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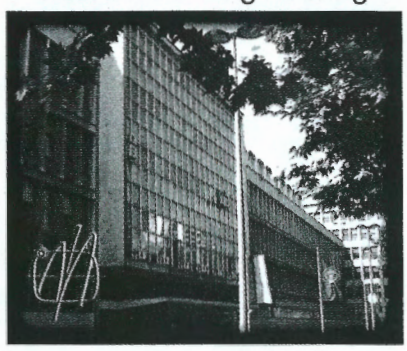

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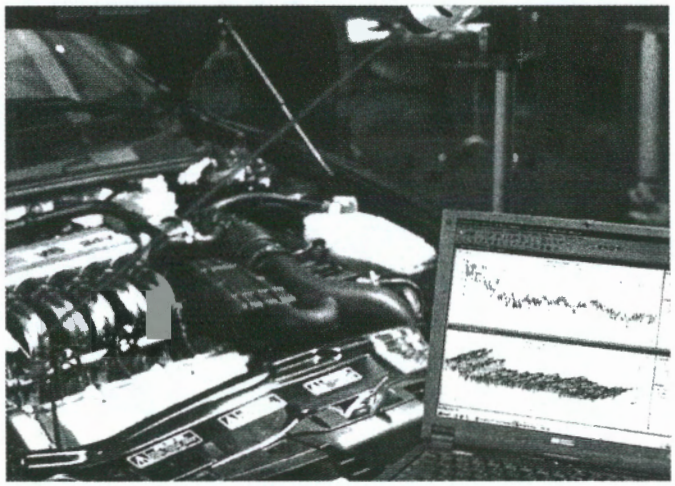
on Advances in Experimental Mechanics



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Belgrade, Serbia

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Serbian Society of Mechanics

University of Belgrade
Faculty of Mechanical Engineering

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Preface

Welcome to the 29th Danubia-Adria Symposium dealing with methods and applications in experimental mechanics as means for verifying quality of structures from the point of view of integrity, service and residual life, and technical safety. The DA Society has the objective to promote experimental mechanics, covering all aspects from the development to applications of the methods for quality improvement of processes and products to the development of a new model of education in experimental mechanics. To achieve this purpose, the Society aims to encourage exchanges of teachers, researches and students between Universities and other technical and scientific institutions.

Danubia-Adria Symposiums on Advances in Experimental Mechanics has a long tradition, since 1984. The 29th Symposium in Belgrade presents continuation of this tradition. Serbia joints to Danubia-Adria Society in 2008 year and got active member in organization and participation of DAS which take place every year in one of DA member country. This year Belgrade has been chosen as the Conference venue and we offering the hospitality for our Symposium. Serbian society for mechanics is the member of DA Society and University of Belgrade, Faculty of Mechanical Engineering is executive organizer of DAS-29.

University of Belgrade has been funded at the end of 19th century and Faculty of Mechanical Engineering in the mid of 20th century. Today our Faculty has more than 16 hundreds active students at all three levels, Bachelor, Master and PhD in relation of 3+2+3 nominal education years. At the master level education process contains about 20 branches (education modules) of engineering (not mechanical only). For majority of these branches experiments in research and in education is the main tool.

This year's DAS has received 111 accepted submissions from 12 countries (Austria-7, Croatia-14, Czech Republic-4, Germany-3, Hungary-9, Italy-5, Poland-13, Romania-6, Slovakia-6, Slovenia-4, Bosnia & Herzegovina-1, Serbia-39). The Program Committee selected 12 papers for podium presentation and 99 papers for poster presentation. I believe that the present Symposium, with its aim to exchange ideas concerning the search for new models, design solutions, and manufacturing technologies, will constitutive the next, very important step in the development of experimental mechanics.

On behalf of the Organizing Committee of the 29th DANUBIA-ADRIA Symposium on Advances in Experimental Mechanics, organizers wish a worm WELCOME to all the participants in Belgrade, and hope that all the guests will have a pleasant time in Serbia.

Chairman of 29th DAS on Advances in Experimental Mechanics

Milosav OGNJANOVIĆ

Content

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COMPARATIVE RESULTS OF WAGON STRESSES OBTAINED BY MEASURING WITH STRAIN GAUGES AND STRESSES OBTAINED BY FEM CALCULATION

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1. Introduction

Numerical simulations are a well-proven and extremely useful tool for solving problems in industrial production. Numerical simulations reduce time and cost in developing of new products. The advantage of simulations is that potential problems on product are eliminated in design phase, which leads to significant reducing of product's cost. The most widely applied and powerful tool for the numerical simulation is finite element method (FEM).

Based on results of numerical simulations next step in projecting phase is working on the prototype. The information obtained during the design of prototype and theirs testing are the key factors in deciding whether to go into serial production or to give up from it. Because of that it is very important to make a comparative analysis of the FEM calculation results and measurements on a prototype and verify their mutual matching. Measurement result and the results obtained by FEM calculation must meet all requirements for static and fatigue strength according to standards.

The paper presents one example of this. According to TSI standard [1] (Clause 4.2.2.3.1) and requirements from Clause 3, British Standard EN 12663:2000 [2], static and fatigue strength analysis of wagon for transportation scatter materials are done. Tests and measurements were performed on a prototype made, and then conducted a comparative analysis of stresses obtained by measuring with strain gauges and stresses obtained by FEM calculation.

2. FEM Model

Wagon is intended for transportation of scatter materials, resistant on the atmospheric influence. Wagon was modeled using FEMAP software [3]. According to the construction type shell elements with specified thickness and 3D elements are used for creating the finite element mesh.

Figure 2 shows a quarter of the model, which will be used, taking in consideration correspondent symmetry, for the load cases. Full model was used for unsymmetrical load cases and half model for analysing of wagon lifting. Colors on Figure 2 match the various thicknesses of shell elements.

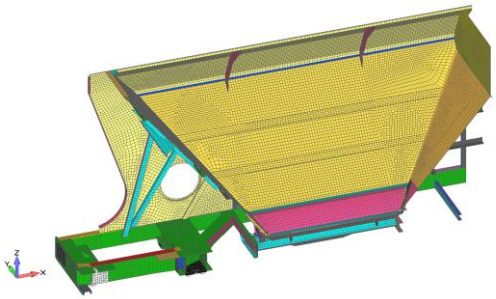

Fig. 1: Finite element mesh – quarter wagon model

3. Safety factor and permissible stress

According to EN 12663:2000, Clause 5.4, calculated permissible stress using Clause 3.4.2 is lower than calculated stress using Clause 3.4.3. Therefore, under the static load cases as defined in EN 12663:2000, Clauses 4.1 to 4.5, the ratio of yield stress ($R=R_e$) to calculated stress (σ_c) must be greater than or equal to S_1, Table 1.

Material	Safety factor S_1	σ_{cmax}[MPa]
S355J2+N	1.15	309

Tab. 1: Safety factor and permissible stress for static loads – parent material

According to Clause 3.4.2 of EN 12663:2000, safety factor S_1 may be taken as 1.0 for superposition of load cases.

Table 2 shows limit values for static test to verify fatigue strength accordance with Eurocode 3, Part 1.9 [4], using Figure 7.1 and Table 3.1.

Direct stress range $\Delta\sigma_C$ [MPa]	Permissible maximim fatigue stress σ_{maxlim} [MPa]	Limit stress for safe life [MPa]	
		Low consequense (γ_{Mf}=1,15)	High consequense (γ_{Mf}=1,35)
160	347	301	257
100	217	188	160
90	195	170	144
80	173	151	128
71	154	134	114
63	136	119	101
56	121	106	90
50	108	94	80

Tab. 2: Limit stress values for static test to verify fatigue strength in steel S355J2+N

4. Load cases and requirements

According to TSI, Clause 4.2.2.3.1, wagon structure is necessary to calculate in relation to different types of load:

- Exceptional loads, which cover: longitudinal design loads, maximum vertical load, load combinations, lifting and jacking and other exceptional loads;
- Service (fatigue) loads

Exceptional load cases are specified in TSI, Clause 4.2.2.3.2 and EN 12663:2000. For all exceptional load cases maximum value of calculated stress must be lower than the permissible stress shown in the Table 1.

Service (fatigue) loads are specified in TSI, Clause 4.2.2.3.3 and EN 12663:2000. For service (fatigue) loads maximum value of calculated stress in welded joints must be lower than the limit stress for safe life in the Table 2.

5. Measuring and position of strain gauges

According to results obtained by FEM calculations for all load cases defined in accordance with the TSI standard, and with British Standard EN-12663:2000 on wagon set up strain gauges and measurements were carried out. At the locations of strain gauges stresses were obtained.

Position of strain gauges mounted so that it covers all the places on the wagon, on which the numerical calculations shows a stress concentration. Schematic of the strain gauges are shown on Figure 2.

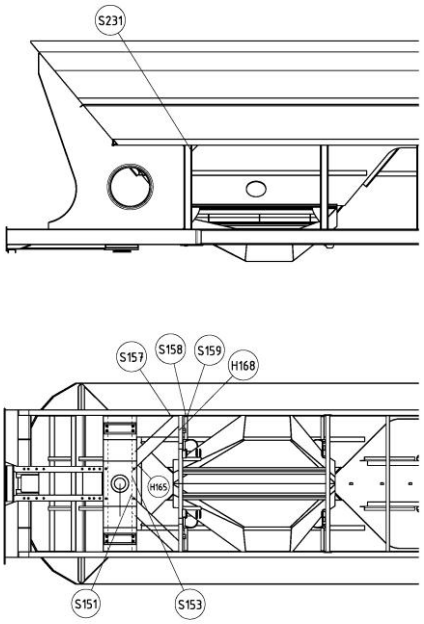

Fig. 2: Position of strain gauges

6. Comparative results of stresses

For all cases of static and dynamic loads were read values of stresses at the locations of strain gauges. It compared the measured stresses at the locations of strain gauges and the stresses obtained from the FEM calculations, using software PAK [5].

The aim of the analysis is to show that on the basis of measurements and calculations based on FEM obtained similar values of stress, bellow values of permissible stress defined according to TSI and EN 12663:2000

At the place of strain gauge 158 normal stress of 322MPa was measured for longitudinal case of load, when compressive force acting at coupler level; F=2000kN.

Stresses shown in report obtained by measuring with strain gauges actually are normal stresses in direction of strain gauge.

Places of strain gauge 158, as strain gauges 157 and 159 are shown on Figure 3. Results obtained by FEM analysis are shown on Figure 4.

Fig. 3: Strain gauges 157, 158 and 159

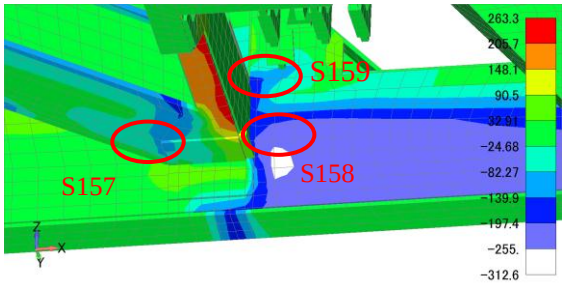

Fig. 4: X Normal stress field

In the Table 3 are shown comparative results obtained by strain gauges and appropriate normal stresses obtained by FEM analysis.

Strain gauge number	Stress σ_{xx} [MPa]		Difference in %	Figure number	
	Strain gauge	FEM analysis		Strain gauge	FEM analysis
157	-31	-30.9	0.3	3	4
158	-322	-312.6	2.9		
159	-248	-258.7	4.1		

Tab. 3: Comparative results obtained by strain gauges and FEM analysis for longitudinal case of load when compressive force acting at coupler level; F=2000kN

Difference between results obtained by strain gauges and FEM analysis is lower than 5% which is acceptable. It can be observed that stress is higher than 309MPa and that does not meet safety factor 1.15. It should be noted that stress 332MPa is lower than R_e=355MPa for material S355J2+N. According to BS EN 12633 Clause 3.4.2, S_1 may be taken as 1.0 where the design load cases are to be verified by test.

For the load case of maximal vertical load at positions 151, 153, 165 and 231, comparative results obtained by strain gauges and appropriate normal stress obtained by FEM analysis are given in the Table 4.

Strain gauge number	Stress [MPa]		Difference in %	Figure number	
	Strain gauge	FEM analysis		Strain gauge	FEM analysis
151	-126	-121.7	3.4	5	6
153	-127	-121.7	4.2		
165	114	106	7	7	8
231	-122	-116	4.9	9	10
168	112	125	10	11	12

Tab. 4: Comparative results obtained by strain gauges and FEM analysis for longitudinal case of load when compressive force acting at coupler level; F=2000kN

Fig. 5: Strain gauges 151 and 153

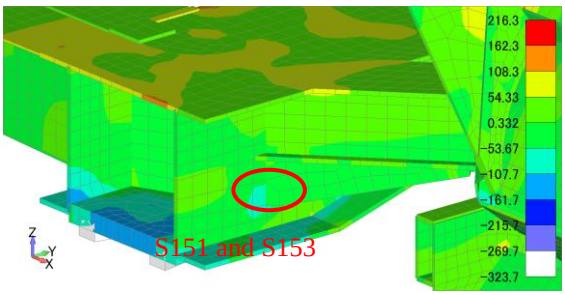

Fig. 6: Y Normal stress field

Fig. 7: Strain gauge 164 and 165

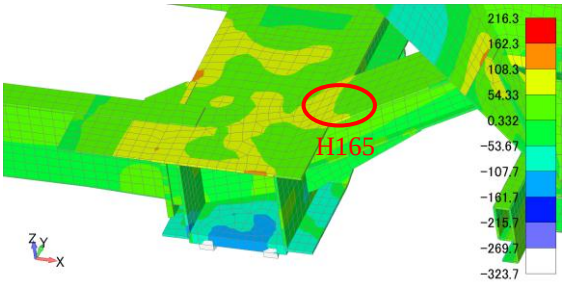

Fig. 8: Y Normal stress field

Fig. 9: Strain gauge 231, 233 and 235

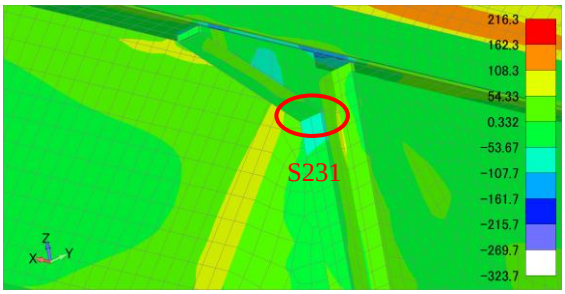

Fig. 10: Y Normal stress field

Fig. 11: Strain gauge 166, 167 and 168

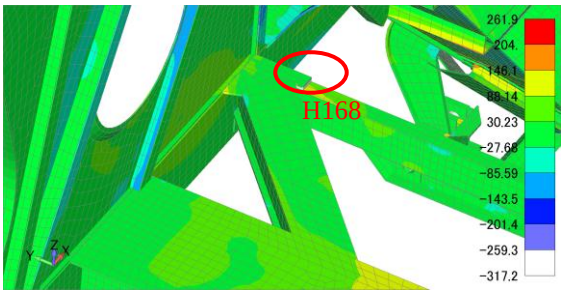

Fig. 12: X Normal stress field

Based on measured and calculated stresses given in the Table 4 and limit stresses given in Table 2, it can be concluded that the measured and calculated stresses are below limit stress for safe life (high consequence γ_{Mf}=1.35) for the parent material and welded joints (detail category 100).

Conclusions

The aim of this paper was to compare results of stresses obtained by measuring with strain gauges and stresses obtained by FEM calculation. Example demonstrates applying of the most common European standards for calculating static and dynamic strength of wagon. Comparing the numerical results with the results of measuring, it is verified that software gives good agreement with the experimental results. Difference between results obtained by strain gauges and FEM analysis is lower than 10%. According to presented results it can be concluded that FEM analysis can reduce number of the testing new products. This would lead to big savings and significantly less cost of products.

7. Acknowledgement

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8. References

[1] TSI Standard - Freight wagons of the trans-European conventional rail system
[2] EN 12663 - Railway applications – Structural requirements of railway vehicle bodies, European Standard
[3] FEMAP Version 10 (2009) User Guide, Siemens Product Lifecycle Management Software Inc, Munich – Germany
[4] Eurocode 3: Design of steel structures - Part 1.9: Fatigue
[5] Zivkovic M., Kojic M., Slavkovic R., Grujovic N., PAK–S Program for FE structural analysis, Faculty of Mechanical Engineering, University of Kragujevac (2003)