U.P.B. Sci. Bull., Series D, Vol. 78, Iss. 3, 2016 ISSN 1454-2358

EXPERIMENTAL AND NUMERICAL ANALYSES OF THE STRESS STATE IN THE BOLSTER OF THE Y25 Cs BOGIE AROUND THE SIDE BEARERS

Leonidă FĂINUŞ[1], Nicuşor Laurenţiu ZAHARIA[2], Daniela Ioana TUDOSE[3], Anton HADĂR[4]

In order to validate the finite element calculation performed on steel structures, one can carry out experimental tests either on reduced models or on scaled parts of the structure. To verify the precision of the numerical results, experimental determinations of the stress state using strain gauges were undertaken in this paper on a real scale module cut from an Y 25 Cs bolster. Rosette strain gauges were glued on this module, which was subjected to forces applied on the side bearer; the values of loads were chosen as both almost identical to the maximum operating load of the bogie and 50% larger than the maximum operating load. Based on recorded strain, the von Mises stresses under loads were calculated. A geometrical model of the tested module was conceived in order to obtain the von Mises stresses using the finite element method for the same loading cases as used in the experimental tests. The main objective of the research was to validate the numerical model, in order to establish if such model may be further used for the analysis of a complete bogie.

Keywords: Y25 Cs bogie, bolster, welded side bearer, experimental stress analysis, strain gauges, finite element analysis

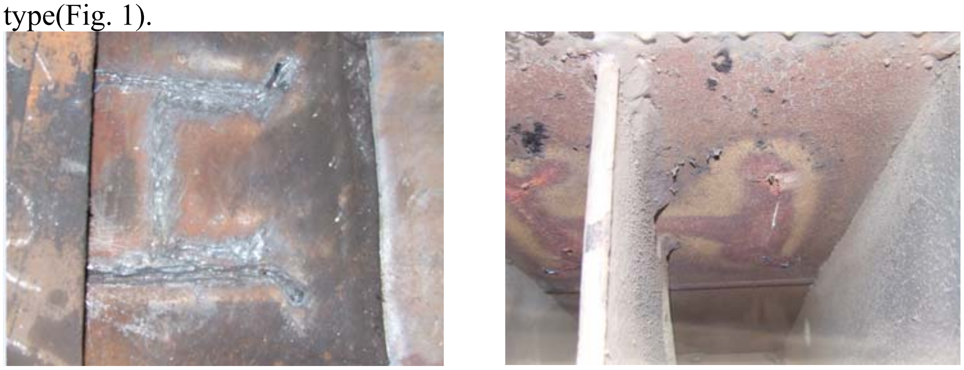
1. Introduction

Railway wagons built to carry large loads at high speed on straight and curved rails are equipped with bogies. A bogie is a part of a railway car where interaction between vehicle and rail occur; the main purpose of the bogie is to easily negotiate curves. Also, the bogies carry the weight of the car and cargo and transmit the longitudinal forces (traction and braking), the lateral force when vehicle runs on straight and curved rails. The forces due to the railways irregularities, oscillations and shocks are transmitted through the bogie to the body of the vehicle.

[1] PhD student, University POLITEHNICA of Bucharest (e-mail: mr_fainus@yahoo.com).
[2] Engineer, Romanian Railway Authority - AFER, Bucharest, Romania, (e-mail: renti.zaharia@yahoo.com).
[3] Lecturer, Department of Strength of Materials., University POLITEHNICA of Bucharest, România (e-mail:. tudor_dana2003@yahoo.com).
[4] Professor, Department of Strength of Materials., University POLITEHNICA of Bucharest, Romania (e-mail: anton.hadar@upb.ro).

Due it's position (between rails and the body of the vehicle) the bogie determines the running characteristics of the vehicle, safety dynamics, static and dynamic effects of the vehicle upon the railway. Y25 Cs bogies are standardised with 20 tones axle load used for freight wagon. This type of bogie is not manufactured nowadays
because new types of bogies are made – Y25 R bogie for example (20 tones axle load) with reinforced frame (some problems of the Y25 C bogie were solved with this new type) or the Y25 L bogie (22.5 tones axle load). Nevertheless, a large number of Y25 Cs bogies are still in service.

During service, some cracks were noticed on the bolster in side bearer area of the Y25 Cs bogie of the Fals type wagons since 1986. The Fals wagons are used for coal transportation in Romania. Recently, similar cracks were observed on the bolster in the side bearer area of the Y25 Cs bogie of the Uacs dust wagons type(Fig. 1).



a) cracks on upper plate of bolster (view outside bolster)   b) cracks on upper plate of bolster (view inside bolster)

Fig. 1. Y25 Cs bolster with cracks in side bearer area

For freight wagons, the maximum value of the loads applied on side bearer and the maximum stress on superior plate of bolster in side bearer area occur when the freight wagon run with low speed on curved rails [1]. Running with low speed on Romanian railway network occur many times on main and secondary railways due continuously degradation of the infrastructure as a consequence of insufficient funds for maintenance and repairing.

2. Objective of tests

Before homologation and putting in service, the bogies are loaded with static and fatigue loads on test rigs and endurance tests in service. According to [2] and [3] there are seven static load cases in test rigs for the freight bogie frames. In [4], the stress in the frame and bolster of Y25 Cs was calculated for the above mentioned seven static load cases, using the finite element method.

In Fig. 2 the coordinate system, the constraints and the loads applied on the bogie frame are shown.

In Table 1, the load cases for the Y25 Cs bogie for all the seven load cases are presented.

Following the finite elements simulations done for all seven load cases according to [4], it was observed that for load cases 4 and 5, the stress is higher than the allowable strength of the material - 160 MPa of the frame and bolster (steel OL 44.3k, [5]) in the area of side bearer . The values of the stress were 170.6 MPa for load case 4 and 182.23 MPa for load case 5. The applied force on the side bearers for load case 4 and 5 is $F_{z1} = F_{z2}$=97882 N, the applied force on the bolster F_{zp}=391527 N and lateral forces $F_{y1} = F_{y2} = F_y/2$ = 78480/2 = 39240 N, but the sense is different [4].

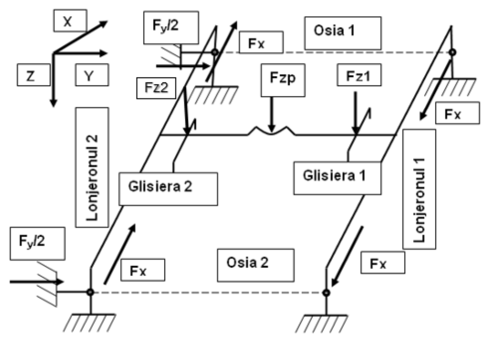


Fig. 2. Coordinate system, constraints and the applied loads

In Fig. 3, the von Mises stress distribution in the upper plate of the Y25 Cs bogie bolster in the area of side bearer for load case 4 is presented.

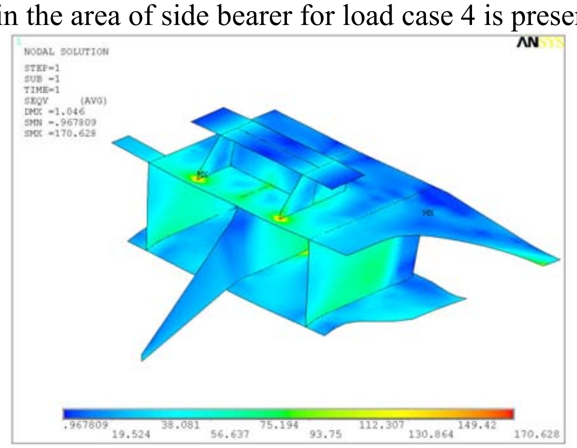


Fig. 3. The von Mises stress distribution for load case 4 under normal payload

Table 1.

Normal service loads applied on freight wagon's bogie frames on test rigs

Load case	Force on side bearer 1 Fz_1	Force on bolster Fz_p	Force on side bearer 2 Fz_2	Lateral force Fy
1	0	Fz	0	0
		376469		
2	0	(1+β)Fz	0	0
		489409		
3	0	(1-β)Fz	0	0
		263528		
4	0	(1-α)(1+β)Fz	α(1+β)Fz	Fy
		391527	**97882**	107157
5	α(1+β)Fz	(1-α)(1+β)Fz	0	-Fy
	97882	391527		-107157
6	0	(1-α)(1-β)Fz	α(1-β)Fz	Fy
		210822	52706	107157
7	α(1-β)Fz	(1-α)(1-β)Fz	0	-Fy
	52706	210822	0	-107157

where: *Fz* is the vertical load for each bogie, β is the bounce (dynamic) coefficient, α - roll coefficient. According to [2] and [3], β = 0,3 and α = 0,2.

The main objective of the test was to determine the difference between experimental results and the finite element results [4] in order to validate the numerical model and to verify the efficiency of some solutions for the reinforcement of the bolster in the side bearer area.

3. Preparation of the specimen

Analysing the numerical results, it was observed that the maximum stress occurs in the upper plate of the bolster at the end of the side bearer rib (Fig. 3). Since in the used facilities it was not possible to test the frame of the bogie, the authors decided to cut a part (module) of the bolster, containing the side bearer to obtain the test specimen. Owing to the symmetry of the tested member, two strain gauges rosettes $0^o/45^o/90^o$ type 1RY11-6/120 with gauge length of 6mm were glued. The first rosette was glued near the side bearer rib and the second one was glued on the symmetry axis of the bolster, at the end of the inner rib (Fig. 4).

The precision of the measurement depends on the characteristics of the strain gauges and on how they are mounted and used. In order to have a proper adhesion of the rosette to the metal it was necessary to remove the paint of the test specimen. For that reason, polishing operations were made [6, 7, 8, 9].

After surface polishing, using sandpaper with 180 granulation, a proper roughness was obtained; cleaning of the surface was made with RMS 1 cleaning agent. Adhesive Z70 and accelerator BCY 01 for adhesive were also used to glue the rosettes. The rosettes were protected against humidity with SG 250 silicone rubber. The conectors of the rosettes were soldered to the measuring cables.

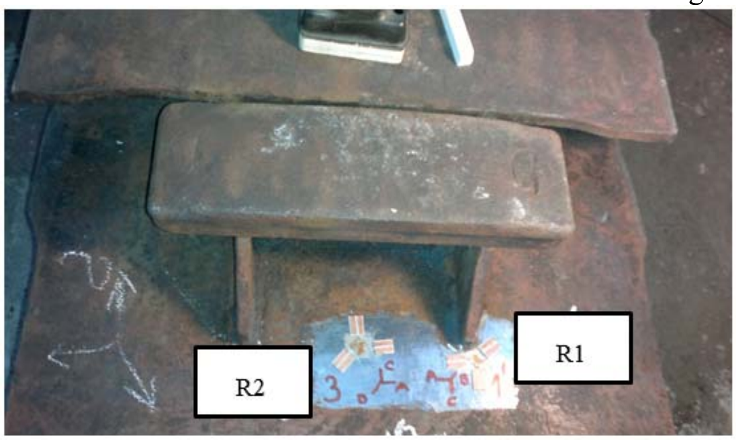


Fig. 4. The test specimen and the strain gauge rosettes

4. The equipment used for experimental measurements

The tests were performed in the laboratories of the Romanian Railway Authority (AFER). The equipment used for the experimental tests is presented in Table 2,

Table 2.

The equipment used in the experimental measurements

No.	Name of equipment
1.	Data acquisition system for static tests HBM CENTIPEDE with 100 measuring channels
2.	Data acquisition system for dynamic test HBM Spider 8
3.	Universal testing machine (static and dynamic tensile, compressive and bending) MUP 100
4.	Force cell HBM C2 200kN

In order to measure the stress with proper accuracy, it is necessary to glue the rosette near the end of the side bearer in the area where the maximum stress was obtained using the finite element method. Due to technical reasons, it was possible to mount the rosette only at 7 mm distance from the side bearer rib. The measuring cables were anchored on the fixed part of the universal testing machine, near the rosettes in order to avoid damaging of rosettes or creating supplementary tensile loads in the rosettesFig. 5). A schematic view of the testing specimen mounted on the testing machine is shown in Fig. 6.

The data acquisition system HBM Centipede 100 is a signal amplifier that can makeobtain data simultaneously on 100 measuring channels (Fig. 7). The connection between rosettes and amplifier was made using cables with four wires. The sample rate of the signal was 1 Hz (frequency aasuitable for static tests).

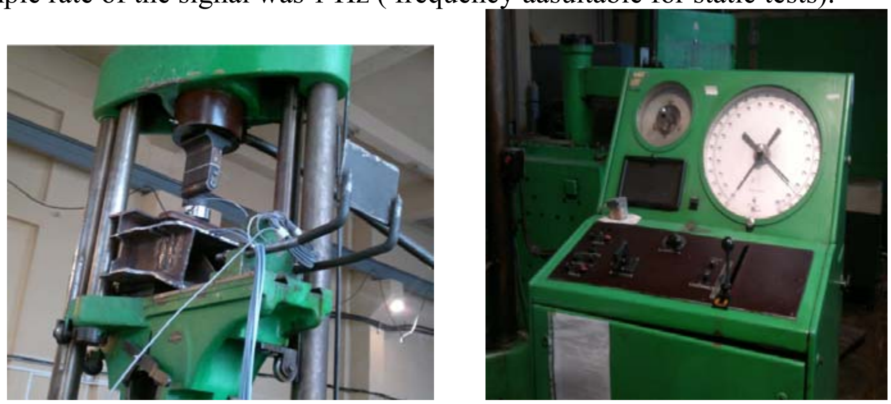


Fig. 5. The testing machine

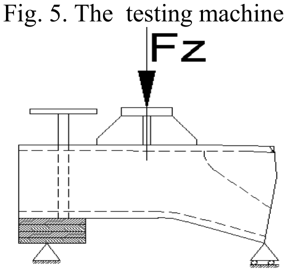


Fig. 6. The loading and constraints of the testing specimen mounted on the testing machine

For a higher accuracy of force measurement, an HBM C2 200 kN force cell was used (Fig. 8). The main features of force cell are:

- Measuring domain: 1 - 200 kN;
- Resistance: 350 Ω;
- Full bridge connection.

Fig. 7. HBM data acquisition systems

The data acquisition system was connected to a laptop with a cable interface. The software Catman Professional was used and a special application for these tests was created.

Fig. 8. Force cell HBM C2 200kN

5. The experimental tests

The experimental tests were done in the following sequence:

- The rosettes were glued on the points determined following the finite element analyses;
- The test specimen was mounted in the universal testing machine in horizontal position;
- The measuring cables were soldered at soldering terminal of the rosettes and the cables were connected to HBM Centipede (as quarter bridge);
- The rosettes and soldering terminal were protected with silicone rubber against humidity;
- A data acquisition interface (application) was created in the Catman software;
- The force cell C2 was mounted between the side bearer and the testing machine;
- The main features of the rosettes and force cell were introduced in the data acquisition system.
- The following elastic constants were considered: Young's modulus E = 207000 MPa and Poisson's ratio $\nu = 0.3$
- The calibration of the amplifier was performed;
- Forces were applied on the test specimen;
- The strains were measured and the stresses were calculated using the well-known equations of theory of elasticity. These values are listed in Table 3.

The calculus of the angles of principal directions α, the principal stresses σ_1, σ_2 , the equivalent stress σ_{eq} and the principal strains ε_1, ε_2 was done in Catman based on the equations implemented in the software. Then, the user must choose the used type of rosette in the software [11]. Since it was not possible to test the entire bogie, the stresses in the area of the side bearer were calculated taking into account only the loads that act on the side bearer. The maximum load applied on side bearer for load cases 4 and 5 is $F_{z2} = F_{z1}$ = 97.88 kN [4]. Thus, the tests were performed both for the same force (slightly different due to the precision of the testing machine) and for a force 50% larger. For a higher accuracy, two tests were performed for each load.

Analysing the results, it was observed that the highest values were recorded for rosette R1.

Table 3.

Experimental results

Measuring point	Load F_{zi} [kN]	ε_a [µm/m]	ε_b [µm/m]	ε_c [µm/m]	α [°]	ε_1 [µm/m]	ε_2 [µm/m]	σ_1 [MPa]	σ_2 [MPa]	σ_{ech} [MPa]
R1	**100.4**	-338.4	-186.1	-114.5	80.08	-108.2	-345.8	-48.22	-86.06	**74.71**
	102.8	-345.2	-185.5	-117.5	79.02	-109.4	-354.5	-49.08	-88.12	**76.48**
	150.2	-488.5	-258.4	-167.5	78.28	-154.2	-503.6	-69.44	-125.0	**108.54**
	151.8	-486.4	-257.4	-165.8	78.397	-152.8	-501.1	-68.96	-124.4	**107.97**
R2	**100.4**	313.07	193.90	117.36	173.85	315.79	115.77	79.73	47.88	**69.51**
	150.2	458.83	284.91	164.08	174.89	461.81	162.73	116.15	68.53	**101.13**

6. Finite element analyses

The geometric model of the test specimen was created in Ansys [12]. The bogie is built from welded steel plates, sothe mesh was obtained using the Shell 63 element. Shell 63 is a four node element with six degrees of freedom per node (translations and rotation). The average size of the elements was chosen 20 mm. In the area where the rosette R1 was glued, the mesh was refined. The model had 10210 nodes and 10059 elements. The meshed model is presented in Fig. 9. For the numerical analyses the forces and constraints applied on the model were similar to the ones used in the experimental tests. The applied forces on the model were F_1=100400N, F_2=102570N, F_3=150200N and F_4=151810N. The forces were applied as distributed pressure on the entire side bearer. In Table 4, the applied pressures resulted for each force are listed.

Table 4.

Loads on the side bearer

Load case	F_{zi} [N]	p_{zi} [N/mm^2]
1	100400	3.72
2	102570	3.80
3	150200	5.56
4	151810	5.62

To compare the numerical and experimental results, a selection of the finite elements in the area with rosettes was done (Fig. 10).

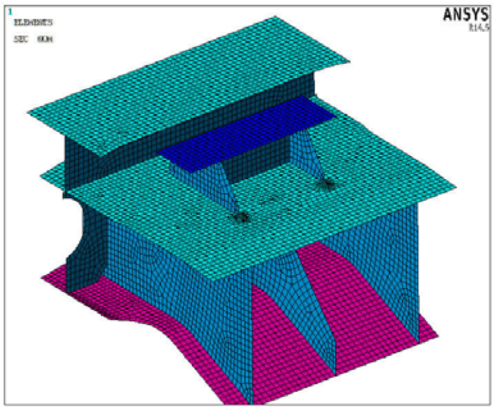


Fig. 9. The finite element model of the test specimen

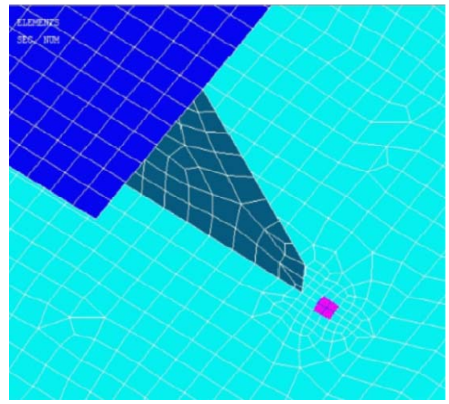


Fig. 10. Selected finite elements in the area of rosette R1

In Fig. 11, the von Mises stress distribution in the upper plate of the bolster for F_{z1}= 100400N is presented; the maximum value of the stress occurs at the end of the ribs.

The stress distribution in the selected elements in the area of the rosette R1 for all load cases is presented in Figs 12-15. The values of the stress obtained with the finite element method are presented in Table 5. The notations used in Table 5 are: σ_{max} is the maximum stress at the end of the rib, σ_{ave} is the average stress in the finite elements in the area of rosette R1.

Table 5.

The stressobtained with the finite element method

Number	F_{zi} [N]	σ_{max} [MPa]	σ_{med} [MPa]
1	100400	133.08	73.48
2	102570	135.94	76.04
3	150200	198.90	111.26
4	151810	201.05	112.47

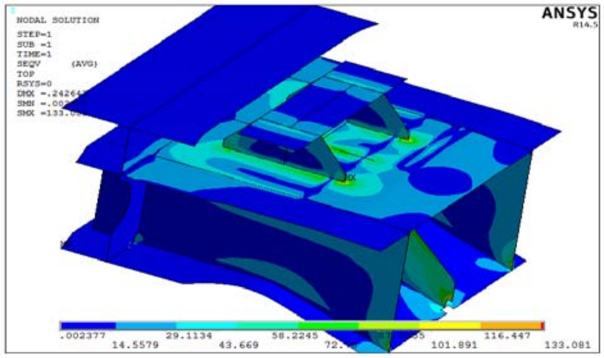


Fig. 11. The von Mises stress distribution for F_{z1}=100400N

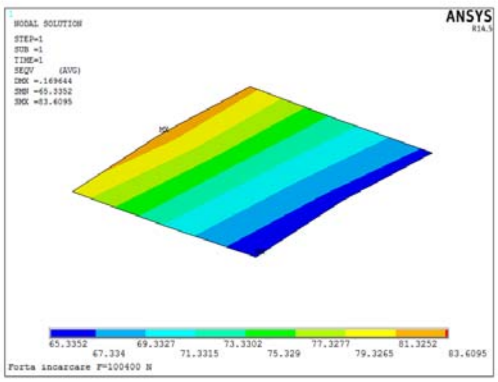


Fig. 12. The von Mises stress distribution in the area of rosette R1, load F_{z1} = 100400 N

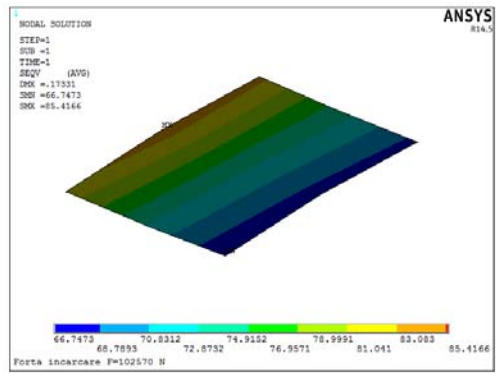


Fig. 13 The von Mises stress distribution in the area of rosette R1, load F_{z2} = 102570 N

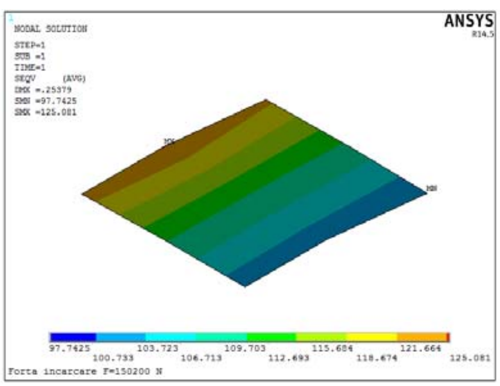


Fig. 14. The von Mises stress distribution in the area of rosette R1, load F_{z3} = 150200 N

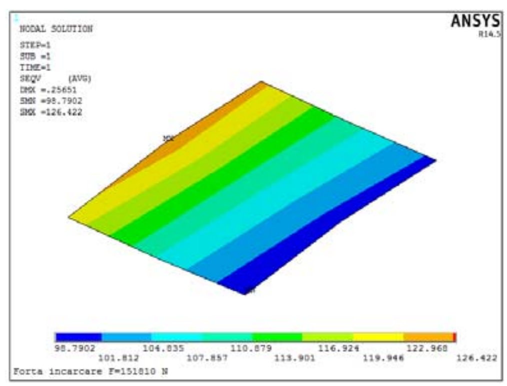


Fig. 15. The von Mises stress distribution in the area of rosette R1, load F_{z4} = 151810 N

7. Conclusions

The tests performed on real structures are more convincing and tests can be done using scale models [12] or modules (parts) of a real structure [13]. Based on that, a part with the side bearer was cut from the frame bogie bolster. The relative error between the experimental and numerical results is shown in Table 6. The maximum value of the error is 4.16%.

Table 6.

Comparison between experimental and numerical results

Number	F_{zi} [N]	Experimental σ_{exp} [MPa]	Numerical σ_{ave} [MPa]	Relative error □ [%]
1	100400	**74.71**	73.48	1.64
2	102570	**76.48**	76.04	0.6
3	150200	**108.54**	111.26	2.5
4	151810	**107.97**	112.47	4.16

Since the relative error is smaller than 5%, one can conclude that the finite element model is validated . The stress results presented in [4] are accurate and the numerical model can be used to further verify some reinforcing solutions of Y25 bogie bolster in the side bearer area.

R E F E R E N C E S

[1]. *Făinuş , L., Hadăr, A,* Analisys of the Stress State in the Frame of the Y 25 CS Bogie at Running in Curves", Conference Proceedings of the Academy of Romanian Scientists, PRODUCTICA Scientific Session, 9 May 2014, **Volume 6**, Number 1/2014, Bucharest, p. 59-70.

[2]. *** UIC 510-3 O. Wagons - Strength testing of 2 and 3-axle bogies on test rig, edition 1-1989.

[3]. *** EN 13749: 2011. Railway applications. Methods of specifying structural requirements of bogie frames.

[4]. *Făinuş , L.*, Analiza stării de tensiune şi de deformație a cadrului boghiului Y 25Cs aflat în regim normal de exploatare [The stress and strain analysis of Y25 bogie under normal service], Disertation thesis, University Politehnica of Bucharest, 2013 (in Romanian).

[5]. ***Raport de încercare electrotensometrică a boghiului Y 25 Cs – nr. 2165 [Testing report of Y25 Cs bogie experimental stress analysis with strain gauges]-Institute of Studies and Research in Transports, Bucharest, 1972 (in Romanian).

[6]. *Hoffman, K.,* An Introduction to Measurement using Strain Gages, Hottinger Baldwin Messtechni şi se poate GmbH, Darmstadt, Germania, 2005.

[7]. *Mănescu, T. Ş., Copaci I., Olaru S., Creangă F.Ş,* Tensometria electrică rezistivă în cercetarea experimentală [Experimental stress analysis with strain gauges for experimental research], Editura Mirton, Timişoara, 2006

[8]. *Mocanu, D.R. şi s.a.*, Analiza experimentală a tensiunilor [Experimental stress analysis]-**Vol. I**, technical Publishing House, Bucharest, 1977 (in Romanian)

[9]. *Sandu M., Sandu A.,* Captoare cu traductoare rezistive, proiectare, aplicații [Resistive

transducers, design, application], Editura Printech, ISBN 973-9475-26-4, Bucureşti 1999.

[10]. *** Catman 4.5 User's Guide, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germania, 2004

[11]. *Zaharia, N.L.,* Contribuţii privind optimizarea structurilor portante ale vagoanelor cisternă de cale ferată în vederea creşterii sarcinii pe osie şi micşorarea tarei vehiculelor [Contributions regarding the optimization of the railway tank wagon strength structure with a view to increasing the axle load and minimizing the vehicle tare], Teză doctorat, Universitatea Eftimie Murgu, Reşiţa 2010.

[12]. *Sorohan, Şt., Constantinescu, I.N.,* Practica modelării şi analizei cu elemente finite [Finite element practice], Editura Politehnica Press, Bucureşti, 2003

[13]. ***EN 15227+A1:2011, Railway applications. Crashworthiness requirements for railway vehicle bodies.