Strength Investigation of Main Frame in New "Track friendly" Railway Bogie

Pavol Šťastniak[1], Marián Moravčík[2], Lukáš Smetanka[1], Peter Baran[1]
[1]Faculty of Mechanical Engineering, University of Žilina, 010 26 Žilina. Slovak Republic. E-mail: pavol.stastniak@fstroj.uniza.sk, lukas.smetanka@fstroj.uniza.sk, peter.baran@fstroj.uniza.sk,
[2]Tatravagónka Inc., Štefánikova 887/53, 05801 Poprad. Slovak Republic. E-mail: marian.moravcik@tatravagonka.sk.

The paper deals with the strength conditions assessment of new design of modern railway bogie through FEM analysis. The bogie, which was developed as part of European structural funds project, is characterized mainly by better dynamic properties while driving on the track, higher safety against derailment and lower negative effect on the track (reduction of wear). For analysis of bogie frame, there has been created a substitute simulation model. Results from calculations and prototype tests prove, that investigated design of new construction satisfies strength conditions.

Keywords: Strength Tests, Bogie Frame, Computer Simulation.

1 Introduction

University of Žilina and Tatravagónka Inc. Poprad jointly developed a new freight railway bogie TVP 2009-R (Fig. 1) for broad track gauge of 1520 mm, as part of project supported by the Operational Programme Research and development funded by the European Regional Development Fund (ERDF) with name "Development of two types of freight wagons with bogies for non-standard wheelbase or track wheelset, complying with the criteria for interoperability, environmental issues, safety and reliability".

The concept is derived from the bogie type TVP 2007, which has been certified under Technical Specifications for Interoperability (TSI) and they are currently used on the EU tracks with track gauge of 1435 mm. Designed bogie hence used:

- simplicity and reliability of friction damping by system Lenoir,
- reliability based on verified design solutions,
- real speeds increase by using bogie technology with a rigid frame,
- transition improving through curves with small radiuses for wheelset radial position ensuring.

The bogie type Y25 is characterized by wheelset guiding, in which is primary suspension with progressive damper as part of axlebox. The damper is always located on one side of the axlebox suspension of each wheelset. Bogies equipped with this standard configuration have a certain size of guiding forces while driving along the curve of the track and related technical consequences [3]. In order to reduce these forces, the new design of bogie uses the connection of wheelsets by means of cross coupling. The purpose of cross coupling is radially adjustable wheelset position in curves. Therefore, the vehicle achieves better dynamic properties (lower guiding forces and better angle of attack), higher safety against derailment and lower negative effect on the track (reduction of wear), known as "track friendly" bogies.

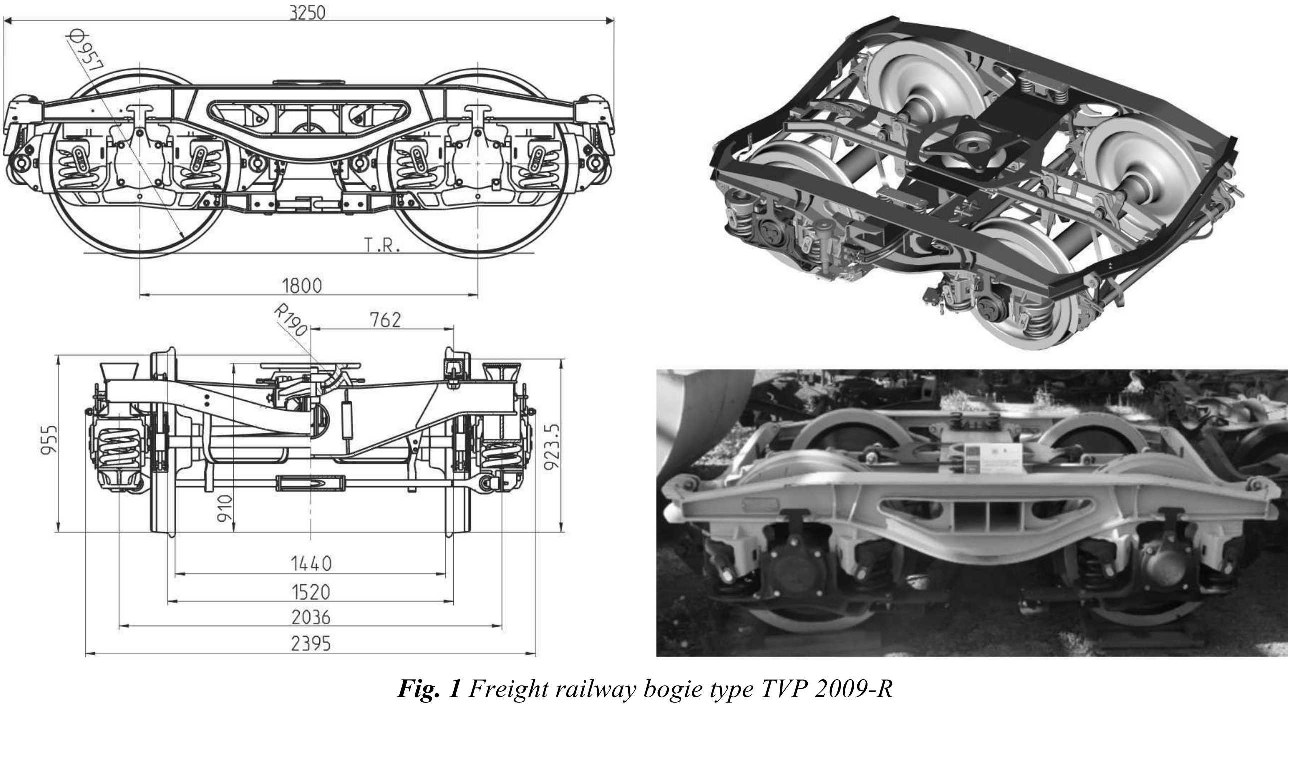

Fig. 1 *Freight railway bogie type TVP 2009-R*

Basic technical and dimensional parameters of the bogie are listed in Tab. 1.

***Tab. 1** Dimensional and technical parameters of the bogie*

Wheelbase	1800 mm
Wheel diameter	957 ±7 mm
Axle pin diameter	130 mm
Axle pin length	190 mm
Height of the bogie pivot above the top of rail	900 ±12 mm
Lateral clearance of all axles	±10 mm
Longitudinal clearance of all axles	±8 mm
Weight	4900 kg ±5 %
Maximum speed at an axle load of 25 t	120 km/h
Temperature range	+50 °C to -60 °C
Special equipment	ready for Automatic system MATROSOV
	composite brake blocks

2 Bogie frame assessment by means of computer simulations

Every new freight bogie or wagon prototype before start in operation must be assessed and approved according to requirements of TSI. As part of the documentation, which the applicant must submit, are the results of prototype tests. The aim of the validation plan is to prove that the design of the bogie frame fulfils the conditions defined in the technical specification. In addition, it shall show that the behaviour of the bogie frame, constructed according to the design, will give satisfactory service without the occurrence of defects such as catastrophic rupture, permanent deformation and fatigue cracks. It shall further demonstrate that there is no adverse influence on the associated bogie components or sub-assemblies. The procedure for the validation of the mechanical strength of a bogie frame against the acceptance criteria shall be established on the basis of analysis (computations), laboratory static tests, laboratory fatigue tests and track tests.

Currently, by using advanced computer technology is possible those tests at high levels predict by simulation analysis. The great advantage of the mentioned simulations is that the entire development process of rolling stock is so accelerated, leading to a reduction in overall costs. Simulations and subsequent design optimization of the vehicle structure (shape and thickness of components) is made before production of the vehicle itself. This leads to minimizing the number of unsatisfactory results conducted on a real vehicle. This may, in such a stage of development lead to delays and increased costs. Computational models of vehicles and their components are more or less simplified compared with the actual ones. This simplification is seen when comparing the results from real tests.

The object of our calculations is the strength test of new design of freight bogie frame through FEM analysis.

2.1 Computational model – geometry and material properties

Computational model (Fig. 2) was created in program MSC.Marc. For analysis of bogie frame design by finite element method has been created mesh of shell finite elements, which lies in the planes center surfaces individual parts of analyzed design. The analysis is performed in a linear region. The distortion of the results of the analysis resulting from the introduction of the simplifications mentioned is considered negligible.

They are used as isoparametric, four-node shell elements with average size of elements 10 mm. The thickness of the shell elements was determined according to the drawing documentation. Location of forces and boundary conditions (hemispherical bogie pivot, slides, etc.) are modeled by 2-node beam elements. The springs of suspension are replaced with very soft beam elements.

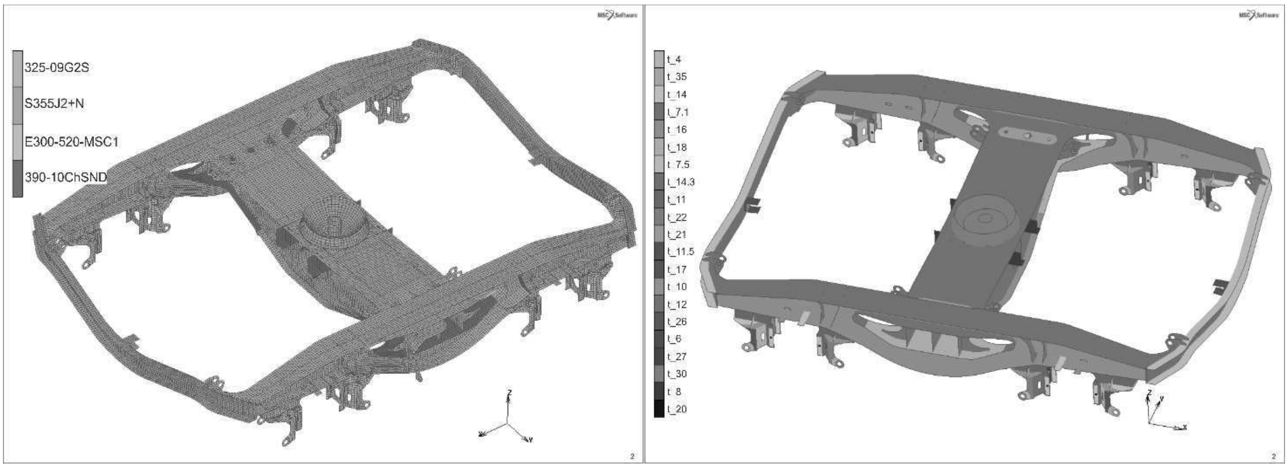

***Fig. 2** Freight railway bogie type TVP 2009-R*

Frame parts were designed from structural steel of 09G2S, 10ChSND, S355J2+N and their properties are shown inTab. 2. Castings (axle guard) are designed of E300-520-MSC1.

Consideration is being given to the fact, that the material is linear, elastic and isotropic. Mechanical properties: Young modulus of elasticity E=2.1e5 MPa, Poisson´s ratio μ=0.3. Goodman diagrams were used according [5], curves "a1", "a2", "b", annex F.3, with conditions of application of the annex F.4, safety factor 1.1.

Tab. 2 *Material properties*

Material	Norm	Thickness [mm]	Min. yield strength Re [MPa]	Min. tensile strength Rm [MPa]
325-09G2S	GOST 19281-89	from 10 to 20	325	450
10ChSND	GOST 19281-89	up to 40	390	510
E300-520-MSC1	UIC 840-2	casting	300	520
S355J2+N	EN 10025-2	up to 16	355	470
S355J2+N	EN 10025-2	from 16 to 40	345	470

2.2 Boundary and load conditions

Boundary conditions (Fig. 3) are captured:

- in the middle of lower flangeplate of transverse beam,
- in two nodes of lower flangeplate of transverse beam (exceptional loads),
- in the middle of manganese plates of axle guide (normal service loads),
- under 8 substitute springs.

The first two boundary conditions are used only for the stability of calculation, because reactions in them are practically zero.

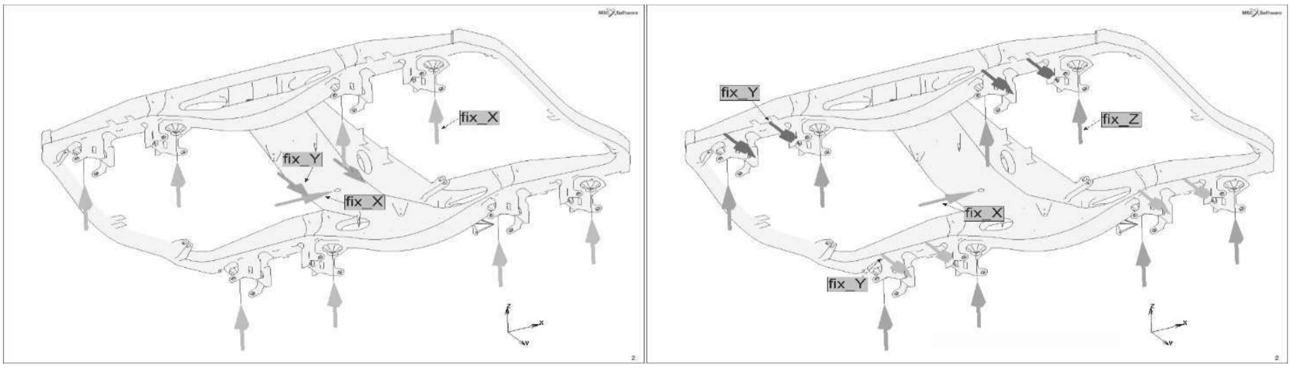

Fig. 3 *Boundary conditions for exceptional loads (left) and normal service loads (right)*

In reality the loads are combined in a complex manner and so it is difficult to represent them exactly in analysis. Consequently, it is generally the practice, for ease of analysis, to represent the true loads by a series of load conditions which include the above effects in a simplified form, either individualy or in combination. It is essential that the simplification ensures that the effects of the true loads are not underestimated. The load conditions required for the design and assessment of the bogie frame will be depend on the application being considered.

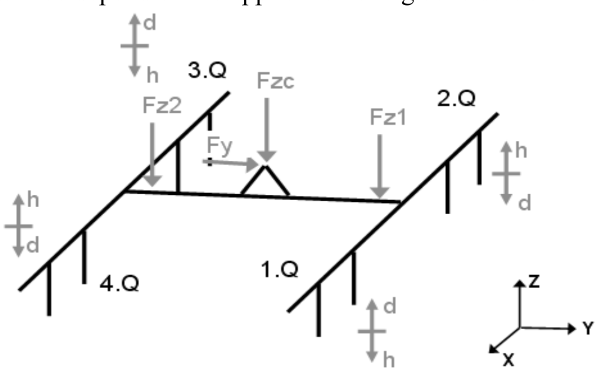

Fig. 4 *Load forces – schematic view*

The source data does not indicate how the specified loads should be reacted. Therefore, the designer needs to consider load balances appropriate to the application. In particular, the reactions to the lateral loads specified as acting at the wheelset should include the bogie inertia forces to determine realistic secondary suspension forces.

Load conditions were created according [4] for axle load 25 t. These are combinations of vertical loads in hemispherical bogie pivot, in slides, lateral forces in pivot and unevenness of the track. All loads used as the basis for the bogie design should incorporate any necessary allowance for uncertainties in their values. Schematic view of loading forces are shown in Fig. 4.

Loading conditions according [4] are divided into two groups:

- ***Test under exceptional loads***

Tab. 3 *Load cases for tests under exceptional loads*

Load Condition	Vertical Forces [kN]			Lateral Forces	Unevenness of track [‰]	Brake Forces
	Sidebearer 2	Hemispherical bogie pivot	Sidebearer 1	F_y [kN]		
	$-F_{z2}$	$-F_{zc}$	$-F_{z1}$			
1		884.9				
2h		464.6	199,1		30	
2d		464.6	199,1		-30	
3		464.6	199,1	183.5		
4	199.1	464.6		-183.5		
5		530.9				F_B

According [2], annex J, counts with 1.2 times the braking forces. Longitudinal force in hemispherical bogie pivot and friction force between wheels and track are in balance during maximum braking.

- ***Test under normal service loads***

***Tab. 4** Load cases for tests under normal service loads*

Load Condition	Vertical Forces [kN]			Lateral Forces [kN]	Unevenness of track [‰]
	Sidebearer 2	Hemispherical bogie pivot	Sidebearer 1	F_y	
	$-F_{z2}$	$-F_{zc}$	$-F_{z1}$		
1		442.4			
2		619.4			
3		265.5			
4		495.5	123.9	98.1	
5	123.9	495.5		-98.1	
6		212.4	53.1	98.1	
7	53.1	212.4		-98.1	
4h		495.5	123.9	98.1	15
4d		495.5	123.9	98.1	-15
5h	123.9	495.5		-98.1	15
5d	123.9	495.5		-98.1	-15
6h		212.4	53.1	98.1	15
6d		212.4	53.1	98,1	-15
7h	53.1	212.4		-98.1	15
7d	53.1	212.4		-98.1	-15

2.3 Evaluation of simulation

The static strength requirements correspond to the exceptional load conditions under which the bogie shall remain fully functional. It shall be demonstrated by analysis and/or testing, that no permanent deformation, instability or fracture of the structure as a whole, or of any individual element, will occur under the exceptional design load conditions. It is important to ensure that the design loads are expressed in a form that is consistent with the method of analysis and the way in which the permissible material stress levels are defined.

Exceptional loads

The analysis is intended to detect the most critical places in the structure after axle load of 25 tons. We examined sizes of equivalent von Mises stress for all load conditions. The highest values, which were detected, are listed in Tab. 5. Some graphic behaviour of stresses on the undeformed bogie frame are shown in Fig. 5 and Fig. 6.

In load cases 3 and 4 was exceeded the permissible value. It is a place on the upper flangeplate of longitudinal beam (Fig. 6) with value of stress 338 MPa. Exceeding of permissible value about 4 %, but it is just in area 4 elements on upper sheet.

***Tab. 5** The highest values of von Mises stress and their position*

Place on the bogie frame	Number of loading condition	Max. detected stress [MPa]	Allowable stress [MPa]	Safety factor [-]
Main transverse beam	1	318	325	1.02
Conection of mein transverse beam and longitudinal beam	1h	239	325	1.36
Conection of mein transverse beam and longitudinal beam	1d	238	325	1.37
Upper flangeplate of longitudinal beam	3	338	325	0.96
Upper flangeplate of longitudinal beam	4	338	325	0.96

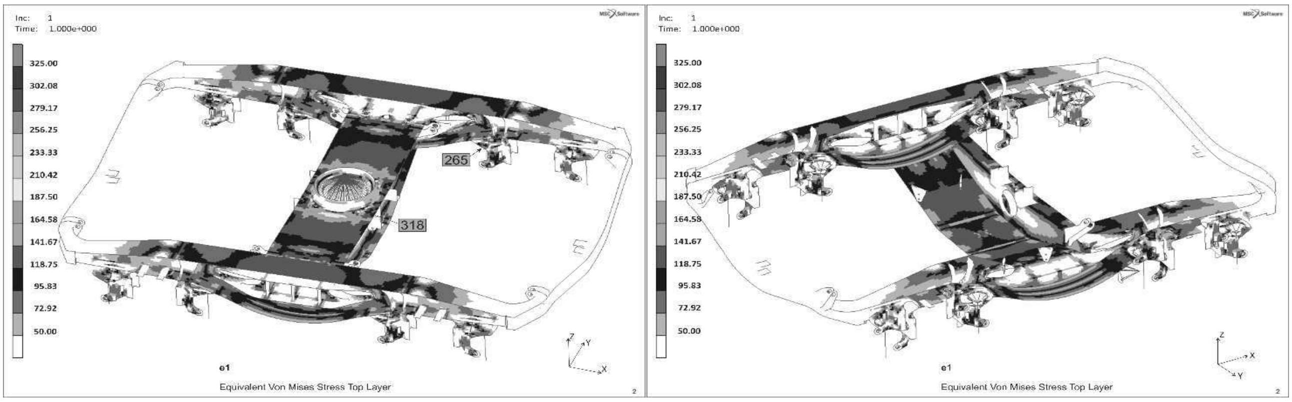

***Fig. 5** Behaviour of von Mises stress for load condition no. 1*

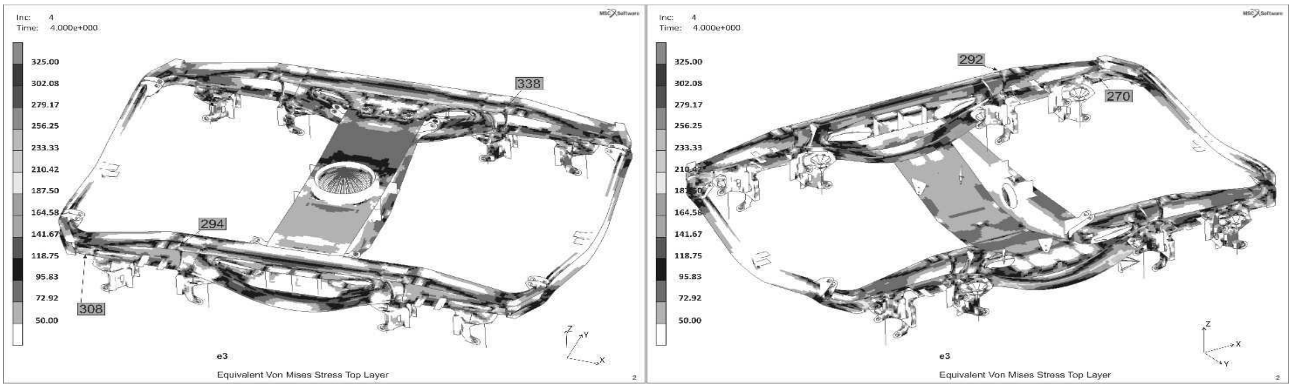

***Fig. 6** Behaviour of von Mises stress for load condition no. 3*

Normal service loads

For evaluation of simulation was used method according [2], annex J, point J.2. On the Fig. 7 and Fig. 8 are shown elements, which exceeded curves of Goodmans diagram (limit values for curves "a2", "a1" and "b" according [5], annex F.3, with safety factor 1.1).

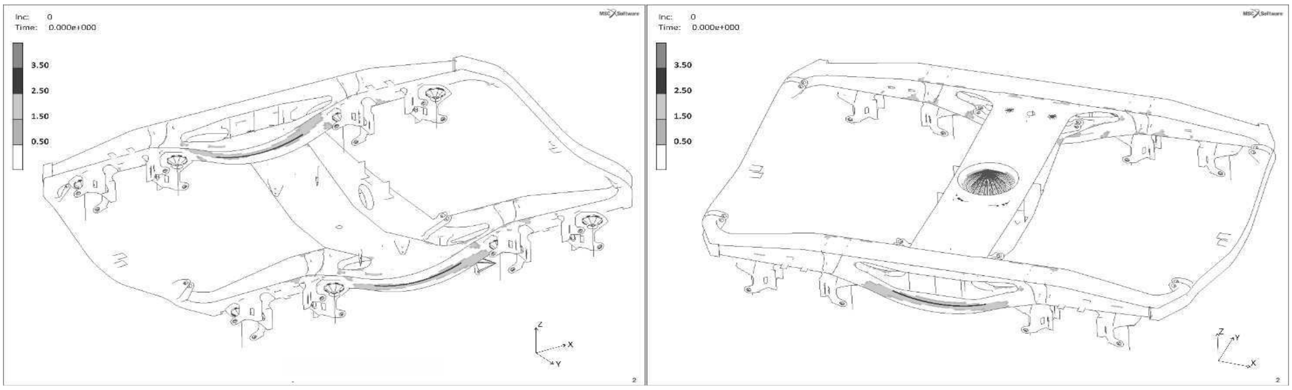

***Fig.** 7 Exceeded curve "b" (red color) – lower flangeplate of longitudinal beam*

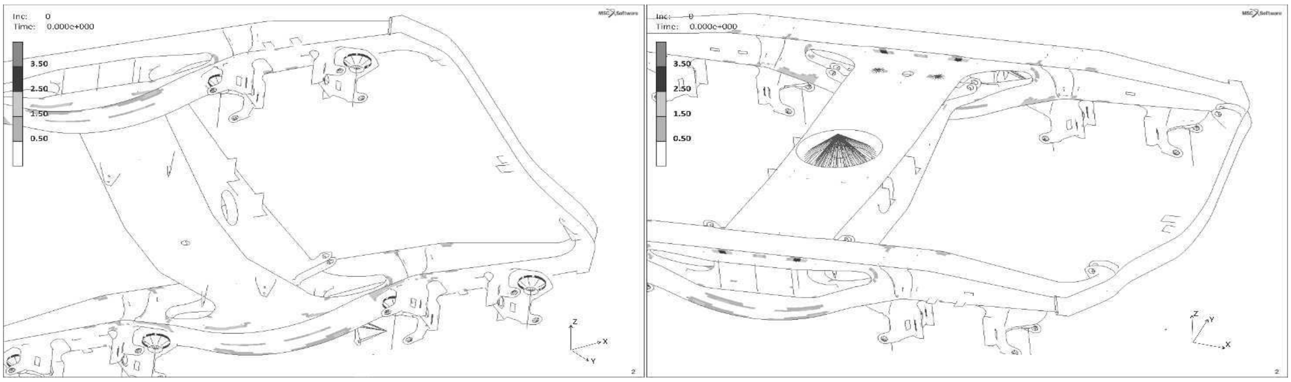

***Fig. 8** Exceeded curve "a1" (blue color) – longitudinal beam web*

According [2] annex J, point J.2, if exceeded value are not greater than 20 % in a limited number of points and no cracks are detected during the test, values are acceptable.

3 Conclusion

Computational simulations are now an integral part of the development process of rolling stock. They allow a more detailed analysis of the behaviour of the vehicle as a whole or its individual parts. Therefore, it is possible to better optimize the design of rail vehicles and prevent potential problems in the operation, which would require increased costs. The bogies of rail vehicles are required to withstand the maximum loads consistent with their operational requirements and achieve the required service life under normal operating conditions with an adequate probability of survival.

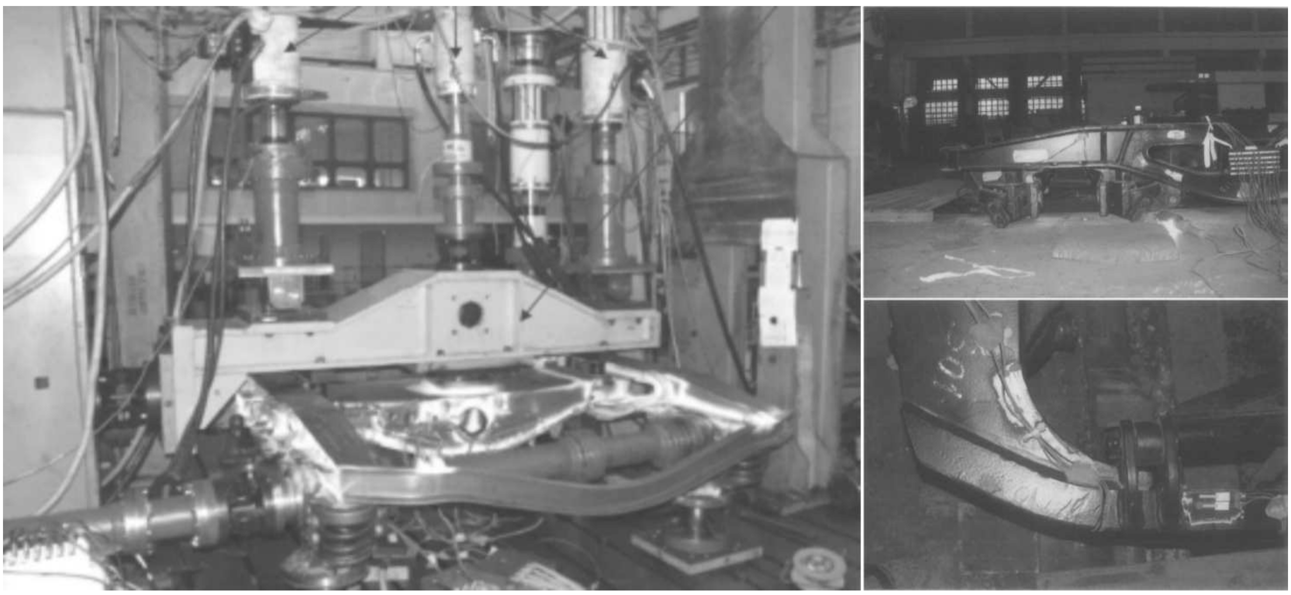

***Fig. 9** Static and fatigue tests of bogie frame prototype*

Static and fatigue tests of bogie frame prototype (Fig. 9) have been performed in internationally accredited institution. The results of the measurements and the defectoscopic tests showed no deformations or cracks. Results of calculations and prototype tests prove, that new designed construction of the bogie frame satisfies strength conditions.

With this research and development subjects deals other publications too [1, 6, 7, 8, 9, 10, 11].

Acknowledgement

This paper was created in accordance to the processing of the project "Development of two types of freight wagons with bogies for non-standard wheelbase or track wheelset, complying with the criteria for interoperability, Environmental Issues, safety and reliability ", ITMS Code 26220220070 based on the support of Research and Development Operational Program co-financed from EU sources.

The work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in project No. KEGA 077ŽU-4/2017: Modernization of the Vehicles and engines study program. The work was also supported by the project No. APVV-0842-11: Equivalent railway operation load simulator on the roller rig and VEGA Nr. 1/0927/15: Research of the use of alternative fuels and hybrid drives on traction vehicles with aim to reduce fuel consumption and air pollutants production.

Research-Educational Centre of Rail Vehicles (VVCKV)

References

[1] BLATNICKÝ, M., ŠTAUDEROVÁ, M., DIŽO, J. (2016). Stress analysis of a steel structure for the calibration of car axle scales. In: *Transport means 2016*: proceedings of the 20th international scientific conference: October 5-7, 2016 Juodkrante, Lithuania. - ISSN 1822-296X. - Kaunas: Kaunas University of Technology, 2016. - pp. 567-574.

[2] Commission Decision 2006/861/EC (Annex J) of 28 July 2006 and Commission decision of 23 January 2009 amending Decisions 2006/861/EC and 2006/920/EC (2009/107/ES).

[3] ČIŽÍK, P. (2016). *2-axle bogie according to line Y25 for freight wagons*. In: Dynamical problems in rail vehicles 2016: Slovak - Polish scientific workshop: Žilina December 6th and 7th, 2016 Slovak Republic: proceeding of the workshop. - Žilina: University of Žilina, 2016. - ISBN 978-80-554-1299-3. - pp. 146-154 (2016).

[4] EN 13 749 (2011) *Railway applications - Wheelsets and bogies - Method of specifying the structural requirements of bogie frames.* European Committee for Standardization (2011).

[5] ERRI B12/RP17, No. 8, Programme of Stresses to be carried out on Wagons with Steel Underframe and Body Structure. European Rail Research Institute (1996).

[6] GERLICI, J., et al. (2016). Slipping and skidding occurrence probability decreasing by means of the friction controlling in the wheel-braking pad and wheel-rail contacts. In: *Manufacturing technology: journal for science, research and production*. - ISSN 1213-2489. - Vol. 17, No. 2 (2017), pp. 179-186.

[7] HAUSER, V., et al. (2017). Impact of wheelset steering and wheel profile geometry to the vehicle behaviour when passing curved track. In: *Manufacturing technology: journal for science, research and production*. - ISSN 1213-2489. - Vol. 17, No. 3 (2017), pp. 306-312.

[8] KASSNER, M. (2012). Fatigue strength analysis of a welded railway vehicle structure by different methods. In: *International Journal of Fatigue*. - ISSN 0142-1123. - Vol. 34 (2012), Iss. 1, pp. 103-111.

[9] KOPAS, P., JAKUBOVIČOVÁ, L., VAŠKO, M., HANDRIK, M. (2016). Fatigue resistance of reinforcing steel bars. In: *Procedia Engineering*. - ISSN 1877-7058. - Vol. 136 (2016), online, pp. 193-197.

[10] BITTNER, V., et al. (2017). Using the fourier transform in the analysis of vibration load tests of heterogeneous mechanical systems. In: *Manufacturing technology: journal for science, research and production*. - ISSN 1213-2489. - Vol. 17, No. 6 (2017), pp. 836-841.

[11] SOUKUP, J., SKOČILAS, J., SKOČILASOVÁ, B., DIŽO, J. (2017). Vertical vibration of two axle railway vehicle. In: *Procedia Engineering*. - ISSN 1877-7058. - Vol. 177 (2017), online, pp. 25-32.

10.21062/ujep/98.2018/a/1213-2489/MT/18/2/315