# Experimental Verification of Auto Carrier Car Strength Calculation

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*In this paper a calculation method and experimental analyses of auto carrier car bearing structure strength are shown. The calculation includes both the static and dynamic analyses of the bearing structure; also the determination of the car body torsion rigidity calculation has been performed with the programming package based on Finite Element Method. The analyses of the bearing structure strength for the load case due to the car lateral inertia forces at lateral acceleration of* 0,1·*g has also been included. The calculation covered one quarter of the wagon with two doors as the weaker ones. The object tested was the auto carrier car composed of the underframes, sidewalls and two mobile upper platforms without side and front doors and without roof. Stresses were measured by the strain-gauge method on* 120 *measuring points. Some of them were connected to form strain gauges in three directions thus enabling the estimation of principal stresses. The measuring results show that the stress conditions in all load cases are remarkably under the allowable stresses. The residual stresses were in acceptable limits. Bearing structure deflections were very small and did not exceed* 0,6‰ *from the centre pin distance, which is well below allowable value.*

***Keywords**: strength calculation, experimental analyses, auto carrier car, strain-gauge method.*

## 1. INTRODUCTION

In this paper a calculation method and experimental analyses of auto carrier car bearing structure strength are shown. The calculation includes both the static and dynamic analyses of the bearing structure. Calculation was performed with the programming package based on Finite Element Method (FEM). In addition to this main task, the calculation covers also the determination of the car body torsional stiffness as well as the determination of the body gravity center height for both empty and loaded car. The analyses of the bearing structure strength for the load case due to the car lateral inertia forces at lateral acceleration of 0,1·*g* was also included.

## 2. CALCULATION PROCEDURE

General symmetry of the car body in respect of the transversal and longitudinal planes had to be assumed due to the model complexity and the necessity for the large number of computational elements in order to have realistic presentation. That is why the calculation covers only one quarter of the wagon. In order to cover some symmetry deviations, which however do not disturb significantly the general symmetry of the structure, the calculation covered the quarter with two doors as the weaker ones, Figure 1.

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The introduction of the appropriate boundary conditions into the nodes situated in the planes of symmetry provides the independence of the chosen quarter of the wagon. Depending on the presence of symmetric or anti-symmetric loads the corresponding translations and. rotations of the nodes in the planes of symmetry is prevented accordingly.

The adopted mechanical model has 7183 nodes and 7448 elements [1]. For the purpose of simpler and easier considerations and analyses, they are divided into several groups. Model implies that the upper platform is movable i.e. particularly jointed to the remaining part of the structure thus participating in vertical load only by its own portion of load. The remaining part of the structure supports the upper platform load (at its support points). This leverage has been taken into account through the corresponding support reactions at the connection points, different for each vertical load case. The upper platform does not participate in any other load cases and therefore it is not included in these models.

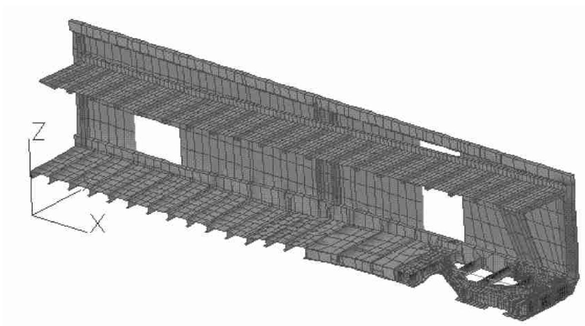


**Figure 1. Model of wagon bearing structure**

Table 1 contains the review on the calculation results for each of the eleven load cases. Modeling of almost complete bearing structure was done using plate type elements for which stresses were calculated using the Von Misses's failure theory [2]. For the beam type elements the highest normal stresses, σ, at any actual section were calculated using GREDASIG programme developed by the Faculty of Mechanical Engineering Belgrade [1]. The programme calculates stresses due to the axial forces and bending moments at two major inertia planes and their super position for all edge points for each section. As the shearing stresses due to whole structure torsion, τ, are very low and the shearing stresses, τ, at the relevant edge points are equal to 0, the calculated stress, σ, is valid for further strength analysis.

In order to verify calculation results and strength of the bearing structure, experimental verification according to UIC 566 [3] has been conducted.

**Table 1. Calculation results**

| Load case | Locations with highest stresses | Calculated stress [N/mm$^2$] |
|---|---|---|
| Load case 1<br>1000 kN pressure applied to buffer supports | Locally at the buffer attachment point | 316 |
| | The cross beam in the front section | 240 |
| | Gusset plates of auxiliary diagonal of bearing front-part<br>The point of connection between the main cross girder<br>Main longitudinal girder in the part farther from the car front | 210 |
| Load case 2<br>500 kN pressure applied on the fixing points of two diagonal buffers | Locally at the buffer attachment point | 281 |
| | The cross beam in the bearing front-part<br>(second from the car front) | 230 |
| | Gusset plates at the point of connection between the support-outside and auxiliary diagonal at the front on the bottom plate | 192 |
| | The draw gear support on the bottom plate | 188 |
| Load case 3<br>2000 kN pressure applied on the automatic coupling supports | Gusset plate at the connection point of the connection support and the main cross girder | 320 |
| | Locally at the point of the automatic coupling pressure supports | 270 |
| | The connection point between the main longitudinal girder and the floor cover | 245 |
| Load case 4<br>1500 kN tension applied at the point of the automatic coupling draw supports | The draw gear support at the draw supports point | 281 |
| | Connection between the main cross girder bottom plate and the main longitudinal girder | 200 |
| Load cases 5 and 6<br>Vertical load applied on the upper platform during loading and elevating | In the cantrail section of the upper platform main longitudinal girder | 155 |
| Load case 7<br>Extraordinary vertical load | Within the main cross girder in the region of its connection to the main longitudinal girder | 89 |
| | Locally at the upper platform support point | 70 |
| | At the bottom of the door pillar near the main cross girder | 60 |
| | Within the cantrail in the middle of the car | 50 |
| Load case 8<br>Combined vertical load and 1000 kN pressure applied to buffer supports | Locally at the buffer attachment point | 317 |
| | The beam in the car front (the second one from the front end) | 280 |
| | Gusset plate of auxiliary diagonal profile of the front part and at the point of connection between the main cross girder and the main longitudinal girder | 240 |
| Load case 9<br>Combined vertical load and 1500 kN tension at the point of the automatic coupling draw supports | Within the draw gear support at the draw support points | 281 |
| | At the connection point between the bottom plate of the main cross girder and the main longitudinal girder | 200 |
| Load case 10<br>Lifting on one end together with the bogie | Locally in the region of supporting onto support -front | 93 |
| | The zone round the door i.e.<br>within the cantrail above the door | 80 |
| | Within the cantrail in the middle of the car | 50 |
| Load case 11<br>Vertical exploitation load | The cantrail section of the upper platform main longitudinal girder | 155 |
| | Within the main cross girder in the region of its connection to the main longitudinal girder | 82 |
| | Locally at the upper platform support point | 65 |
| | At the bottom of the door pillar near the main cross girder | 55 |
| | Within the cantrail in the middle of the car | 46 |

## 3. EXPERIMENTAL PROCEDURE

### 3.1. Testing object and test rig

The object tested was the bearing structure of the auto carrier car (DDm type), composed of the under frames, sidewalls and two mobile upper platforms without side and front doors and without roof (Figure 2). The equipment for platforms elevating and their locking in elevated position was mounted and was operational during testing.

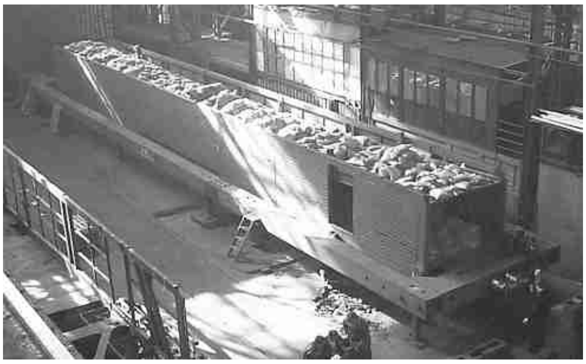

**Figure 2. Testing object and test rig**

The bearing structure was measured before testing. Weighing was carried out on the accessory bogies, and then bogie-by-bogie was weighed. Also, complete bogies were weighed independently and reused during testing as well as the roof was used as the part of the load. Weighing results are shown in Table 2. Vertical loads used further in the verification experiments were defined as based on these data.

**Table 2. Weighing results**

| Item | Mass (kg) | Mark | Part |
|---|---|---|---|
| 1 | 17480 | $m_{ns}$ | Bearing structure for testing |
| 2 | 33300 | | Wagon ready to run |
| 3 | 5200 | | Bogie |
| 4 | 2497 | | Roof, both parts |
| 5 | 8000 | $m_{21}$ | Pay load on the lower platform |
| 6 | 7000 | $m_{22}$ | Pay load on the upper platform |

The bearing structure was supported on the bogies during testing. The primary and the secondary suspension were blocked, including the bogie bolster transversal movement in relation to the frame.

The test rig consists of the steel frame with all necessary hydraulic equipment and accessories (Figure 3). Hydraulic equipment enables achieving all of the longitudinal forces foreseen by the experimental protocol [4]. Hydraulic cylinders were placed between the test frame and car at one end to apply the forces. The car is supported on the frame on equivalent place over accessory braces at the opposite side.

Hydraulic equipment was used in the case of wagon lifting at one end as well. The vertical load for this case was performed by means of sand bags placed inside the profiles limiting the walking area on the lower and upper platform.


**Figure 3. Hydraulic equipment**

### 3.2. Measuring equipment

Stresses were measured by the strain-gauge method using 6/120LY11 strain-gauge type [5].

Figure 4 shows the principal scheme of the measuring chain. A compensation strain gauge for neutralizing of temperature changes impact during measuring was connected at each ten strain gauges. Two UPM 60 [5] measuring units were used and connected to the laptop over RS232C serial connectors, thus immediately transferring and storing results to the PC during measuring.

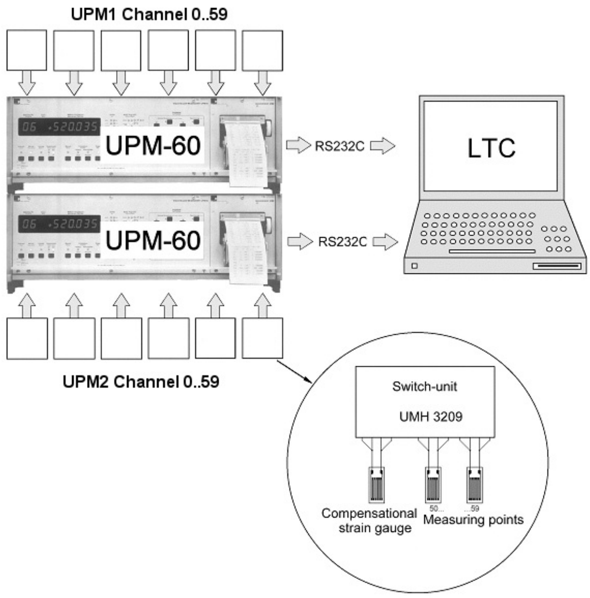


**Figure 4. Principal scheme of the measuring chain**

The comparators with 0,01mm accuracy were used for the framework deflection measuring. They were fitted on one end to the stands and on the other end to the measuring points of the car body. Figure 5 shows the comparators on the measuring points for vertical movement and for longitudinal movement. Diagonal measures of the door opening on the sidewall were measured by means of 0,1 mm accuracy sliding caliper during vertical loading (load case 7). Measuring was performed before loading, at the maximal loading and after the framework unloading.

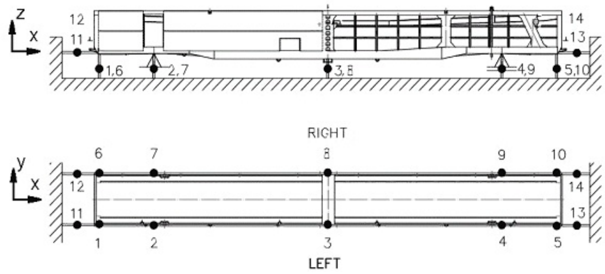


**Figure 5. Arrangement of comparators**

### 3.3. Sensor placement

The stresses were measured at 120 measuring points [4]. Some of them were connected in the way to form strain gauges in three directions thus enabling the estimation both amplitude and direction of principal stresses. Figure 6 shows the bottom view of the headstock in the automatic coupling area with fitted strain gauges.

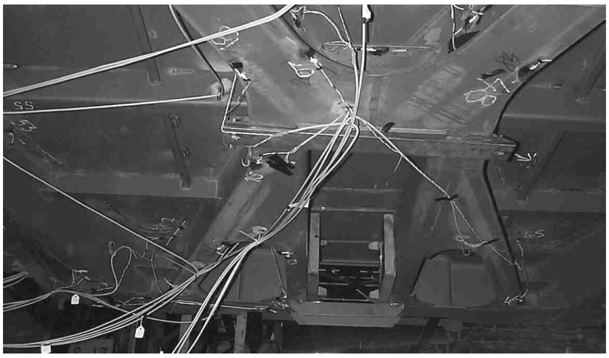

**Figure 6. Headstock in the automatic coupling area with fitted strain gauges**

Deflections were measured on designated points as shown in Figure 5. According to the Protocol the longitudinal deflections should be measured only in cases where the only impact comes form the longitudinal force.

## 4. VERIFICATION RESULTS

Measurement results are given below for different loading conditions.

*Load case* 1: 1000 kN *pressure applied to buffer supports*

The largest stress of 125 N/mm$^2$ was measured on the main longitudinal girder, immediate behind the main transversal girder. The stresses over 100 N/mm$^2$ appeared on 11 measuring points. All these points are on the wagon under frame made of steel St 52-3. The measured stresses were remarkably under the allowable values, which is 325 N/mm$^2$ for St 52-3 in weld areas.

The largest residual stress was -5,5 N/mm$^2$, which is within the acceptable limit.

Maximal vertical deflection measured on the center of wagon, for 100% loading condition was +6,39 mm. Wagon compression was -10,5 mm on the left and -10,1 mm on the right main longitudinal girder. The residual deflections were negligible.

*Load case* 2: 500 kN *pressure applied on the fixing points of two diagonal buffers*

According to the absolute value the largest measured stress of -46 N/mm$^2$ was on the front part of the under frame behind the automatic coupling support. The stresses over 40 N/mm$^2$ appeared on 3 measuring points on the under frame. The other measured stresses were small. The largest residual stress was -5,5 N/mm$^2$, which was within the acceptable limit.

Measured vertical deflection was under 1,5 mm. Deformations of wagon under frame shearing were 0,4 and 0,44 mm. The residual deflections were negligible.

*Load case* 3: 2000 kN *pressure applied on the automatic coupling supports.*

The absolute largest stress of -184,9 N/mm$^2$ was measured on the brace immediate behind the automatic coupling support. The stresses over 150 N/mm$^2$ appeared on 4 measuring points on the same brace. The measured stresses were bellow allowable values for St 52-3 in weld areas. The largest residual stress was -3 N/mm$^2$, which is negligible.

The maximal vertical deflection measured on the center of wagon for 100% loading condition was +5,76 mm. Wagon compression was -8,4 mm on the left and -8,2 mm on the right main longitudinal girder. The residual deflections were negligible.

*Load case* 4: 1500 kN *tension applied at the point of the automatic coupling draw supports.*

The largest measured stresses were on the two measuring points immediate along side with the automatic coupling supports over which the tensioning force is inserted. Theirs values were +205,1 N/mm$^2$ and +187 N/mm$^2$ respectively. On the other measuring points the stresses were under 150 N/mm$^2$. The measured stresses were under the allowable values for St 52-3 in weld areas. The largest residual stress is 5,5 N/mm$^2$ which is negligible.

Maximal vertical deflection measured on the center of wagon for 100% loading condition was 3,7 mm. Wagon stretching (elongation) was +6,2 mm on the left and +5,9 mm on the right main longitudinal girder. The residual deflections were within acceptable limits.

*Load cases* 5 *and* 6*: Vertical load applied on the upper platform during loading and elevating*

These two cases were treated together because they follow each other without zero-line between them. When the platform is loaded in a lower position the largest measured stress was +78,1 N/mm$^2$ on the symmetric measuring points near to the center of platform. When the platform was elevated in that loaded condition the largest measured stresses were +77,1 N/mm$^2$ and -73,4 N/mm$^2$ at the support of the platform-elevating cylinder. The all measured stresses were remarkably under the allowable limit of 325 N/mm$^2$.

Wagon deflections in those cases are not important but they were nevertheless measured and were 0,5 mm.

*Load case* 7: *Extraordinary vertical load*

The largest stress of +154,8N/mm$^2$ was measured on the center of the upper platform. The next largest one was the stress on the lower angle on the side door post and it was –122,8N/mm$^2$. The stresses over 100 N/mm$^2$ appeared on 5 measuring points of which 4 were on the upper platform. Measured stresses were remarkably under the allowable values, which is 325 N/mm$^2$. The largest residual stress is in acceptable limits and was -6,8 N/mm$^2$.
Maximal measured vertical deflection on the center of wagon for 100% loading condition was -4,55 mm. The residual deflections were negligible.

*Load case* 8*: Combined vertical load and* 2x1000 kN *pressure applied to buffer supports*

According to the results of experimental verification, load case 1 (2x1000 kN pressure force) produces deflection upwards, while tension force of 1500kN (load case 4) produces deflection downwards. Because of that, this case is abandoned, and only load case 9 (vertical load and 1500 kN tension force), as a less favorable, was applied.

*Load case* 9: *Combined vertical load and* 1500 kN *tension at the point of the automatic coupling draw supports*

The largest stresses were +200,9 N/mm$^2$ and +190,8 N/mm$^2$ recorded on the measuring points placed immediately along the coupling draw supports over which the tensioning force is inserted. The values were very close to the measured values for load case 4. At other measuring points the stresses were below 140 N/mm$^2$. All measured stresses were under the allowable values for St 52-3 in weld areas.

*Load case* 10: *Lifting on one end together with the bogie*

The wagon was lifted at the end with side door. The largest stress was recorded on the measuring point placed in the lower corner of side door post near to the headstock. The stress was -60,4 N/mm$^2$. The second largest one was recorded on the measuring point placed at the diagonal corner of the same door on the centrail. The stress was -56,8 N/mm$^2$. These stresses were remarkably under the allowable limit, which is 325 N/mm$^2$ for St 52-3.
Deflections in this case were not measured since the vertical movement on the headstock during the elevating was over 100 mm. This exceeded the measuring range of the used comparators.

*Load case* 11: *Vertical exploitation load*

As it was mentioned for load case 9 the results with added load on the platform were not adequate for this case. In this case the adequate stresses were achieved by multiplying of stresses measured for 100% loading condition with *k* coefficient. Keeping in mind the additionally inserted 554 kg the coefficient k can be determined as follows:

$$k = 1 + \frac{\text{car body mass being tested} \quad (m_{ns})}{\text{loading mass } [1,2 \cdot (m_1 + m_2) - m_{ns} + 554\text{kg}]} = 1,61$$

The largest stress of +112,4 N/mm$^2$ was on the center of the upper platform. The next one in site was the stress on the measuring point placed in lower corner on the side door post, toward the center of the wagon, which was -104,4 N/mm$^2$. The other stresses were under 100 N/mm$^2$.

All measured values were under the allowable stress, which is 200 N/mm$^2$ for St 52-3 in case of exploitation load in all weld areas except but-welds. All stresses were also under the allowable stress for RSt 37-2, which was the material, used for lining and floor sheet.
The largest deflection, in the center of the wagon was -3,98 mm.

If we compare the calculations results given in Table 1 with the measurements it is possible to conclude that applied calculation method is able to recognize the most critical points in the bearing structure.

## 5. CONCLUSIONS

The measuring results show that the stresses in all load cases were remarkably under the allowable values. The largest measured stress for the case of extreme loads was for load case 4 (1500 kN force tension) and it was +205,1 N/mm$^2$. The allowable stress for the steel in St 52-3 category, in the weld areas, is 325 N/mm$^2$ . The stresses in the parts made of steel RSt 37-2 category (lining and floor sheet) were remarkably under the allowable value as well, which is 220 N/mm$^2$ in weld areas for the mentioned steel type.

Figure 7. shows stress distribution according to calculation results for load case 4 (1500 kN force tension) in which was the largest measured stress.

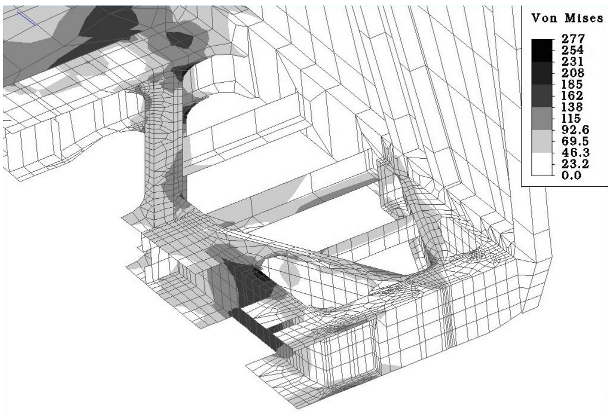


**Figure 7. Stress distribution for load case 4 in headstock area.**

In the case of exploitation load (load case 11) the maximal stress of +112,4 N/mm$^2$ was, also, remarkably under the allowable one for the steel St 52-3 category, which is 200 N/mm$^2$. Other measured stresses were, also, under the allowable one (145 N/mm$^2$) for the steel RSt 37-2 category. The residual stresses were very small and in acceptable limits. Bearing structure deflections were very small and did not exceed 0,6‰ from the centre pin distance, which is well below allowable value. The overall conclusion based on the performed measurements is that the auto carrier car satisfies the requested conditions regarding its strength.

Figure 8. shows deformed structure in the case of torsional stiffness calculation.

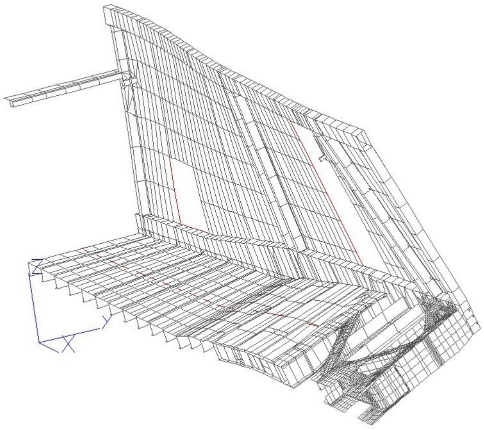

**Figure 8. Deformed structure in the case of torsional stiffness calculation.**

The verifications results have shown that developed model for wagon strength calculation based on Finite Element Method is capable of predicting critical points in the bearing structure of wagon.

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## ЕКСПЕРИМЕНТАЛНА ВЕРИФИКАЦИЈА ПРОРАЧУНА ЧВРСТОЋЕ ВАГОНА ЗА ПРЕВОЗ АУТОМОБИЛА


**Војкан Лучанин, Горан Симић, Драган Милковић**



У раду је дат прорачун и експериментална анализа напонског стања носеће структуре вагона за превоз аутомобила. Прорачуном је обухваћена статичка и динамичка анализа носеће структуре, као и одређивање торзионе крутости применом методе коначних елемената. Анализа чврстоће носеће структуре је обухватила и оптерећење под дејством бочне силе настале услед убрзања од 0,1 *g*. Анализирана је четвртина вагона са бочним вратима, као најслабији део структуре. Испитивањем је обухваћена носећа структура вагона која се састоји од постоља, бочних страница и две покретне платформе, без чеоних и бочних врата као и крова. Напони су мерени помоћу мерних трака на 120 мерних места, од којих су поједина омогућавала мерење напона у сва три правца. Резултати мерења показују да су напони у свим случајевима оптерећења значајно испод дозвољених. Заостали напони су били у дозвољеним границама. Угиби носеће структуре су били веома мали и нису прешли 0,6 ‰ растојања оса своржњака, што је значајно испод дозвољене вредности.