the design of new constructions of the wagons of the same series as well as more effectively to optimize the parameters of the supporting construction of this type of wagon.

Certain shell model problems were identified in the strength analysis due to modeling, correct mesh generation, stress values etc. Detailed information about these and other issues can be found in [18].

Based on the analysis and conclusions, a simple answer cannot be given as to which model – Shell or 3D solid – should be used for FEM analysis of the wagon. It is a matter of experience and personal preference which finite elements – shell or 3D solid – should be used to build a calculation model. The authors recommend the use of 3D solid finite elements, because of greater similarity with test data for high stress values. They have a number of advantages: a more precise and easy construction of the geometry, a clear visualization of the elements of the structure, fewer restrictions in modeling etc.

Construction of the hybrid model (if possible) composed of 2D and 3D finite elements for strength-deformation analysis of the wagon structure is appropriate and will reduce the modeling errors.

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