CETRA 2018

5th International Conference on Road and Rail Infrastructure

17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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COMPARATIVE STRENGTH ANALYSIS OF THE RAILWAY CANTILEVER

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Abstract

The paper is dedicated to comparative analysis of the results of the static strength calculation of the cantilever and the tests that have been carried out. Strength calculations have been made using the Finite Elements Method in the Department of Railway Engineering at the Technical University – Sofia. Three different types of Finite Elements (solid, shell and beam) have been used for calculations. The tests of the cantilever have been carried out in the Testing laboratory of Department of Railway Engineering. It was found that the stress results are very similar, especially in the areas with maximal values. This proves that a suitable calculation model with a relatively small number of finite elements has been developed. This allows solving a wide range of problems concerning the improvement of the cantilever with similar construction.

Keywords: cantilever, FEM analysis, test

1 Introduction

This report presents the results of a strength assessment of the elements of the catenary using the finite elements method. Sophisticated computational models built from a mesh of different types of finite elements, which accurately describe the geometry of the console carrying the contact wire, have been developed. Theoretical calculations were made in the Department of Railway Engineering using SolidWorks Simulation [1, 2]. All prescribed load cases [3, 4, 5] were analyzed. In order to be able to select the most accurate computational model, the results obtained by calculation are compared with results from tests. The equipment of the German company HBM (Spider 8) [6, 7] was used for measurement of strain.

2 FEM models

The Finite Element Method used for analysis has been proven over the past decades as the most accurate method of stress-strain analysis of complex machine tools [1, 2, 4, 5, 8, 9]. It allows a structure to be modeled with different types of finite elements (solids, shells, beams, etc.), and the choice of the type of the finite element is purely subjective [5,9,10]. Four different models of cantilever were built. When developing these models, the next steps were followed:

2.1 Analysis of the documentation

This analysis gives us information on the geometry and the shapes of the individual structural elements, their material characteristics, the particularities of the connections between welded, bolted, articulated and other types of joints on the consoles.

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2.1.1 Characteristics of the material

The materials used for cantilever have the following physical properties [4, 11, 12]:

Table 1 Physical properties

Alloy type	Aluminum Alloy	Stainless steel 1.4567
Yield Strength	260 MPa	340 MPa
Young module	70 GPa	200 GPa
Poisson Coefficient	0.33	0.3
Density	2700 kg/m^3	7900 kg/m^3

2.1.2 Geometrical peculiarities

Fig. 1a shows a general view of the console with a straight retainer, and Fig. 1b – one with a counter-lock. The figures provide information about the pipe sections used to construct the structure. The connections between them are made using U-shaped bolts that connect the individual elements with cast tips and joints.

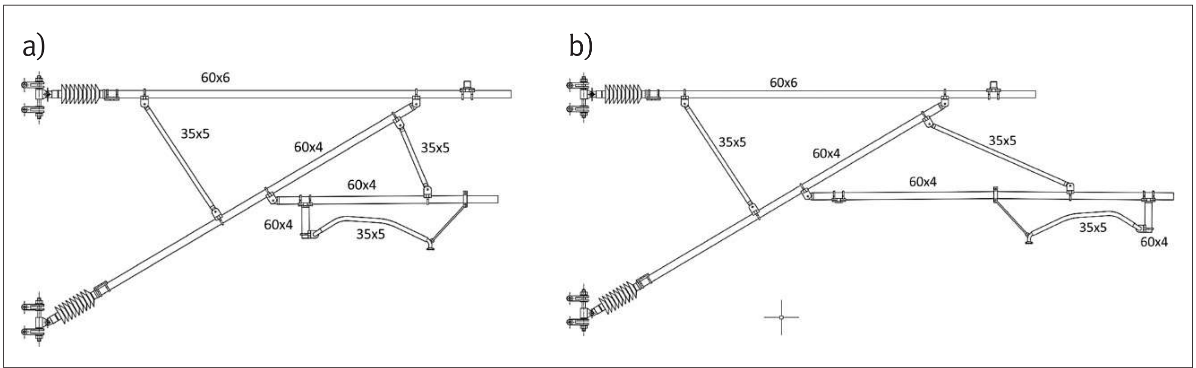

Figure 1 Construction of the cantilever

The geometric characteristics of the console and its component elements do not allow for a unambiguous solution to choose the type of finite elements to be used to construct the computational model. For the purpose of the present study, computational models were developed using three types of finite elements, theoretically corresponding to the adequate representation of the actual construction.

2.2 Development of calculation models

The design features were taken into account when building the computational models. Each one of the computational models is characterized by the following features in chapters 2.2.1, 2.2.2 and 2.2.3.

2.2.1 Restraint definitions

The restraint definitions are applied to the connection of the cantilever insulators with the pole (Ux = 0, Uy = 0, Uz = 0).

2.2.2 Loads

The loads on all FEM models are presented as follows:

- F_{H2} a force acting horizontally on the steady arm carrying the contact wire applied to the link of the arm with the cantilever.
- F_v force generated by the masses of the carrier components.
- F_{H1} horizontal force acting in the bracket linking the cantilever and the messenger wire.
- Cantilever tare weight.

2.2.3 Load cases

Load cases in the calculation models are defined according to the requirements of the normative document of the Bulgarian National Railway Infrastructure Company: Subsystem electrical power supply of the traction vehicles 25 kV, 50Hz. Overhead contact system. Pantographs. Mechanical interaction between pantograph and catenary [3]. Table 2 shows the load cases. For both types of consoles the nominal values (H_{nom}), the maximum permissible operating values (X_w), The maximum (X_{max}) and the test (X_{test}) loads determined for the specific conditions of the electrified sections of the infrastructure must be guaranteed.

Table 2 Load cases

element	Load, kN					
	Force	Scheme №	X_{max} ›	X_{nom}	X_{test}	X_w
Single cantilever	F_V	1	6,9	4,6	3,7	2,3
	F_{H1}		5,4	3,6	2,9	1,8
	F_{H2}		5,1	3,4	2,7	1,7

Computational models for all load cases on the cantilever with a straight retainer have been developed. For this purpose, workloads – X_w have been taken into account in the development. They were used for verification of the computational models. Forces in all models are applied as shown on Fig. 2.

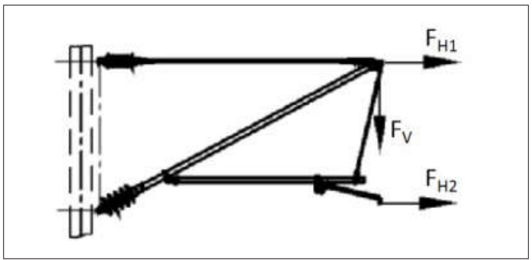

Figure 2 Load scheme [3]

2.3 Calculation models

2.3.1 Calculation model with solid elements mesh and pin connection

Its geometry is constructed as a monolithic body. The connection between the individual units is made by pins. This allows rotation of different components relative to one another. Additionally, a “no penetration” connection is established between the individual components. Convergence of the solution was studied. In Fig. 3 a overview of the finite elements mesh is given. A mesh type used is built up of solids elements. The model is built up with 121020 nodes including 64015 elements. The minimum element size is 4 mm and the maximum is 19 mm.

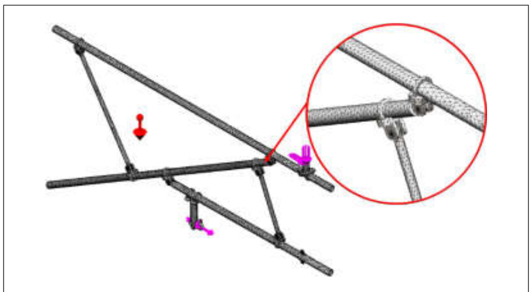

Figure 3 Solid mesh

2.3.2 Hybrid calculation model with mixed mesh – solid and beam elements

The geometric modeling of the connecting elements is interpreted as a 3D solid element. Pipes are presented as beam elements. Fig. 4 shows a model with a mixed mesh of finite elements. The model is build up with mixed mesh that contains solid and beam elements. The model parameters are as follows: number of nodes 28357, number of elements 15006, maximum element size 19 mm, minimum element size 1 mm.

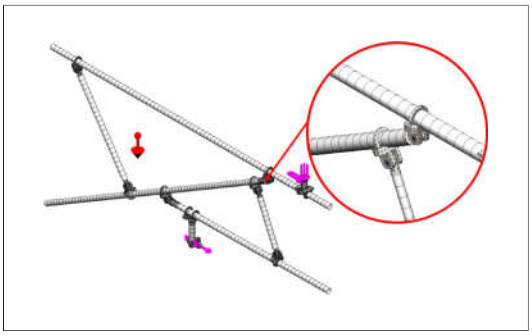

Figure 4 Mixed mesh – solid and beam elements

2.3.3 Hybrid calculation model with mixed mesh – solid and shell elements

This calculation model is the same as that in point 2.3.2 with the difference that the pipes of the structure are modeled as surface (shell elements) as shown in fig. 5. The cantilever model is built by mixed mesh – solid and shell elements. Parameters of the mesh are: 54605 nodes, 28651 elements, maximum element size 25 mm, minimum element size 5 mm.

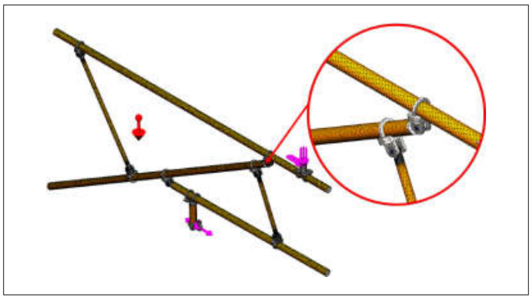

Figure 5 Mixed mesh solid and beam elements

2.3.4 Calculation model with shell elements

The calculation model is made entirely of surfaces. The disadvantages of this type of modeling are the inability to build the tube attachments. The reason for this is that the surfaces are suitable for modeling products made of sheet material.

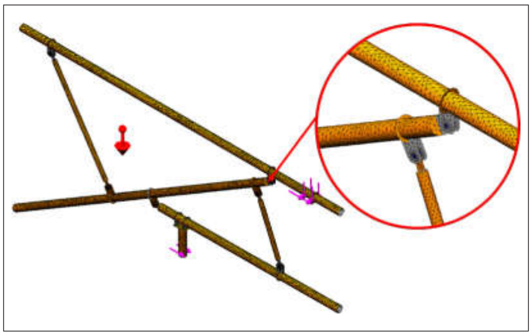

Figure 6 Model whit shell mesh

The model in Fig. 6. is built up with shell elements. The dimensions of the finite elements are 16 mm for areas where there are no sudden changes in geometry appears and 5 mm in areas with stress concentration. The number of elements is 18866 and the number of nodes 38172.

3 Test

The test was carried out on a special bench in Testing laboratory of Department of Railway Engineering at the Technical University – Sofia, as shown in Fig. 7.

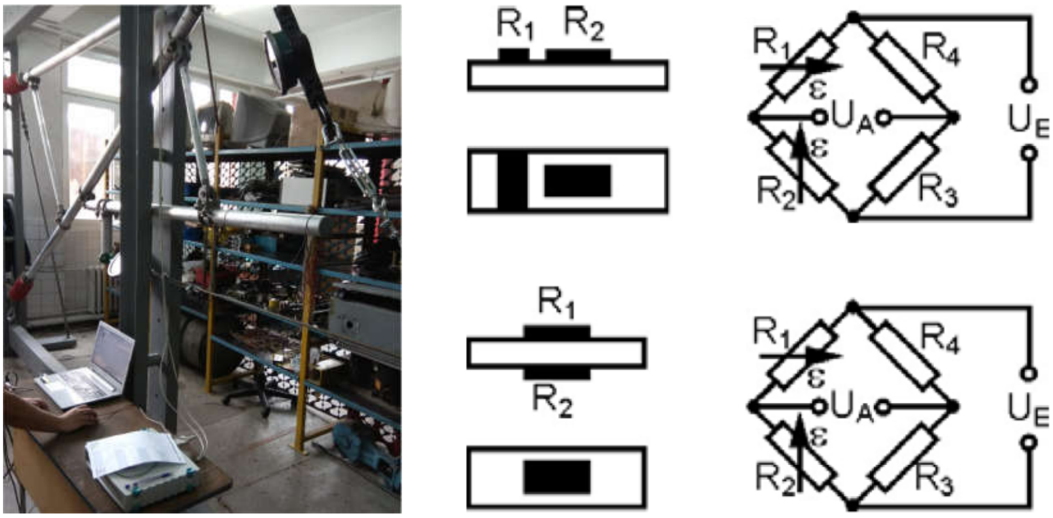

Figure 7 Test bench and connection configuration of the strain gauges[13]

From the theoretical studies and the analysis of the results it is clear that the maximum stresses in all models are in the same area of the construction. This is important, because knowing the location of the most endangered sections, the exact position of the strain gauges can be determined. The number of locations where the measurement is performed is limited, taking into account only areas with maximum stresses.
During the bench tests, a half-bridge circuit with two reference resistors and two strain gauges [6, 13, 14, 15] was used. Four strain gauges were placed in the investigated area. Two of them are located at the top of the carrier tube and two at the bottom. The placement of gauges is T-shaped, one located along the longitudinal axis of the profile and the other along its transverse axis [16]. For the purpose of this study, two principal binding schemes were used (fig. 7) [13] and three groups of studies have been conducted.

4 Results analysis

The following variables were examined: equivalent stresses in finite elements, stresses in nodes, stresses in longitudinal direction of the tube. The calculations results show, that there are no areas with insufficient strength in whole model. An analysis of the results can provide clearness about the most loaded areas of the construction. This helps to identify the most endangered sections, hence the location of the strain gauges to account the adequacy of the model. Figure 8 a,b,c,d shows: stress diagrams obtained by the FE analysis. The recorded values of stresses from the tests via the connection schemes shown in Fig. 7 [6, 13, 14, 15] are similar to values obtained theoretically. The comparative analysis of the results given in Table 3 is done for different elements used in calculation [9]. Reason for this approach, on the one hand, gives us the analysis of the results obtained for the stresses by nodes and by elements. The values obtained show minimal difference. On the other hand, the strain gauge detects deformations of a particular area [9].

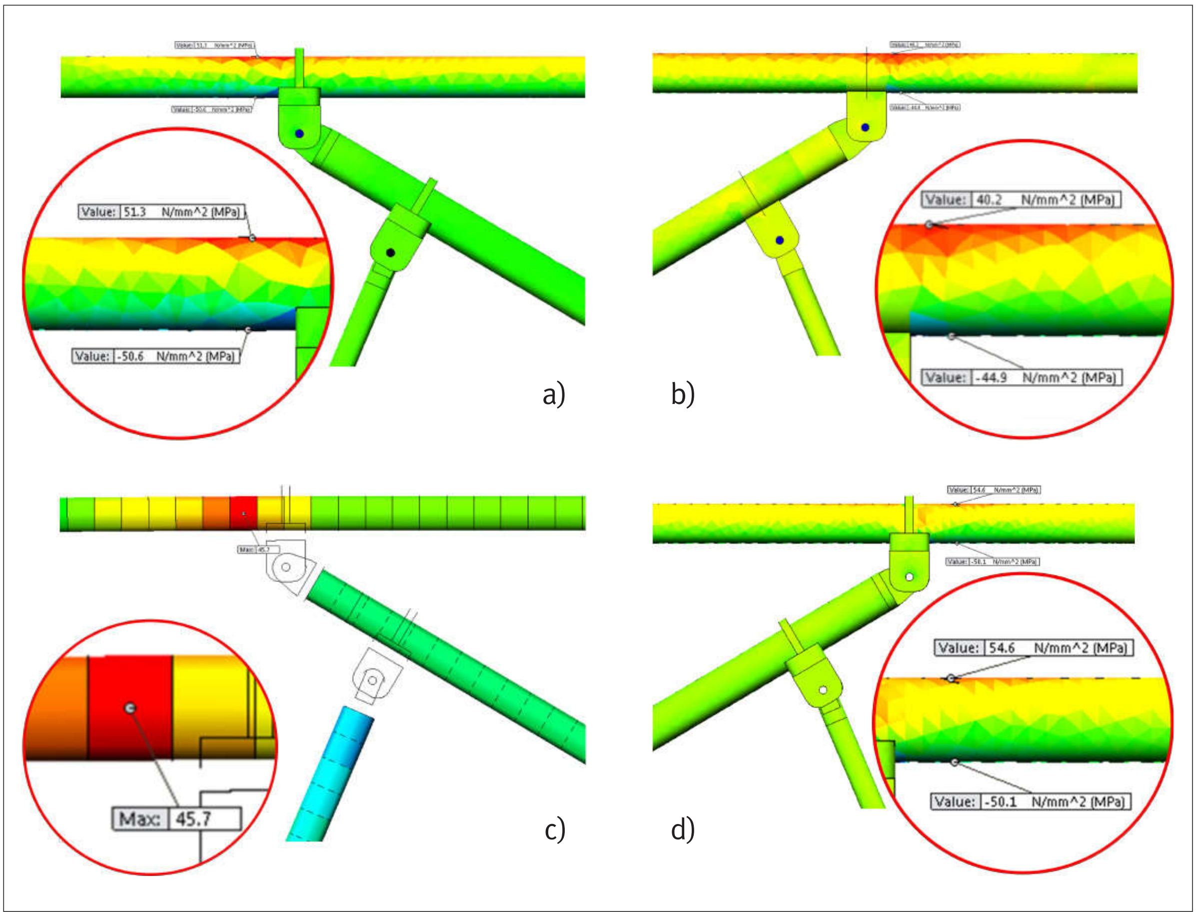

Figure 8 a) Solid; b) Shell; c) Hybrid- solid/beam; d) Hybrid- solid/shell

Table 3 Measurement results

Model	FEM			TEST		
	Bottom	Top	Average	Half bridge Bottom	Half bridge Top	Half bridge Top-Bottom
	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
Shell	-44.9	40.2	42.6	-49.787	51.952	52.060
Solid	-50.6	51.3	50.95			
Solid/Beam		45.7	45.7			
Solid/Shell	-50.1	54.6	51.3			

5 Conclusions

Summarizing the overall work on this study, the following conclusions can be made: Data analysis shows the presence of good matching results for the stresses obtained by the calculations and those of the test. The minimum differences can be explained by: the simplification adopted in the modeling; the way of gluing and placement of the strain gauges; errors of measuring equipment; constructive and technological inaccuracies in the construction design. Calculation models with solid mesh and hybrid with mixed mesh (solid and shell elements) exactly describe the behavior of the construction. The stress values obtained by this two me-

shes are as close as possible to the values obtained by test. They are suitable for research and optimization of other elements of the cantilever, such as wire joints, clamps, brackets, etc.
In conclusion, it should be noted that the developed calculating models can be used in the design of new constructions,which additionally can be tested with test bench at the laboratory of the Department of Railway Engineering.

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References

[1] Kurowski, P.: Engineering Analysis With COSMOSWorks 2005. Schroff Development Corporation, 2005

[2] Steffen, R.J.: Analysis of Machine Elements Using SolidWorks Simulation 2014. S. D. Corp., 2013. ISBN-13: 978-1-58503-856-5, ISBN-10: 1-58503-856-3

[3] National Railway Infrastructure Company. Subsystem electrical power supply of the traction vehicles 25 kV, 50Hz. Overhead contact system. Pantographs. Mechanical interaction between pantograph and catenary. 29.09.2006.

[4] Kiesiewicz, G., Knych, T., Kwaśniewski, P., Rojek, A.: Development and Testing of New Solutions of Overhead Contact Line Accessories, pp. 39-50. Instytut Kolejnictwa (Railway Research Institute) Volume 60, Issue 171 2016 ISSN 0552-2145.

[5] Stoilov, V.: Strenght Analysis Of The Bearing Console For The Contact Conductor Of Electrified Railway. TRANS&MOTAUTO"09, Sunny Beach, 17-19.09.2009.

[6] Gittins, N.: Short Guide to Strain Gauging Methods, pp.1-12, http://www.disensors.com/downloads/products/Strain%20Gauge%20Installation%20Methods%20-%20Short%20Guide_786.pdf, Accessed 05.03.2018.

[7] Tsonev, V., Stoychev, G., Chankov, E.: Stress Analysis Of A Link For Slat Chain Conveyor. MATEC Web of Conferences 133, 05001 (2017) DOI: 10.1051/matecconf/201713305001

[8] Stoychev, G.: The Finite Element Method the strength and strain analysis, Sofia, 2000.

[9] Slavchev, S., Georgieva, K., Stoilov, V., Purgic, S.: Analysis Of The Results Of Theoretical And Experimental Studies Of Freight Wagon Fals. XVI Scientific-Expert Conference on Railways RAILCON`14, Nis, 10.2014.

[10] Slavchev, S., Georgieva, K., Stoilov, V.: Issues Of Wagon Modeling With Shell Elements. XVI Scientific-Expert Conference on Railways RAILCON`14, Nis, 10.2014.

[11] EN ISO 3506.

[12] EN 1706:2010. Aluminium and aluminium alloys – Castings – Chemical composition and mechanical properties

[13] Hoffmann, K.: Applying the Wheatstone Bridge Circuit, pp. 1-28, http://eln.teilam.gr/sites/default/files/Wheatstone%20bridge.pdf, Accessed 12.03.2018.

[14] Patel, B., Srinivas, A.: Validation of Experimental Strain Measurement Technique and Development of Force Transducer, International Journal of Scientific & Engineering Research, Volume 3, Issue 10, October-2012 ISSN 2229-5518.

[15] USER GUIDE SCC-SG Series Strain Gage Modules, http://www.ni.com/manuals/, Accessed 09.03.2018

[16] Nikolov, N., Sinapov, P.: Determination Of The Internal Resistance Of A Hammer Drill Chisel. Journal of Theoretical and Applied Mechanics, 56 (2018) 1, pp. 169-178, Warsaw 2018, DOI: 10.15632/jtam-pl.56.1.169.