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Stresses in a Bogie Frame of a Rail Carriage

Rusu-Cassandra Aurelia Liliana*, Baciu Florin, Iliescu Nicolae, Atanasiu Costica

Politehnica University of Bucharest, Splaiul Independentei no 313, Bucharest, Sector 6, 060042, Romania

Abstract

The paper presents a comparative study regarding the distribution of stresses and strains in a bogie frame, a prototype used in plants for the transportation of liquid cast iron, for a case of loading corresponding to common working operating conditions. The results of a numerical analysis carried out using the three-dimensional finite element method and those of an experimental study using the strain gauge technique were compared. Agreement between calculated and measured results obtained was good and areas of the bogie frame with maximum stress were predicted with reasonable accuracy. Knowing the most dangerous stress concentration zones, a new design optimization process could be accelerated without becoming unreliable, ensuring thus a safe transportation of cast iron by rail.

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1. Introduction

Traffic safety, transport economy and transport capacity of rails are main goals of any railway industry and train manufacturers. Nowadays, modern technology and its new features have led to a continuously improving of the design and construction of the rolling stock car body structures. Railway industry has encountered newer stages of progress as: improved running service safety, lightweight structures, assurance of the maximum loading capacity, reduced product design cycle and in the same time lower costs for construction, maintenance and repair. Most of the railway vehicle studies focus on the complete design process of the key structural components of the railway carriage such as bogie frames, axles, wheels and other components, which includes design procedures, assessment methods, verification and manufacturing quality requirements [1].

* Corresponding author. Tel.: +40 21 4029204; fax: +40 21 4029213.

E-mail address: aurar2005@yahoo.com

The bogie is one of the main parts of trains which plays an important role in sustaining the static load from the dead weight of a car body, controls wheel sets on straight and curved tracks and carries the wheels, axles, brakes and suspensions. Therefore, due to frequent geometric changes which are required in early stages of the design process, effective simulation methodologies are indispensable for predicting the behavior of bogies under severe load conditions [2, 3].

Extending our work [4], in this paper a study of a prototype railway carriage bogie frame used for the transportation of the liquid cast iron is presented. The railway vehicle consists of a torpedo pot, two bogies at each end which have four axles each and support the pot and the modular steel beams. The new adopted solution for the designed bogie frame is verified using a numerical analysis with the finite element method and an experimental investigation performed with the strain gauge technique. Comparison of the results obtained for the strain and stress distributions shows a good correlation of the values. The achieved results and the experience developed in the project should be useful for the optimization of the bogie frame design.

2. Experimental investigation

An experimental investigation using reliable measurements with the strain gauge technique was conducted in order to find out the strain and stress state in most dangerous areas of the bogie frame. Figure 1 shows the experimental setup for the test.



Fig. 1. Test setup of the bogie frame.

The gauges manufactured by Hottinger-Baldwin were bonded in 132 points on the areas considered to be most stressed. Several of them are shown in Fig. 2.

Besides the upper central part of the frame, a special interest was given to the four pairs of openings (I-1, I-2; II-1, II-2; III-1, III-2 and IV-1, IV-2), due to the problems that occur in service in these areas of the bogie [5]. Initial measurements were performed for a small radius of the openings. The stresses exceeded the allowable stress of the material and in some regions also the yielding stress, therefore the radius was increased at the value of 50 mm and another set of measurements conducted.

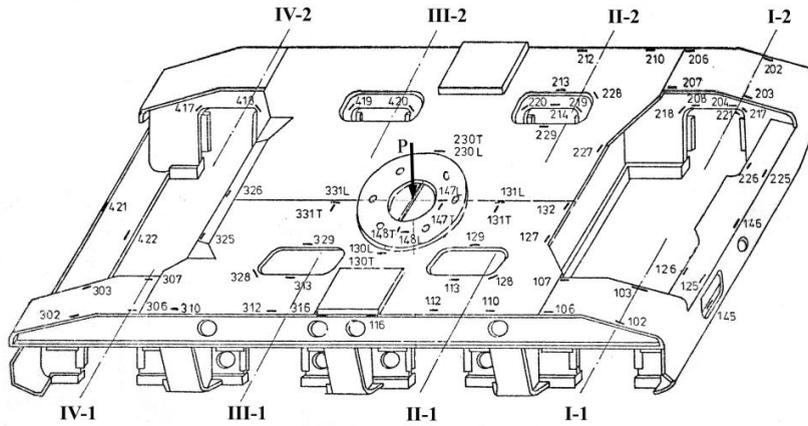


Fig. 2. Position of strain gauges and loading condition.

In addition, a new case in which opening III was designed on both sides of the bogie model with connections in order to limit its deformation under the applied load and to study the behavior of the bogie frame in these regions was investigated (Fig. 3). The strains were measured in the same points as in the previous case.

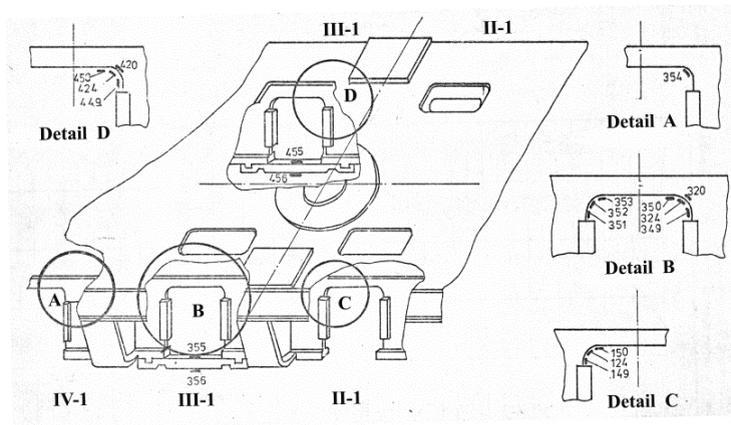


Fig. 3. Strain gauges bonded on the opening areas.

Uniaxial strain gauges were located mainly on the openings I, II, III, IV (Fig. 3) and strain rosettes with two transducers on the top surface of the frame respectively (Fig. 2). Three strain gauges bridges and 13 switch boxes produced by Vishay have been used. A vertical load of 1500 kN induced by the torpedo pot was applied with a hydraulic press. The values of the strains ϵ measured by the gauges bonded on the openings and the corresponding stresses σ are listed in Table 1, which includes results for two cases: without and with connections at opening III. The stresses were calculated using the equation [6, 7]:

$$\sigma = K \cdot E \cdot \epsilon \tag{1}$$

where K is a correction factor depending on the constants of the transducer, $E = 2.1 \times 10^5$ MPa is the modulus of elasticity of steel and $\nu = 0.3$ is Poisson's ratio.

Table 1. Measured strains and calculated stresses in openings.

No. of strain gauge	$\epsilon \times 10^{-6}$		σ [MPa]	
	without connections	with connections	without connections	with connections
320	603	407	128	86
420	629	455	133	96
124	883	982	187	208
324	850	565	180	120
424	824	601	175	127
149	910	1015	193	215
349	879	569	186	121
449	914	665	194	141
150	685	762	145	161
350	815	529	173	112
450	587	425	124	90
351	442	93	94	20
352	488	155	103	33
353	441	173	94	37
354	322	367	68	78
355	-	202	-	43
455	-	181	-	39
356	-	33	-	7
456	-	-17	-	-4

3. Finite element analysis

For the finite element analysis achieved using SOLIDWORKS software [8] the bogie frame was modeled with 3D tetrahedral elements [9]. Fig. 4 shows the finite element mesh consisting of 23593 elements and 47486 nodes. The loading and the boundary conditions were chosen to be similar to those of the model experimentally investigated.

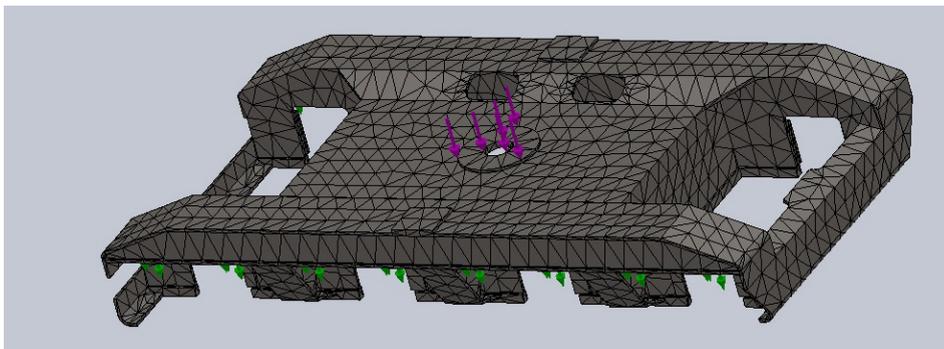


Fig. 4. Finite element mesh, applied load and geometric constraints.

The contour plots of the displacements of the bogie frame modeled without and with connections at opening III are plotted in Fig. 5 and Fig. 6.

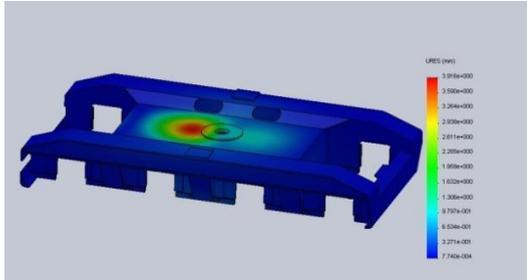


Fig. 5. Displacements of the model without connections.

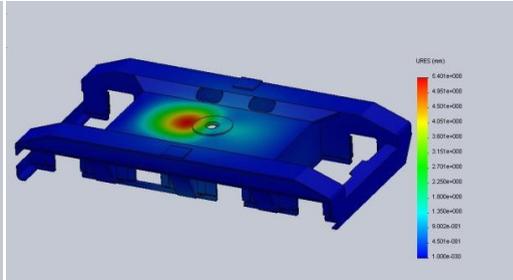


Fig. 6. Displacements of the model with connections.

Figure 7 and Fig. 8 represent the stress contour plots in the two studied cases: without and with connections at opening III.

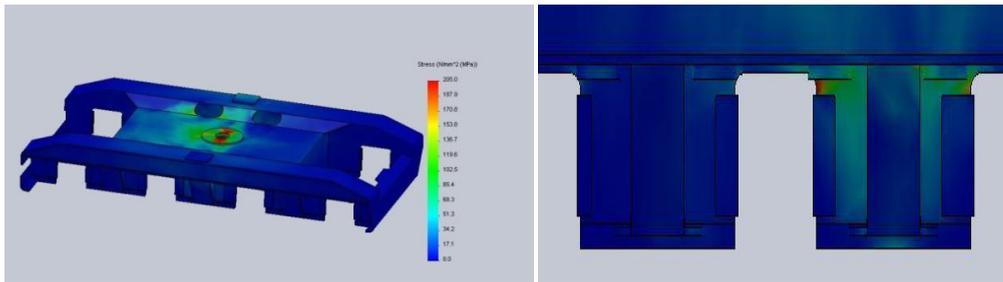


Fig. 7. (a) Stresses for the model without connections, (b) Detail opening III-1.

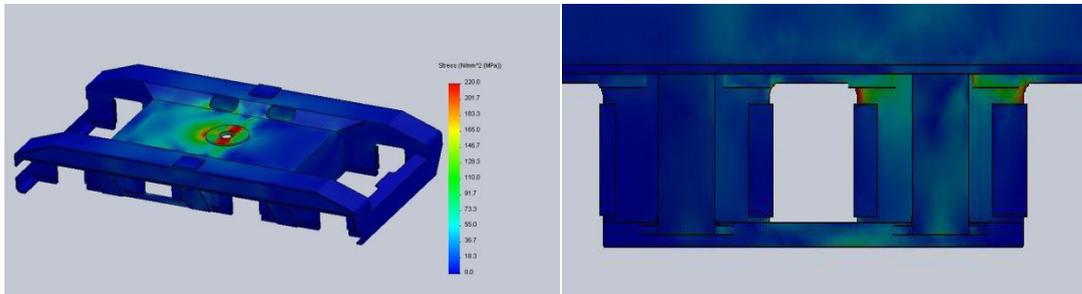


Fig. 8. (a) Stresses for the model with connections, (b) Detail opening III-1.

Conclusions

An analysis of the strain and stress distributions in a prototype of a bogie frame, important part of a railway carriage for the transportation of the liquid cast iron, was carried out using strain measurements and finite element modeling. Based on the comparison of the results obtained, the following conclusions can be drawn:

- The identified critical areas are on the top surface of the frame in the vicinity of the applied vertical load and also at central openings (Fig. 7 a, b). The maximum value of the stress obtained with the numerical analysis is 205 MPa. The simulation results and test results are in good agreement, the error being less than 6%.

- for the case in which opening III was designed with one connection on each side of the model, the highest value of the stress (220 MPa) obtained using FEM occurs in approximately the same regions (Fig. 8 a, b). No noticeable discrepancies occur between theoretical and experimental results. However, while the stresses decreased at opening III, their values increased at the adjoining openings II (215 MPa at the measurement point 149 –Table 1) and IV, which do not have connections (Fig. 9).

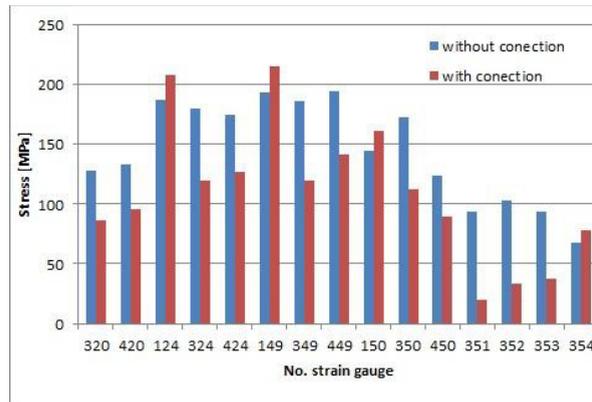


Fig. 9. Stresses in the opening areas II, III and IV.

- Figure 5 and Fig. 6 show that high values of the displacements occur on the top surface of the bogie frame, the maximum being in the case when opening III was designed with connections. Also from Table 1 it can be noticed that in opening III, due to the connections the strains decreased, instead their values increased in the nearest openings II and IV.
- comparison of experimental and numerical results showed similar trends and provided reliable information about the behavior of the bogie frame under loading conditions, estimating the stresses and strains at the critical regions. This information can be useful for the structural optimization of this prototype of frame, to satisfy the design requirement or service life. Therefore, as future work, an analysis of the mechanical behavior of a model designed with connections at all openings may be carried out.

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