



FACULTY OF MECHANICAL AND CIVIL ENGINEERING
IN KRALJEVO
UNIVERSITY OF KRAGUJEVAC



X Triennial
International Conference

HEAVY MACHINERY HM 2021

Proceedings

VRNJAČKA BANJA, SERBIA
June 23 - June 25 2021



**FACULTY OF MECHANICAL AND CIVIL ENGINEERING KRALJEVO
UNIVERSITY OF KRAGUJEVAC
KRALJEVO – SERBIA**

THE TENNTH INTERNATIONAL TRIENNIAL CONFERENCE

HEAVY MACHINERY HM 2021

PROCEEDINGS

ORGANIZATION SUPPORTED BY:

Ministry of Education, Science and Technological Development, Republic of Serbia

Vrnjačka Banja, June 23–25, 2021



PUBLISHER:

Faculty of Mechanical and Civil Engineering in Kraljevo

EDITOR:

Prof. dr Mile Savković

PRINTOUT:

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No. of copies: 80

ISBN 978-86-81412-09-1

REVIEWS:

All papers have been reviewed by members of scientific committee



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PREFACE

Ladies and gentlemen, dear colleagues,

Welcome to Vrnjačka Banja, to the International Scientific Conference Heavy Machinery.

After postponing the 2020 conference due to the Covid-19 pandemic, this year the Tenth International Conference Heavy Machinery is held by the Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, from 23 to 25 June 2021.

It has gained a unique recognizable form for exchange of information, ideas and new scientific researches. The Conference is held in the year when the Faculty of Mechanical and Civil Engineering in Kraljevo celebrates the 61st year of university teaching in mechanical engineering, nine years of university teaching in civil engineering and two years of university teaching in occupation safety.

During several decades of existence, it has acquired specific and recognizable form in domestic and foreign scientific circles thanks to its scientific and research results.

The goal of the Conference is to make the research from the fields covered at the Faculty of Mechanical and Civil Engineering in Kraljevo available and applicable both within domestic and foreign frames. Also, our scientists will have the opportunity to learn about results of research done by their colleagues from abroad in the fields of transport design in industry, energy control, production technologies, and civil engineering through the following thematic sessions:

- Earth-moving and transportation machinery,
- Production technologies,
- Automatic control and fluid technique,
- Applied mechanics,
- Railway engineering,
- Thermal technique and environment protection,
- Civil engineering.

Despite the aggravating circumstances due to the Covid-19 pandemic, a high scientific reputation of domestic and foreign participants as well as the number of papers provide guarantees that the Conference will be very successful.

The papers reflect state of the art and deal with the wide spectrum of important topics of current interest in heavy machinery.

I especially want to thank you the Ministry of Education, Science and Technological Development of Republic of Serbia for support of organization of the Conference and our efforts to promote science and technology in the areas of mechanical and civil engineering in Serbia. I would like to express sincere thanks to all members of scientific, organizing and technical committee, reviewers, as well as to all participants including invited speakers for participation in the Conference and presentation of their papers.

Thank you and see you at the next conference.

Kraljevo – Vrnjačka Banja, June 2021

Conference Chairman,

Prof. dr Mile Savković

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CIP - Каталогизација у публикацији - Народна библиотека Србије, Београд

621(082)
621.86/.87(082)
629.3/.4(082)
622.6(082)
681.5(082)

INTERNATIONAL Triennial Conference Heavy Machinery (10 ; 2021 ; Vrnjačka Banja)

Proceedings / The Tenth International Triennial Conference Heavy Machinery HM 2021, Vrnjačka Banja, June 23-25, 2021 ; [editor Mile Savković]. - Kraljevo : Faculty of Mechanical and Civil Engineering University of Kragujevac, 2021 (Bor : Tercija). - 1 knj. (razl. pag.) : ilustr. ; 29 cm

Tekst štampan dvostubačno. - Tiraž 80. - Str. [7]: Predgovor / Mile Savković. - Bibliografija uz svaki rad.

ISBN 978-86-81412-09-1

a) Машиноградња - Зборници b) Транспортна средства - Зборници c) Производно машинство - Зборници d) Шинска возила - Зборници e) Аутоматско управљање - Зборници

COBISS.SR-ID 41166089

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Experimental and numerical strength analysis of freight wagon type SHIMMNS intended for the transportation of the sheet coils

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Shimmns wagons are very common type of freight wagons that are used for transportation of heavy steel sheet coils, which are further used as an initial material in automotive and other industries. Due to frequent usage, and heavy loading, these wagons are prone to fatigue cracks, which, if not identified in time, could cause catastrophic failures. Therefore, these wagons must satisfy rigorous standards, and must be thoroughly analysed and tested. In this paper, we will present a methodology that combines experimental testing and Finite Element Analysis according to TSI standard and norm EN 12663-2:2010. Measurements with strain gauges and stresses obtained by FEM calculation gives good agreement. FEM model is created in FEMAP software, and analysis was done using NX Nastran solver. Based on the agreement between numerical and experimental results, it can be concluded that the FEM analysis can be reliably applied during the designing of new wagons, or analysis of failures in existing ones. FEM analysis can be used to perform several design cycles virtually, thus reducing the number of the prototypes required for experimental testing. This can lead to great savings in time and money during the design of new wagons.

Keywords: Finite Element Method, Freight wagon, Sheet coils, Fatigue strength analysis, Stress field

1. INTRODUCTION

Finite Element Method (FEM) simulations are widely used for solving various problems in the heavy machinery industry because they reduce the time and cost of developing the new products [1]. FEM analysis results provide very useful information about the product and can indicate the potential problems that can be eliminated in the virtual environment. The second step in the design cycle is making a prototype, based on the results obtained using FEM. The strain gauges are placed where FEM analysis predicts the high stress concentration, and measurements are carried out for required load cases. When the prototype testing is finished, in a third step a comparative analysis of the results obtained by FEM calculation and experimental measurements on a prototype is performed. Measurement results and results obtained by FEM calculation must satisfy all requirements defined in the standards.

In the case of SHIMMNS freight wagon analysis, presented in this paper, strength validation is done according to TSI standard [2] and norm BS EN 12663-2:2010 [3].

The paper is organized as follows. In the Chapter 2, the FEM model of the SHIMMNS freight wagon is described. This chapter also contains descriptions of analysed load case, standard requirements, safety factor and permissible stress. In the Chapter 3, we will present measuring procedure, positioning of the strain gauges and obtained experimental stress values. Chapter 4 features FEM results and their comparison with experimental data. In the conclusion, FEM analysis results and experimental data are discussed, and based on these results, we can conclude that analysed SHIMMNS wagon satisfy all of the safety requirements defined by standards [2], [3].

2. FEM MODEL OF SHIMMNS WAGON

The SHIMMNS freight wagons are used for the transportation of sheet metal coils, placed on five wagon saddles as shown in the Fig. 1.



Figure 1: SHIMMNS wagon

These coils can have different diameter, length, mass, and different saddle placement. Wagon must be able to withstand a wide range of load cases set by the International Union of Railways (UIC).

FEM analysis, according to standards [2] and [3] was performed using the NX Nastran solver, which is built in FEMAP pre and post-processor [4]. FEMAP is used to create a finite element mesh, that primarily consists of shell elements, which have appropriate thicknesses in accordance with the part of construction. Some 3D elements were also used for modelling of support plates, relief ring, traction device. The construction is modelled in detail with 153420 elements and 151650 nodes, and the system of about 900 thousand equations is solved during the calculation. The average size of the element is 40 mm. Full FEM model is shown in the Fig. 2.

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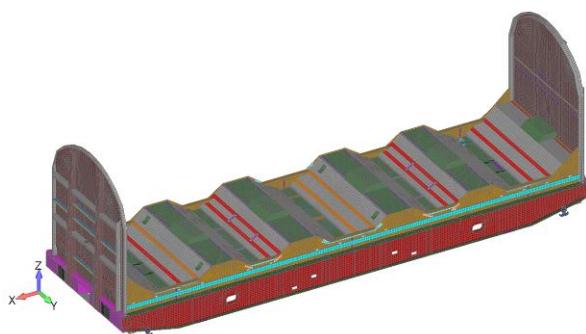


Figure 2: FEA model of SHIMMNS wagon

In the most of the load cases, due to symmetry, we were able to use one quarter of the model, shown in the Fig. 3, which saved us a lot of computational time.

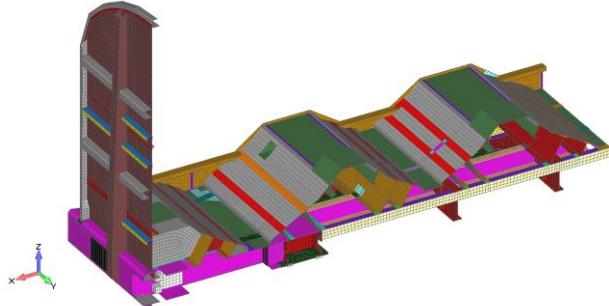


Figure 3: One quarter FEA model of SHIMMNS wagon

The main characteristics of the SHIMMNS wagon, according to [5] are given in Tab. 1.

Table 1: Technical data of wagon type SHIMMNS

| | |
|------------------------------------|--|
| Track width | 1435mm |
| Gauge | G1 |
| Length over buffers | 12240mm |
| Length without buffers | 10800mm |
| Distance between the central bolts | 7200mm |
| Load opening width | 2400mm |
| Max. axle load | 20t |
| Buffer height | 1.060 mm^{-5} mm^{+10} |
| Tare weight | 23t $\pm 3\%$ |
| Max. cargo weight | 57 t |
| Max. speed (empty/loaded) | 120/100km/h |
| Bogie type | Y25 Cst |
| The smallest curve radius | 70m |

The wagon is made of steel S355J2+N, with the following characteristics, shown in Tab. 2. [5].

Table 2: Material characteristics of S355J2+N

| Physical Characteristics | | |
|----------------------------------|----------------------------------|------|
| E N/mm ² | ρ kg/mm ³ | v |
| 2.10 · 10 ⁵ | $7.85 \cdot 10^{-6}$ | 0.3 |
| Mechanical Characteristics | | |
| R _e N/mm ² | R _m N/mm ² | KV J |
| 355 | 510 | 27 |

According to UIC 577 and BS EN 12663-2: 2010 [3], Clause 5.2.3.1 Tab. 6, the analysis is performed in the case of maximum load of the wagon. Here, the value of the maximum load is increased 1.3 times (30%) in relation to the nominal load, in order to take the dynamics into the account.

The maximum weight of steel coils that this wagon can carry is 57 tons, as shown in Tab. 1, and this weight

can include the combination of different diameters and widths of the coils shown in Tab. 3.

Table 3: Maximum loading of the cradle and dimensions of the steel coils

| Cradle number | Coil diameter mm | Load t |
|---------------|------------------|--------|
| 1 | 1000 – 2250 | 28 |
| 2 | 800 – 1700 | 17 |
| 3 | 1000 – 2250 | 33 |
| 4 | 800 – 1700 | 17 |
| 5 | 1000 – 2250 | 28 |

In accordance with EN 12663-2:2010 [2], clause 6.2.2.1 Tab. 18 and Tab. 19, and based on the material characteristics given in Tab. 2, in this paper, we can calculate permissible stress in parent material, and in the welded joints, shown in Tab. 4.

Table 4: Safety factors and permissible stress in parent material and welded joints

| Material | Safety factor S ₁ | σ_{cmax} MPa |
|---|------------------------------|---------------------|
| S355J2+N | 1.0 | 355 |
| Parent material in the immediate vicinity of welds (S355J2+N) | 1.1 | 323 |

Safety factors specified in Tab. 4, cover static load cases defined in EN 12663-2:2010 [3]. Also, in accordance with EN 12663-2:2010, Clause 6.2.2.1, the maximum deflection on the underframe should not exceed 3% of the wheelbase from the initial position. In accordance with the data given in the Tab. 1, the maximum deflection at half the distance between wheelbase must not exceed 21.6mm.

Horizontal, vertical load cases, load combinations and lifting load cases were analyzed using FEM. Vertical load cases cause the highest stress values in the significant loaded zones and unfavorable vertical load case is used for comparative analysis of experimental and numerical results.

According to the technical characteristics of four-axle bogie wagon type SHIMMNS for transporting sheet metal coils [5], given in Tab. 1, the maximum vertical load of the wagon is 57t. Accordingly, and respecting the limitations regarding the maximum load of cradles given in Tab 3, six cases were performed within the analysis of the vertical load.

In the first load case the second and fourth cradles are loaded with 12t each, with medium sized coils that have a diameter of 1700mm, and width 1000mm, while the middle cradle is loaded with the maximum size coil that according to Tab. 3, has a diameter of 2250mm, width 1000mm and weight of 33t. This combination corresponds to the maximum load capacity of the wagon, which is 57t.

In this paper, we will present experimental testing of the wagon according to the first vertical load case [2] (unfavorable vertical load case) which is shown in the Fig. 4, and afterwards we will show the additional FEM analysis which is used to replicate experimental conditions and to verify calculated stress.

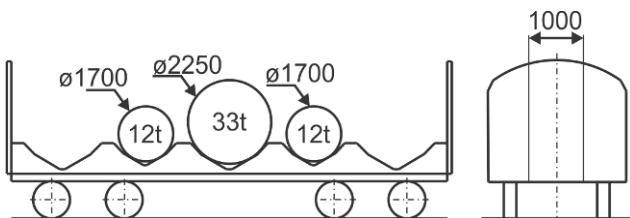


Figure 4: First load case for SHIMMNS wagon analysis

3. EXPERIMENTAL MEASURING OF STRESS IN SHIMMNS WAGON

Analysed model has two main subassemblies: underframe and superstructure. Based on the initial FEA results, strain gauges are placed on the wagon structure, their positions are given in the technical drawings shown in the Fig. 5. (position of strain gauges on underframe) and Fig. 6 (position of strain gauges on superstructure and cradles).

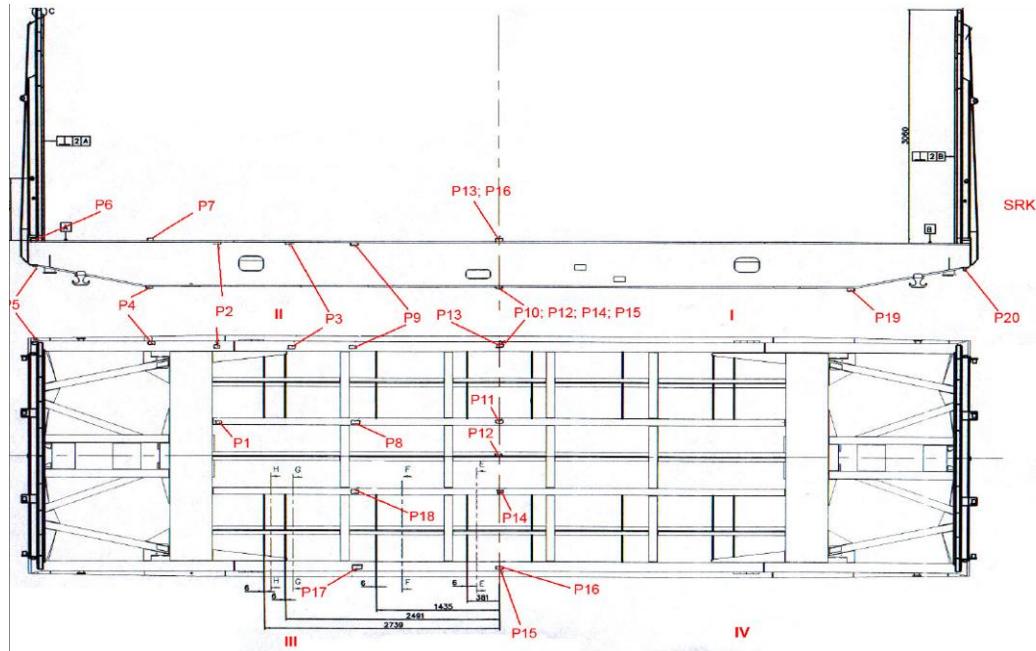


Figure 5: Underframe technical drawings with strain gauge positions

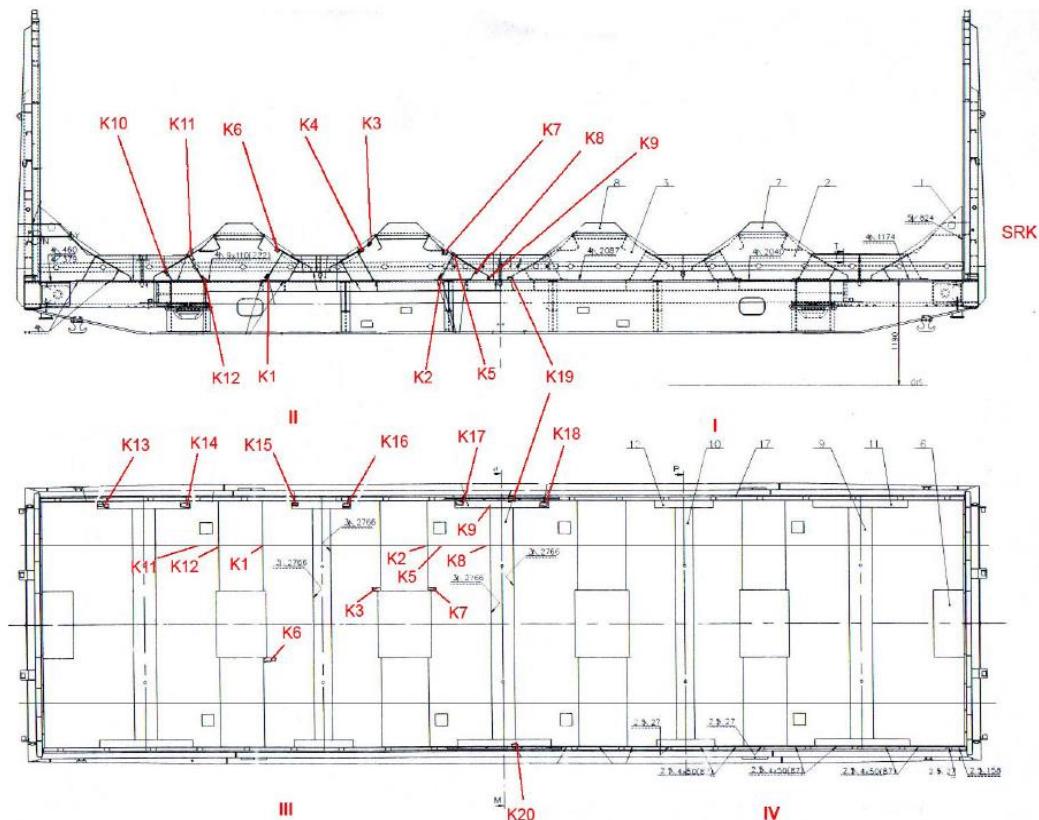


Figure 6: Superstructure technical drawings with strain gauge positions

Unfortunately, coils with the exact dimensions given in the Fig. 3. were not available for testing, so the closest ones at hand were placed on cradles 2 and 4, and the largest coil in the middle cradle is substituted with a combination of 3 coils. Dimensions of the experimental coils are given in Tab. 5, and their placement on SHIMMNS wagon cradles is shown in the Fig. 7.

Table 5: Experimental setup for the first load case

| Cradle number | Coil dimensions mm | Load t |
|---------------|-------------------------|------------|
| 2 | $\phi 1400 \times 1500$ | 11.66 |
| 3 | $\phi 1400 \times 1500$ | 11,8+0,85+ |
| | $\phi 1400 \times 1500$ | 7,26+9+1,6 |
| | $\phi 1400 \times 1500$ | =30,51 |
| 4 | $\phi 1400 \times 1500$ | 11.66 |



Figure 7: Experimental setup for the first load case

Strain gauges are shown in the Fig. 8. and Fig. 9.



Figure 8: Strain gauge P16



Figure 9: Strain gauge P13

Data acquisition equipment is shown in the Fig. 10.

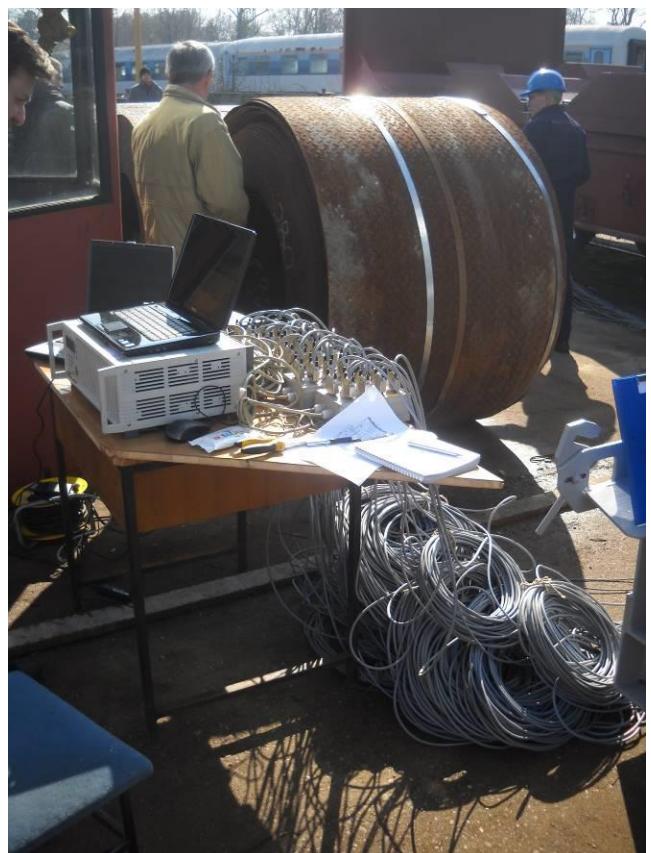


Figure 10: Data acquisition equipment

Stress obtained experimentally by gradual, incremental loading are shown in Tab. 6.

Table 6: Experimental measurements results

| Strain gauge | Stress MPa | | | |
|--------------|------------|---------|--------|---------------|
| | Load t | | | |
| | 11,05 | 23,32 | 35,12 | 53,83 |
| P1 | -14,960 | -27,271 | -40,36 | -63,2 |
| P2 | 0,954 | -1,28 | -1,116 | 0,173 |
| P3 | 0,211 | -4,337 | -6,759 | -10,42 |
| P4 | 1,972 | 1,703 | 2,745 | 3,401 |
| P5 | 1,857 | -0,102 | 0,159 | 0,078 |
| P6 | -0,448 | -0,341 | -0,177 | -0,074 |
| P7 | 0,547 | 0,315 | 1,178 | 2,934 |
| P8 | 1,000 | 13,006 | 14,821 | 17,337 |
| P9 | -1,514 | -1,498 | -4,129 | -7,918 |
| P10 | 14,658 | 24,691 | 50,972 | 91,693 |
| P11 | 3,336 | 2,122 | 19,283 | 46,619 |
| P12 | -4,702 | -3,714 | 3,333 | 13,743 |
| P13 | -4,939 | -10,201 | -20,63 | -37,33 |
| P14 | 0,157 | 2,05 | 16,031 | 37,004 |
| P15 | 10,816 | 23,13 | 45,091 | 78,301 |
| P16 | 0,626 | -10,624 | -21,24 | -36,68 |
| P17 | -1,642 | -1,909 | -3,829 | -6,931 |
| P18 | 3,631 | 12,989 | 13,539 | 14,083 |
| P19 | - | - | - | - |
| P20 | 0,793 | -0,176 | -0,253 | -0,19 |
| K1 | -2,713 | -7,73 | -8,485 | -10,17 |
| K2 | -0,618 | 0,169 | -1,137 | -5,437 |

| | | | | |
|-----|--------|---------|--------|---------------|
| K3 | 16,985 | -21,188 | -19,52 | -17,61 |
| K4 | -2,399 | 55,958 | 74,489 | 80,549 |
| K5 | 15,301 | 10,026 | 31,578 | 66,241 |
| K6 | -4,483 | -34,452 | -34,91 | -35,64 |
| K7 | 10,448 | 3,479 | 1,982 | 1,603 |
| K8 | -0,784 | -0,615 | -2,347 | -5,737 |
| K9 | 7,166 | -2,389 | -25,66 | -59,14 |
| K10 | -1,681 | -4,556 | -6,625 | -9,733 |
| K11 | -0,651 | 9,28 | -14,92 | -25,2 |
| K12 | 0,919 | -3,405 | -4,487 | -6,581 |
| K13 | 2,546 | 3,373 | 5,528 | 10,768 |
| K14 | -2,283 | 0,286 | 0,726 | 1,327 |
| K15 | -9,789 | -23,434 | -33,40 | -45,55 |
| K16 | 0,043 | -29,033 | -45,91 | -71,45 |
| K17 | -0,495 | -7,521 | -14,97 | -26,74 |
| K18 | -2,115 | 6,388 | 19,147 | 38,035 |
| K19 | 3,041 | -3,79 | -8,158 | -14,52 |
| K20 | -3,527 | -4,002 | -8,235 | -13,94 |

For subsequent comparison with FEM results, we considered only stress greater than 20 MPa which are emphasized in Tab. 6.

4. FEM RESULTS AND COMPARISON WITH EXPERIMENTAL DATA

Subsequent FEM analysis was done for the realistic experimental load case defined in Tab 5, which slightly different from the initial load case shown in the Fig. 4. Von Mises stress field in one quarter model is shown in the Fig. 11. to Fig.16, for different viewing angles, and zoomed in areas with high stress values.

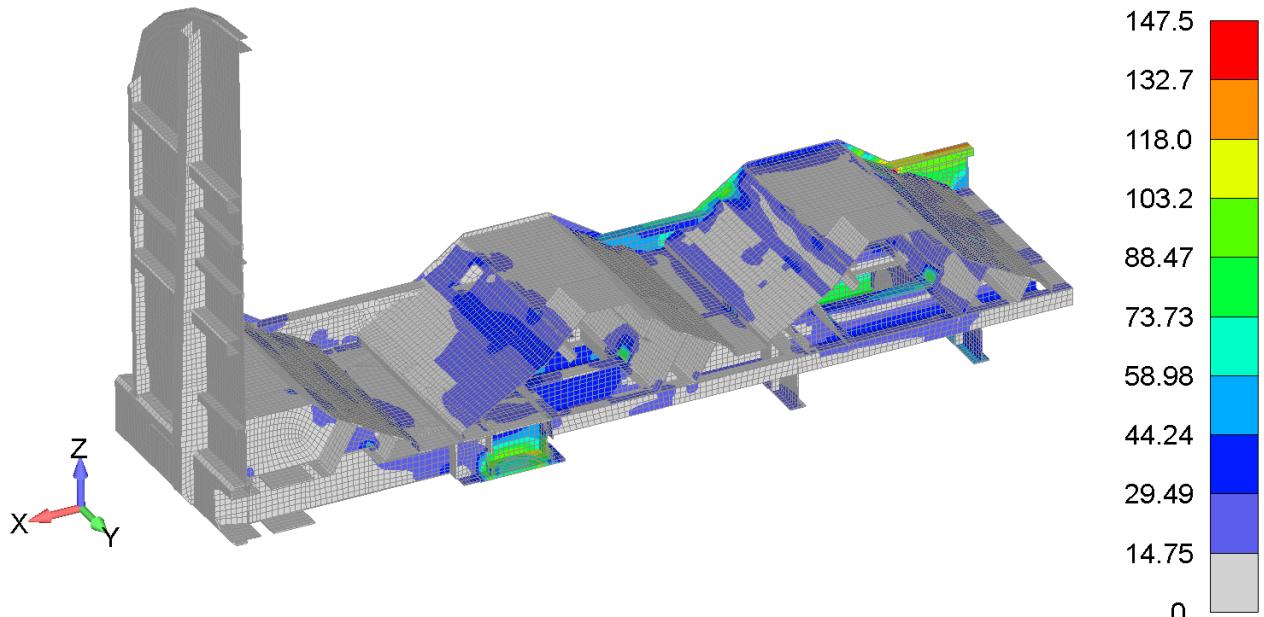


Figure 11: Von Mises equivalent stress field, view I

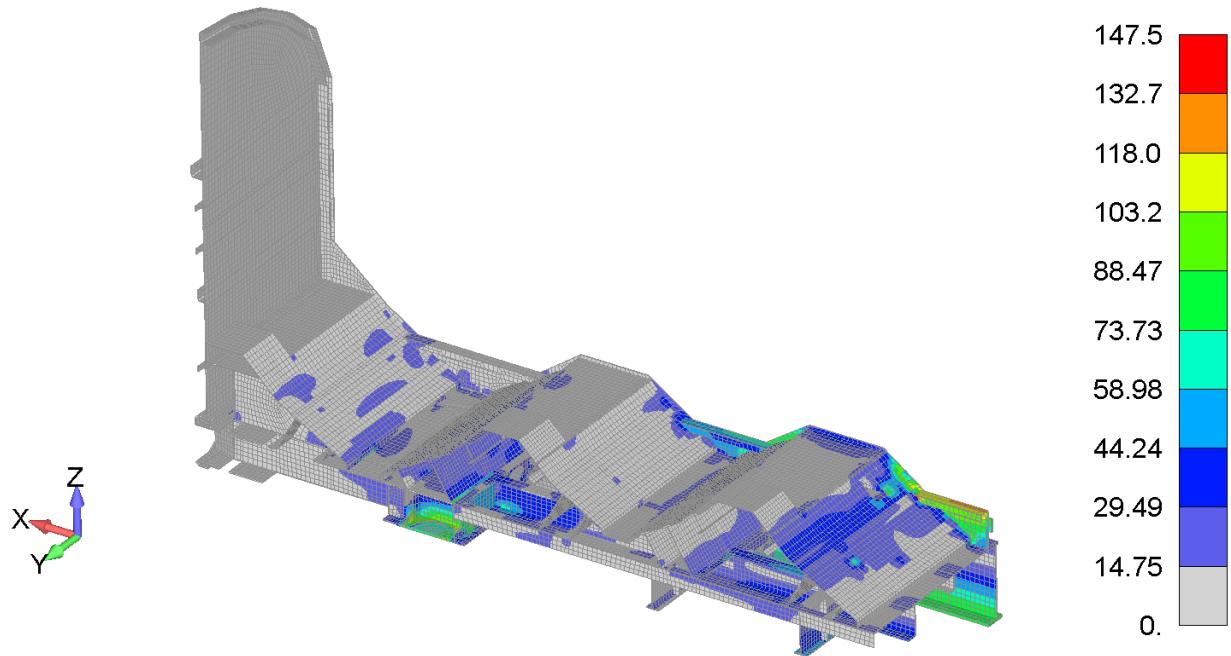


Figure 12: Von Mises equivalent stress field, view 2

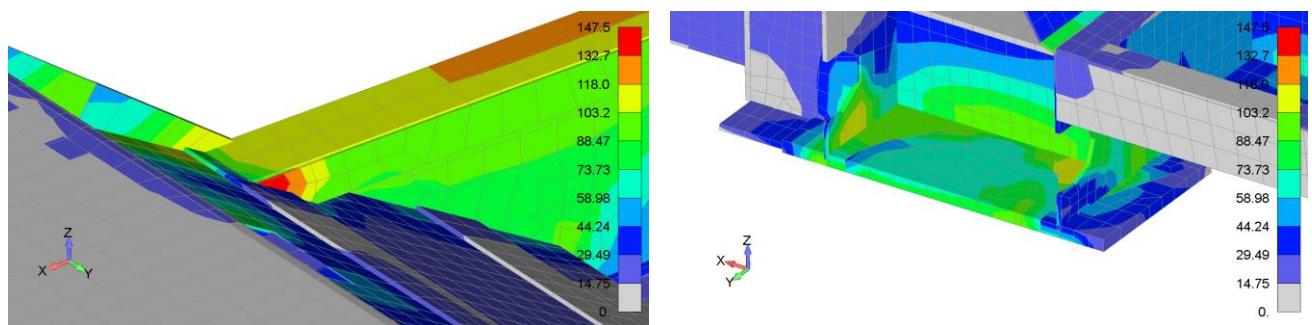


Figure 13: Significant loaded zones, view 3,4

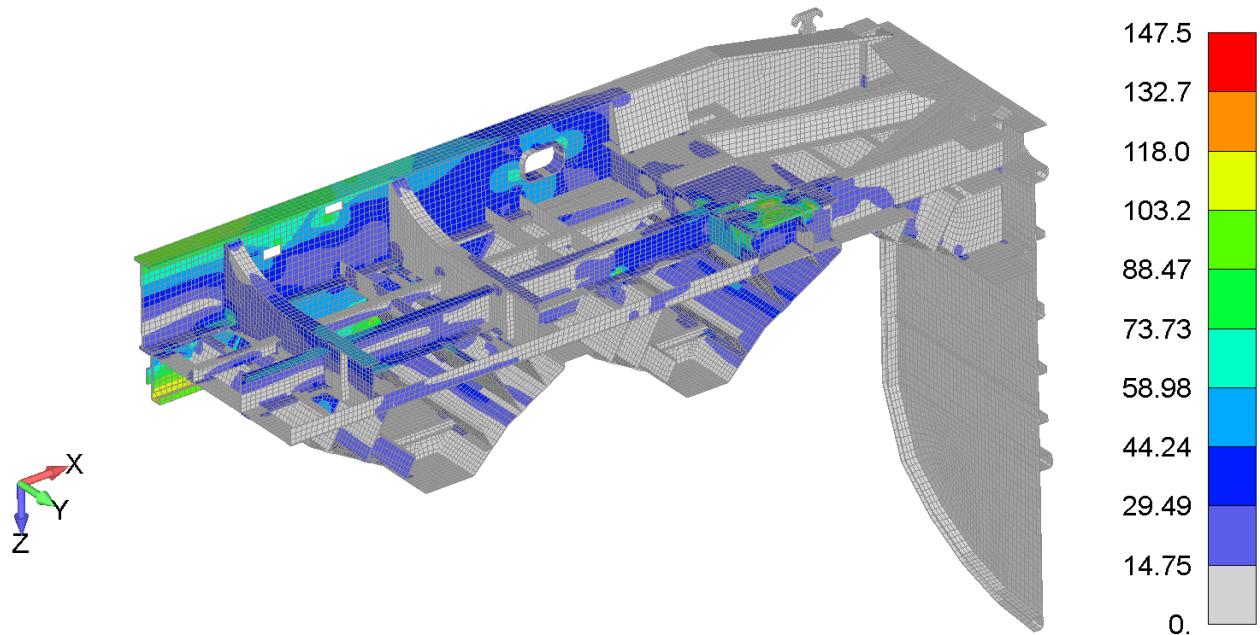


Figure 14: Von Mises equivalent stress field, view 5

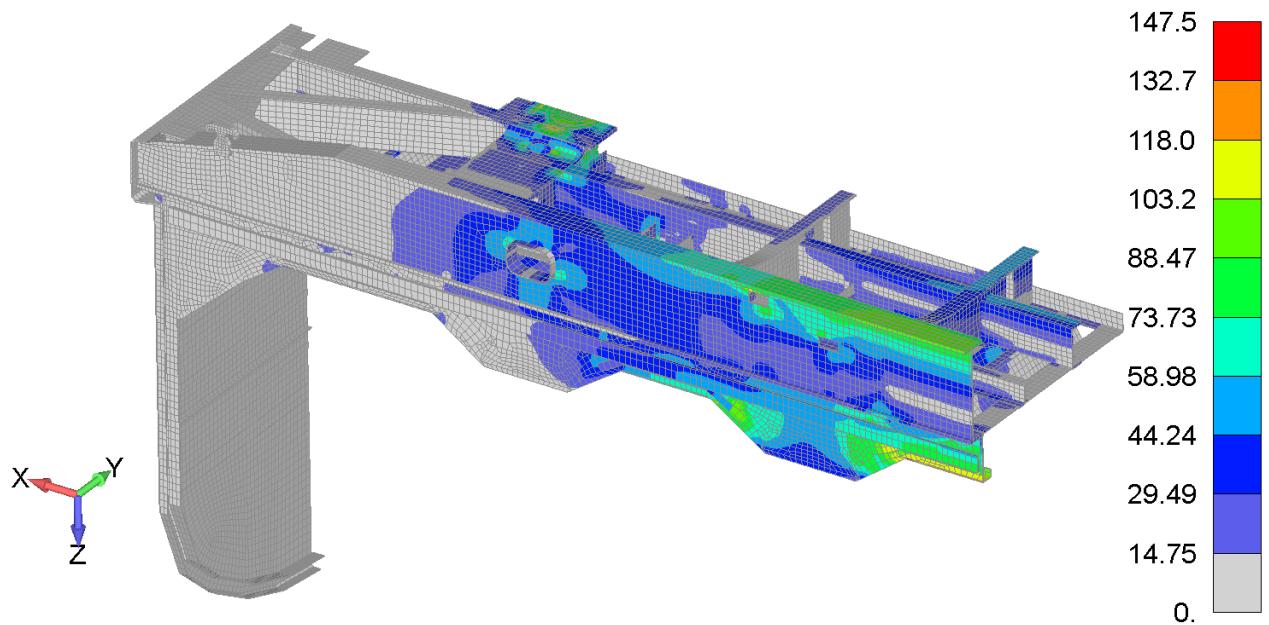


Figure 15: Von Mises equivalent stress field, view 6

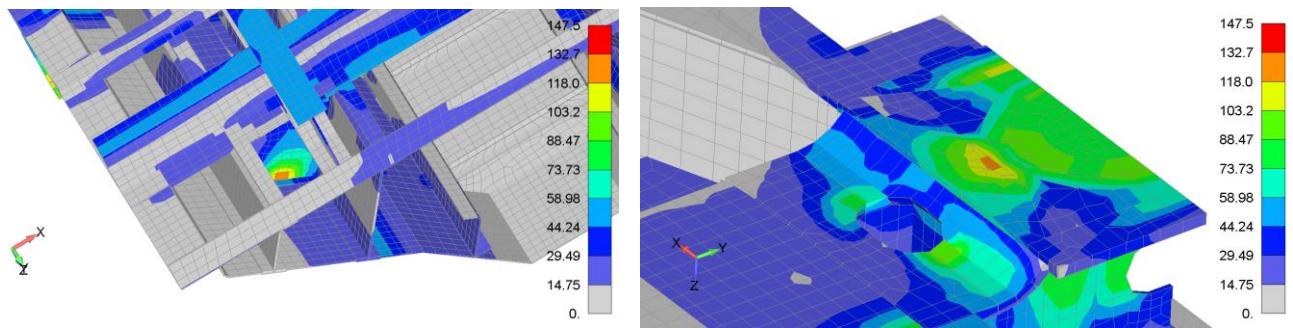


Figure 16: Significant loaded zones, view 7,8

Longitudinal displacement is shown in the Fig. 17.

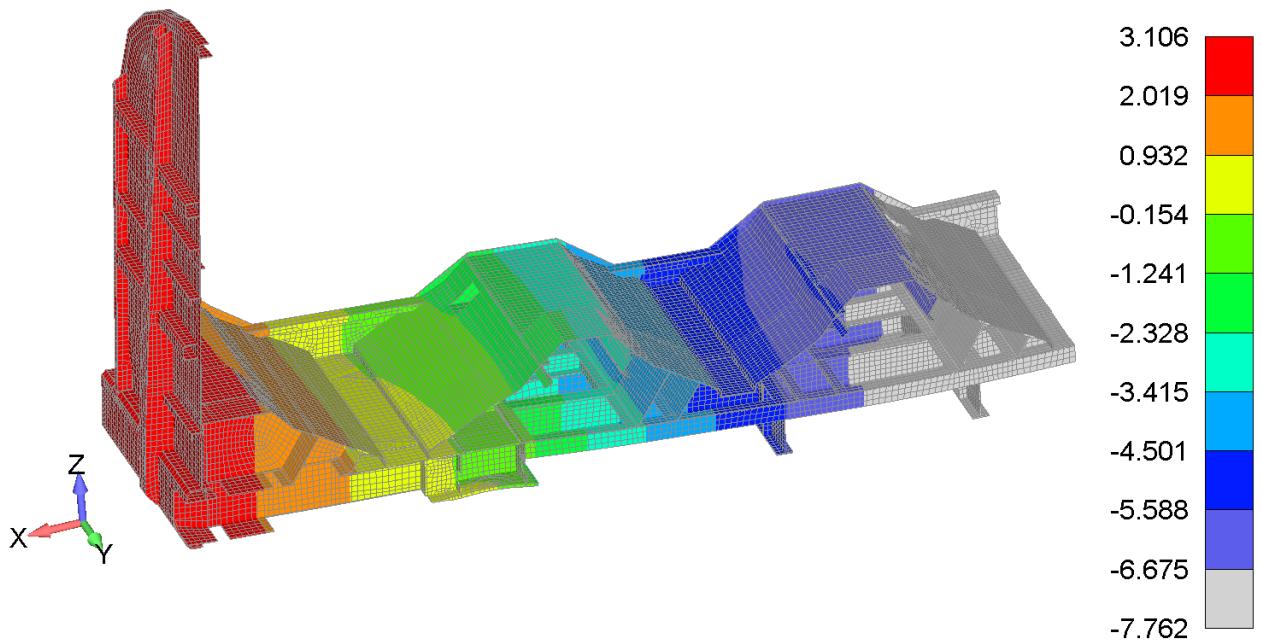


Figure 17: Longitudinal displacement field – U_z

The FEM results show good agreement with experimental data, and that Von Mises equivalent stress in

both parent material and welded joints [6] is far less than permissible stress, as can be seen in Tab. 7.

Table 7: Comparison between experimental and FEM results

| Stress MPa | | | |
|--------------|----------------|--------------|--------------------|
| Strain gauge | Measured value | FEM analysis | Permissible stress |
| P1 | -63,2 | -64.88 | 216 |
| P10 | 91,639 | 92.23 | 238 |
| P11 | 46,619 | 46.11 | 238 |
| P13 | -37,33 | -36.42 | 216 |
| P14 | 37,004 | 46.11 | 238 |
| P15 | 78,301 | 92.23 | 238 |
| P16 | -36,68 | -36.42 | 216 |
| K4 | 80,549 | 60.09 | 216 |
| K5 | 66,241 | 65.66 | 216 |
| K6 | -35,64 | -34.55 | 216 |
| K9 | -59,14 | -62.61 | 238 |
| K11 | -25,2 | -25.93 | 238 |
| K15 | -45,55 | -47.74 | 216 |
| K16 | -71,45 | -62.3 | 216 |
| K17 | -26,74 | -44.77 | 216 |
| K18 | 38,035 | -44.77 | 216 |

Due to the lack of appropriate measuring equipment, the maximum deflection at half the distance between wheelbase is not experimentally confirmed, but based on stress agreement between FEM and experimental testing, we can vouch that this condition is satisfied as well, as shown in Tab. 8.

Table 8: Maximum deflection at the middle of the wagon

| Measured deflection | FEM result | Permissible deflection |
|---------------------|------------|------------------------|
| - | 7.152 | 21.6 |

5. CONCLUSIONS

In this paper numerical analysis of SHIMMNS type wagon is presented along with the experimental verification. According to standards [2] and [3], this type of wagon must be certified to withstand numerous loading conditions that can occur during its exploitation. However, experimental validation can be difficult, impractical and expensive, so FEM analysis is used to refine wagon design before the first prototype for testing is constructed. Six vertical load cases are analysed using FEM according to wagon specifications, and in this paper only the first load case is presented. Exact loading of wagon cradles was

impossible to experimentally recreate due to the lack of sheet coils with specific dimensions and weight, however, the deviation from the targeted values can be neglected having in mind the difference between stress calculated using FEM and experimental values on one side, and permissible stress on the other side.

Analysed wagon satisfies all safety criteria defined in the standards [2] and [3], but its tare weight/cargo weight ratio makes it inferior to the competition, so optimization of wagon is required in order to reduce tare weight and to increase its cargo capacity, which will require multiple repetition of design changes and FEM analysis cycles.

ACKNOWLEDGEMENTS

This research is supported by the Ministry of Education, Science and Technological Development, Republic of Serbia, Grant TR32036 and 451-03-9/2021-14/200378.

One of the authors, Aleksandar Disic, deceased due to COVID-19 complications after this research was done. We would like to keep him on the author list, because his contribution has great impact on this paper

REFERENCES

- [1] M. Kojić, R. Slavković, M. Živković and N. Grujović, "Finite Element Method I - Linear Analysis", Faculty of Mechanical Engineering, University of Kragujevac, (Serbia), (1998).
- [2] TSI Standard - Commission Regulation (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock — freight wagons' of the rail system in the European Union and repealing Decision 2006/861/EC; including amendment Commission Regulation (EU) No 1236/2013 of 2 December 2013.
- [3] BS EN 12663-2:2010 - Railway applications – Structural requirements of railway vehicle bodies, Part 2: Freight wagons, European Standard.
- [4] Femap with NX Nastran user manual.
- [5] Technical description of the SHIMMNS wagon.pdf
- [6] V. Milovanović, V. Dunić, D. Rakić, M. Živković, "Identification causes of cracking on the underframe of wagon for containers transportation - Fatigue strength assessment of wagon welded joints", Eng. Fail. Anal., Vol. 31, pp. 118-131, (2013)