

University of Niš
Faculty of Mechanical Engineering



PROCEEDINGS

XIX SCIENTIFIC-EXPERT
CONFERENCE ON
RAILWAYS
RAILCON '20



October 15 - 16, 2020, Niš, Serbia

Publisher

Faculty of Mechanical Engineering Niš
Prof. Nenad T. Pavlović, Dean

Editor

Prof. Dušan Stamenković
Assis. Prof. Milan Banić

Technical preparation

Assis. Prof. Aleksandar Miltenović

Cover design

Prof. Miloš Milošević

Number of copies

120

Printing

Grafika Galeb, Niš

CIP - Каталогизacija у публикацији
Народна библиотека Србије, Београд

629.4(082)
656.2(082)
625.1(082)
338.47(497.11)(082)

SCIENTIFIC-Expert Conference of Railways (20 ; 2020 ;
Niš)

Proceedings / XIX Scientific-Expert Conference on
Railways - RAILCON '20, October 15-16, 2020, Niš,
Serbia ; [editor Dušan Stamenković, Milan Banić]. - Niš :
Faculty of Mechanical Engineering, 2020 (Niš : Grafika
Galeb). - XVIII, 193 str. : ilustr. ; 25 cm

Na vrhu nasl. str.: University of Niš. - Tekst štampan
dvostubačno. - Tiraž 120. - Napomene uz tekst. -
Bibliografija uz svaki rad. - Registar.

ISBN 978-86-6055-134-6

- а) Железничка возила -- Зборници
- б) Железнички саобраћај -- Зборници
- в) Железничке пруге -- Зборници
- г) Србија -- Саобраћајна политика - Зборници

COBISS.SR-ID 21916169



Ministry of Education, Science and Technological Development of the Republic of Serbia has participated in printing costs of the Proceedings of the XIX International Scientific-Expert Conference on Railways - **RAILCON 2020**

All the publications in these Proceedings have the authorship, whereas the authors of the papers carry entire responsibility for originality and content.



University of Niš



Faculty of Mechanical
Engineering

Program Committee

Prof. Milan Banić, University of Niš, Faculty of Mechanical Engineering, Serbia
Prof. Boban Anđelković, University of Niš, Faculty of Mechanical Engineering, Serbia
Prof. Carmen Alic, Polytechnic University of Timisoara, Romania
Prof. Dobrinka Atmadžova, Todor Kableskov University of Transport, Sofia, Bulgaria
Prof. Nebojša Bojović, University of Belgrade, Faculty of Traffic Engineering, Serbia
Prof. Branislav Bošković, University of Belgrade, Faculty of Traffic Engineering, Serbia
Prof. Dragan Đurđanović, University of Texas at Austin, Mechanical Engineering, USA
Prof. Ratko Đuričić, Faculty of Traffic Engineering Dobož, R. Srpska, Bosnia and Herzegovina
Doc. Juraj Grenčík, University of Žilina, Faculty of Mechanical Engineering, Slovakia
Prof. Daniel Kalinčák, University of Žilina, Faculty of Mechanical Engineering, Slovakia
Prof. Dragutin Kostić, University of Belgrade, Faculty of Traffic Engineering, Serbia
Prof. Predrag Jovanović, University of Belgrade, Faculty of Traffic Engineering, Serbia
Prof. Vojkan Lučanin, University of Belgrade, Faculty of Mechanical Engineering, Serbia
Prof. Dragomir Mandić, University of Belgrade, Faculty of Traffic Engineering, Serbia
Prof. Dragan Marinković, Technical University Berlin, Dep. Of Structural Analysis, Germany
Dr Andrea Mazzone, Bombardier Transportation, Switzerland
Prof. Dragan Milčič, University of Niš, Faculty of Mechanical Engineering, Serbia
Prof. Miloš Milošević, University of Niš, Faculty of Mechanical Engineering, Serbia
Dr Rešad Nuhodžić, Ministry of Sustainable Development & Tourism, Montenegro
Prof. Nenad T. Pavlović, University of Niš, Faculty of Mechanical Engineering, Serbia
Prof. Dragan Petrović, Uni. of Kragujevac, Faculty of Mechanical and Civil Eng., Kraljevo, Serbia
Prof. Mihaela Popa, Polytechnic University of Bucharest, Romania
Dr Danijela Ristić-Durrant, University of Bremen, Germany
Privat doz. Andreas Schöbel, Technical University Wien, Austria
Prof. Miloš Simonović, University of Niš, Faculty of Mechanical Engineering, Serbia
Prof. Dušan Stamenković, University of Niš, Faculty of Mechanical Engineering, Serbia
Prof. Jovan Tanasković, University of Belgrade, Faculty of Mechanical Engineering, Serbia
Prof. Cristian Ulianov, Newcastle University, United Kingdom
Prof. Kiril Velkov, Technical University of Sofia, Faculty of Transport, Bulgaria

Organizing Committee

Aleksandar Miltenović, PhD, President
Miroslav Mijajlović, PhD
Miodrag Milčič
Nataša Zdravković
Vukašin Pavlović
Miša Tomić
Srđan Mladenović
Dušanka Nikolić
Vesna Grozdanović, technical secretary

Patron

Ministry of Education, Science and Technological Development of Republic of Serbia
Serbian Chamber of Engineers

Cofinanciers

KRUCH RAILWAY INNOVATIONS
MOSDORFER
ALTPRO
INSTITUTE „MIHAJLO PUPIN”
IMW INSTITUTE
KRAIBURG STRAIL
SIGNALLING & CONTROL
DESPOTIJA
ELPA

CONTENTS

Plenary session

- ADVANCEMENTS IN THE FIELD OF RAILWAY VEHICLES I
Simon IWNICKI
Institute of Railway Research, University of Huddersfield, United Kingdom
- LIGHTWEIGHT VEHICLES – A NEW PARADIGM IN RAIL FREIGHT III
Cristian ULIANOV
Newcastle University, United Kingdom
Marius FARTAN
REMARUL 16 Februarie, Cluj-Napoca, Romania
Petr VOLTR
Newcastle University, United Kingdom
- OBSTACLE DETECTION FOR RAILWAYS: LESSONS LEARNED FROM PROJECT SMART XI
Danijela RISTIĆ-DURRANT
Institute of Automation, University of Bremen, Germany
Muhammad Abdul HASEEB
Bombardier Transportation GmbH, Mannheim, Germany
Milan BANIĆ, Dušan STAMENKOVIĆ, Miloš SIMONOVIĆ,
Aleksandar MILTENOVIĆ, Vlastimir NIKOLIĆ
Faculty of Mechanical Engineering, Niš, Serbia
Dragan NIKOLIĆ
Harder Digital Sova, Niš, Serbia

Rolling stock

- 1.1. SPECIAL FEM SUPERELEMENT IMPACT ON THE TOPOLOGY OPTIMIZATION TIME CONSUMPTION 1
Marcin KALINOWSKI
Alstom Konstal S.A. Poland
Mirosław SZCZEPANIK
Silesian University of Technology, Poland
- 1.2. NUMERICAL RESEARCH OF IMPACT OF TUBE WALL THICKNESS AND POLYURETHANE FOAM DENSITY ON ABSORPTION CHARACTERISTICS 5
Jovan TANASKOVIĆ, Dragan MILKOVIĆ, Vojkan LUČANIN
Faculty of Mechanical Engineering, Belgrade, Serbia
- 1.3. ANALYSIS OF THE IMPACT OF ELECTRIC LOCOMOTIVES ON ENERGY PARAMETERS IN THE POWER SUPPLY SYSTEM 9
Dragutin KOSTIĆ, Petar MARKOVIĆ
Faculty of Transport and Traffic Engineering, Belgrade, Serbia
- 1.4. INFLUENCE OF HEAD WIND ON THE BRAKING DISTANCE OF SINGLE RAILWAY VEHICLE 13
Dragan MILKOVIĆ, Saša RADULOVIĆ,
Goran SIMIĆ, Jovan TANASKOVIĆ
Faculty of Mechanical Engineering, Belgrade, Serbia
- 1.5. SPECIFIC ASPECTS OF THE RAIL VEHICLE PASS-BY NOISE MEASUREMENT 17
Goran SIMIĆ, Saša RADULOVIĆ, Vojkan LUČANIN
Faculty of Mechanical Engineering, Belgrade, Serbia
- 1.6. NUMERICAL ANALYSIS OF WAGON LEAF SPRINGS 21
Milan BIŽIĆ, Dragan PETROVIĆ
Faculty of Mechanical and Civil Engineering in Kraljevo, Serbia

1.7.	RANDOM VIBRATION ANALYSIS OF THE DEMONSTRATOR HOUSING Milan BANIĆ, Aleksandar MILTENOVIĆ, Miloš SIMONOVIĆ Miloš MILOŠEVIĆ, Marko PERIĆ Faculty of Mechanical Engineering, Niš, Serbia	25
1.8.	A METHOD FOR DIRECT THEORETICAL DETERMINATION OF THE CRITERION AGAINST ROLLING STOCK DERAILMENT BASED ON THE DATA OBTAINED IN A THEORETICAL OR EXPERIMENTAL WAY Dobrinka ATMADZHOVA University of Transport (VTU Todor Kableshekov), Sofia, Bulgaria	29
1.9.	ASSESSING THE IMPACT OF THE LATERAL SWINGING OF THE TRAM TO ITS ELECTRICAL CURRENT COLLECTOR Emil M. MIHAYLOV University of Transport (VTU Todor Kableshekov), Sofia, Bulgaria Sofia Public Electrical Transport Company JSC, Sofia, Bulgaria Emil IONTCHEV University of Transport (VTU Todor Kableshekov), Sofia, Bulgaria Rosen MILETIEV Technical University of Sofia, Bulgaria Boris PETKOV University of Transport (VTU Todor Kableshekov), Sofia, Bulgaria	33

Traffic and transport

2.1.	RANKING OF LEVEL CROSSINGS IN THE PLANNING PROCESS TO SAFETY IMPROVEMENT USING THE VIKOR Norbert PAVLOVIĆ, Ivan BELOŠEVIĆ, Sanjin MILINKOVIĆ Faculty of Transport and Traffic Engineering, Belgrade, Serbia	37
2.2.	APPLICATION OF OPENTRACK AT RAILWAYS OF REPUBLIC OF SRPSKA (RAILROAD TRACKS ŠAMAC – DOBOJ) Rade CVIJANOVIĆ, Jelena KUZMANOVIĆ, Nikola MALINOVIĆ Željeznice Republike Srpske, Doboj, Bosnia and Herzegovina Andreas SCHÖBEL OpenTrack Railway Technology GmbH, Austria	41
2.3.	CLASSIFYING COUNTRIES FOR RAILWAY PERFORMANCE BENCHMARKING: A HIERARCHICAL CLUSTERING APPROACH Miroslav PROKIĆ, Katarina HALAJ, Mira PASKOTA Faculty of Transport and Traffic Engineering, Belgrade, Serbia	45
2.4.	HAZARDS AND RISKS DUE TO TANK CAR EXPLOSION Mirko ĐELOŠEVIĆ, Goran TEPIĆ Faculty Technical Sciences, Novi Sad, Serbia	49
2.5.	ASSESSMENT OF THE DEGREE OF SAFETY AT RAILWAY CROSSINGS IN SERBIA CONDUCTED BY DRIVERS Sandra KASALICA, Goran TRIČKOVIĆ, Milan MILOSAVLJEVIĆ Dušan JEREMIĆ, Dušan VUJOVIĆ High railway school of vocational studies, Belgrade, Serbia	53
2.6.	ENHANCING CAPACITY ON ETCS LINES Andreas SCHÖBEL, Olga PERMIKOVA OpenTrack Railway Technology GmbH, Vienna, Austria	57
2.7.	TRAFFIC SAFETY AT LEVEL CROSSINGS Filip ŠČEKIĆ, Lazar MOSUROVIĆ, Nebojša MIHAJLOVIĆ, Jovo STELJIĆ Directorate for Railways, Belgrade, Serbia	61

Infrastructure

3.1.	EVALUATION OF TIMETABLE ROBUSTNESS CONSIDERING BUFFER TIMES' AMOUNT AND DISTRIBUTION Predrag JOVANOVIĆ, Norbert PAVLOVIĆ Faculty of Transport and Traffic Engineering, Belgrade, Serbia	65
------	--	----

3.2.	ELECTRONIC AXLE COUNTER Dejan LUTOVAC Signalling & Control, Belgrade, Serbia	69
3.3.	ESTIMATION OF RAILWAY BELGRADE RING OPTIC NETWORK USING NETWORK PLANNING TOOL Sanja JEVTIĆ, Marko BURSAĆ High Railway School of Vocational Studies, Belgrade, Serbia Dragan JEVTIĆ Serbian Railway Infrastructure, Belgrade, Serbia Milesa SREČKOVIĆ Faculty of Electrical Engineering, Belgrade, Serbia	73
3.4.	CABLEWAYS AND RAILWAYS – ECOLOGICAL ASPECTS Jovo STELJIĆ, Nataša CEROVIĆ, Filip ŠČEKIĆ Directorate for Railways, Belgrade, Serbia	77
3.5.	ANALYSIS OF THE INTERFACE BETWEEN NATIONAL APPLICABLE GAUGE IN THE BULGARIAN NETWORK AND GAUGE GC, BG AND GA Milcho LEPOEV, Lazar GEORGIEV University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria Vladimir ZHEKOV National railway infrastructure company, Sofia, Bulgaria	81

Vehicle and infrastructure maintenance

4.1.	ANALYSIS OF THE FAILURES OF BOGIES TYPE T73-AD AND Y32 FROM OF BULGARIAN STATE RAILWAYS Dobrinka ATMADZHOVA, Vanio RALEV University of Transport (VTU Todor Kableshkov), Sofia, Bulgaria	85
4.2.	MODELLING AND NON-DESTRUCTIVE TESTING OF HEAD CHECK DAMAGE OF RAILWAYS Csaba TAKACS, Reka ERDEI Mechanical Testing Laboratory, Miskolc, Hungary	89
4.3.	DEVELOPING ADVANCED SUBSYSTEM FOR SECURING STEEL COIL CARGO ON SHIMMNS WAGON CRADLES Vladimir MILOVANOVIĆ, Milan BOJOVIĆ, Miroslav ŽIVKOVIĆ Faculty of Engineering, Kragujevac, Serbia Marko TOPALLOVIĆ, Snežana VULOVIĆ Institute for Information Technologies, University of Kragujevac, Serbia	93
4.4.	RELIABILITY AND SAFETY OF AXLE-WHEEL ASSEMBLY Mladen TODIĆ, Valentina GOLUBOVIĆ-BUGARSKI, Tihomir LATINOVIĆ Faculty of Mechanical Engineering, Banja Luka, Bosnia and Hercegovina	97
4.5.	APPLICATION OF REVERSING OUTPUT DUAL BRAKE PLANETARY TRANSMISSIONS Jelena STEFANOVIĆ-MARINOVIĆ University of Niš, Faculty of Mechanical Engineering, Niš, Serbia Željko VRCAN, Sanjin TROHA Faculty of Engineering, Rijeka, Croatia	101
4.6.	THE MARKET CONCEPT OF RAILWAY VEHICLES MAINTENANCE ON THE RAILWAYS OF REPUBLIC OF SRPSKA Vladimir MALČIĆ, Ratko ĐURIČIĆ, Faculty of Transport and Traffic Engineering Doboj, Bosnia and Hercegovina Rade CVIJANOVIĆ Railways of Republic of Srpska, Doboj, Bosnia and Hercegovina	105
4.7.	OPTIMIZATION OF THE SADDLE SUPPORT STRUCTURE OF THE FREIGHT WAGON TYPE SHIMMNS Vladimir MILOVANOVIĆ, Nikola JOVANOVIĆ, Miroslav ŽIVKOVIĆ Faculty of Engineering, Kragujevac, Serbia Aleksandar DIŠIĆ, Marko TOPALLOVIĆ Institute for Information Technologies, University of Kragujevac, Serbia	109

- 4.8. RELIABILITY COMPARISON OF CLASSICAL BRAKE FOR FREIGHT WAGONS AND THE INTEGRATED BOGIE BRAKE TYPE IBB 10 113
 Erdinč RAKIPOVSKI, Dragan MILČIĆ
 Faculty of Mechanical Engineering, Niš, Serbia
 Tasko SMILESKI
 Faculty of Mechanical Engineering, Skopje, North Macedonia

Strategy and policy

- 5.1. DETERMINING THE RISK ACCEPTANCE CRITERIA FOR OPERATIONAL CHANGES IN THE RAILWAY SYSTEM USING THE "SAFETY II" PRINCIPLE 117
 Slobodan ROSIĆ
 Serbian Railways Infrastructure, Belgrade, Serbia
 Melanija MITROVIĆ, Dušan STAMENKOVIĆ
 Faculty of Mechanical Engineering, Niš, Serbia
- 5.2. MULTICRITERIA APPROACH FOR PSO SERVICES SELECTION IN RAIL SECTOR 121
 Dragana MACURA, Predrag JOVANOVIĆ
 Faculty of Transport and Traffic Engineering, Belgrade, Serbia
- 5.3. USING MULTIPLE CRITERIA DECISION-MAKING TECHNIQUE TO EVALUATE SERBIAN RAILWAY SYSTEM OPERATION PERFORMANCE 125
 Nikola PETROVIĆ, Vesna JOVANOVIĆ, Jovan PAVLOVIĆ
 Faculty of Mechanical Engineering, Niš, Serbia
 Tanja ŽIVOJINOVIĆ
 Faculty of Transport and Traffic Engineering, Belgrade, Serbia
- 5.4. EUROPEAN RAILWAYS THROUGH TIME AND "STORMS" 129
 Branka NEDELJKOVIĆ, Ksenija DUNJIĆ PAVLOVIĆ, Nina IVKOVIĆ
 Directorate for Railways, Belgrade, Serbia
- 5.5. FOURTH RAILWAY PACKAGE – NEW CONCEPTS IN THE FIELD OF SAFETY AND INTEROPERABILITY AND THEIR TRANSPOSITION INTO THE LEGAL FRAMEWORK OF THE REPUBLIC OF SERBIA 133
 Milan POPOVIĆ, Nataša CERVIĆ, Olivera ZDRAVKOVIĆ
 Directorate for Railways, Belgrade, Serbia
- 5.6. THE ROLE OF TREATY ESTABLISHING TRANSPORT COMMUNITY IN DEVELOPMENT OF RAIL TRANSPORT MARKET IN SERBIA 137
 Lazar MOSUROVIĆ, Branka NEDELJKOVIĆ, Zorica RADOVIĆ
 Directorate for Railways of the Republic of Serbia, Belgrade, Serbia
- 5.7. WESTERN BALKAN RAILWAY MARKET THROUGH THE SCOPE OF THE REGULATORY BODY – BENCHMARK WITH EUROPE 141
 Jakša POPOVIĆ
 Directorate for Railways of Republic of Serbia, Belgrade, Serbia
 Mirjana BUGARINOVIĆ
 Faculty of Transport and Traffic Engineering, Belgrade, Serbia

Other Railway aspects

- 6.1. NUMERICAL SIMULATION OF THE WELDING PROCESS, THE INFLUENCE OF CONSTRAINT POINTS LOCATIONS ON THERMAL DEFORMATIONS 145
 Tomasz ZADOROŻNY
 Alstom Konstal S.A. Poland
 Mirosław SZCZEPANIK
 Silesian University of Technology, Poland
- 6.2. APPLICATION OF 3D PRINTING IN RAILWAY INDUSTRY 149
 Marko PERIĆ, Aleksandar MILTENKOVIĆ, Dušan STAMENKOVIĆ, Jovan ARANĐELOVIĆ
 Faculty of Mechanical Engineering, Niš, Serbia

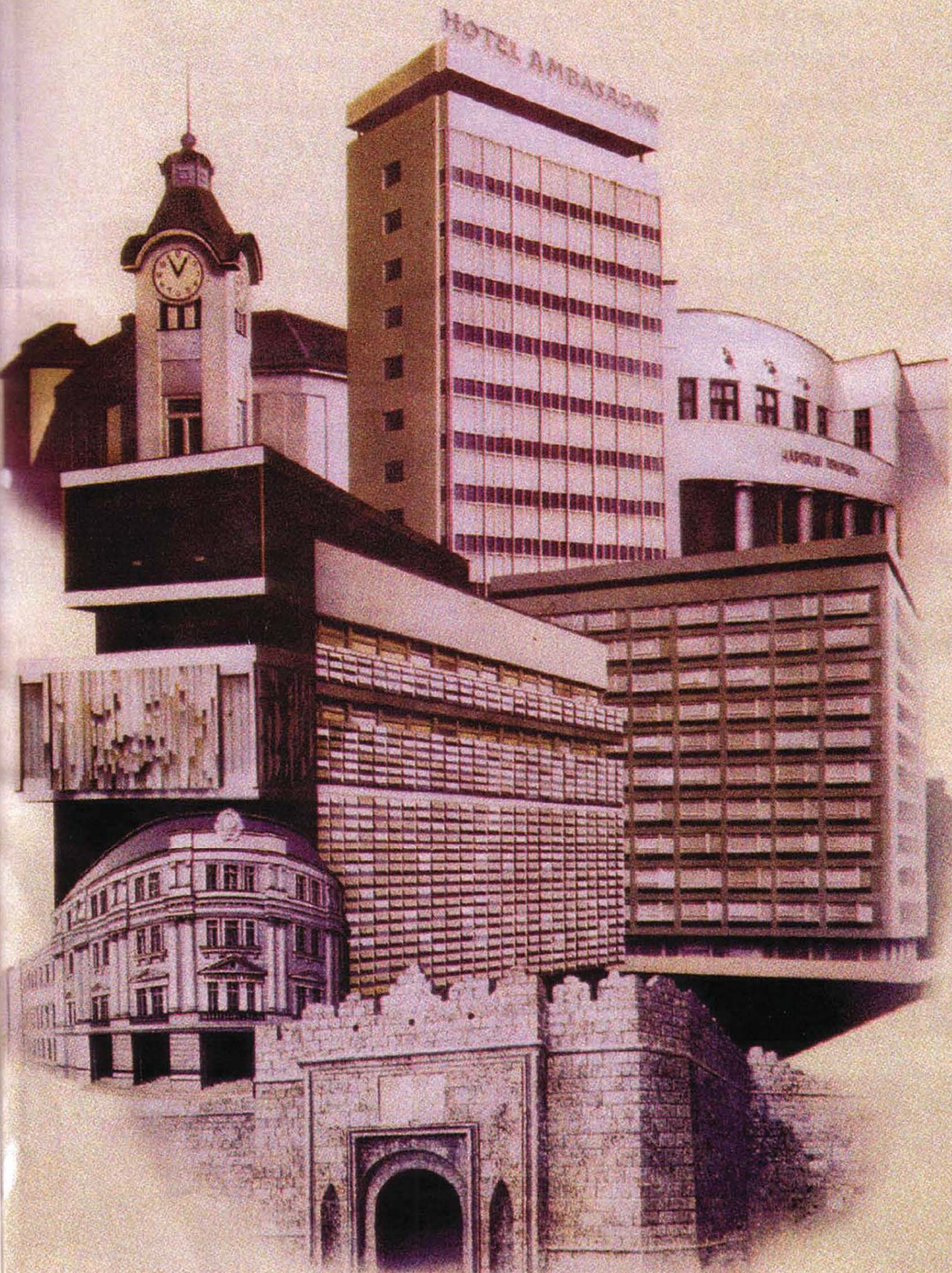
6.3.	APPLICATION OF METALLOGRAPHIC TECHNIQUES IN ORDER TO IDENTIFY DEFECTS IN THE MICROSTRUCTURE OF WELDED JOINTS OF AL ALLOYS Marko SAVIĆ, Andreja RADOVANOVIĆ, Nikola MARINKOVIĆ Ivan VUČKOVIĆ, Branka JORDOVIĆ IMW Institute, Lužnice, Serbia	153
6.4.	ANALYSIS OF LOGISTICS CHAINS, SERVICED BY RAILWAY TRANSPORT AND APPROACHES FOR TECHNOLOGICAL DESIGN OF PROCESSES Andrey BORISOV, Violina VELYOVA University of Transport (VTU Todor Kableshkov), Sofia, Bulgaria	157
6.5.	THE REVIEW OF HARMONIZED STANDARDS OF PERSONAL PROTECTIVE EQUIPMENT FOR SAFE WORK ON RAILWAY Vesna PAVELKIĆ High railway school of vocational studies, Belgrade, Serbia Dragan MAJKIĆ Serbian Railways Infrastructure, Belgrade, Serbia Marija ILIĆ Faculty of Mining and Geology, Belgrade, Serbia Aleksandar BLAGOJEVIĆ High railway school of vocational studies, Belgrade, Serbia	161
6.6.	NOVEL RECOMMENDATIONS OF UIC FOR CALCULATION OF CARBON CONTENT IN RAILWAY INFRASTRUCTURE Vesna PAVELKIĆ, Sandra KASALICA, Aleksandar BLAGOJEVIĆ High railway school of vocational studies, Belgrade, Serbia Marija ILIĆ Faculty of Mining and Geology, Belgrade, Serbia	165
6.7.	CHARACTERIZATION OF BUTT WELD JOINT BY MIG WELDING PROCESS ON THE EXAMPLE OF ALUMINIUM ALLOY EN AW 6082 Nikola MARINKOVIĆ, Andreja RADOVANOVIĆ, Ivan VUČKOVIĆ, Marko SAVIĆ, Branka JORDOVIĆ IMW Institute, Lužnice, Serbia	169
6.8.	HOT FORMING PROCESS OF UPPER PIVOT OF FREIGHT CARS Saša RANDELOVIĆ, Vladislav BLAGOJEVIĆ, Srđan MLADENOVIC Faculty of Mechanical Engineering, Niš, Serbia Mladomir MILUTINOVIC Faculty of Technical Science, Novi Sad, Serbia	173
6.9.	APPLICATION OF LASER TECHNOLOGY IN PRODUCTION AND MAINTENANCE OF RAILWAY VEHICLES Marija VUKŠIĆ POPOVIĆ, Sanja JEVTIĆ High railway school of vocational studies, Belgrade, Serbia	177
6.10.	USAGE OF ÖBB ELECTRIC LOCOMOTIVES ON THE CROATIAN RAILWAY NETWORK Milan BRKIĆ, Dragan MILJANOVIĆ Rail Cargo Carrier-Croatia, Zagreb, Croatia	181

The Graduates and the Future of Railway

7.1.	MAAS IN EU RESEARCH PROJECTS FOR A BETTER POSITION OF RAILWAYS IN PROVIDING TRANSPORT SERVICES Student: Teodora MILENKOVIĆ Mentor: Branislav BOŠKOVIĆ Faculty of Transport and Traffic Engineering, Belgrade, Serbia	185
7.2.	PERFORMANCES AND INDICATORS OF THE RAILWAY SISTEM OF THE SERBIA IN THE TRANSPORT OF GOODS Student: Marija SELAKOVIĆ Mentor: Branislav BOŠKOVIĆ Faculty of Transport and Traffic Engineering, Belgrade, Serbia	187

7.3.	DETERMINATION OF BOTTLE-NECKS FOR THE BEOGRAD CENTAR-NOVI SAD-SUBOTICA RAILWAY THAT LED TO MODERNIZATION DEMAND	189
	Student: Milan JOVETIĆ	
	Mentor: Predrag JOVANOVIĆ	
	Faculty of Transport and Traffic Engineering, Belgrade, Serbia	
7.4.	RISK RATING IN THE TRANSPORT OF DANGEROUS GOODS	191
	Student: Stefan SREDOJEVIĆ	
	Mentor: Branislav BOŠKOVIĆ	
	Faculty of Transport and Traffic Engineering, Belgrade, Serbia	
7.5.	TECHNOLOGY AND PERFORMANCE INDICATORS OF NATIONAL AGENCIES AT BORDER CROSSINGS	193
	Student: Dalibor PETKOVSKI	
	Mentor: Branislav BOŠKOVIĆ	
	Faculty of Transport and Traffic Engineering, Belgrade, Serbia	

Index of authors



OPTIMIZATION OF THE SADDLE SUPPORT STRUCTURE OF THE FREIGHT WAGON TYPE SHIMMNS

Vladimir MILOVANOVIC¹

Aleksandar DIŠIĆ²

Nikola JOVANOVIĆ³

Miroslav ŽIVKOVIĆ⁴

Marko TOPALOVIC⁵

Abstract – This paper presents the optimization process of the saddle support structure of the freight wagon type Shimmns intended for the transportation of the sheet coils using the Finite Element Method. Analysis of the information about the similar wagons and their behavior in exploitation, reveals that there are common characteristic critical areas where the initial cracks occurs, and those are the welded joints in saddle support structure. Due the existence of coil sheets with different dimensions, the whole range of coil sheets is modelled to cover all possible load cases in according to standards. Based on the results of the initial analysis, it is concluded that the greatest impact on the crack formation in the critical area has the fatigue of the material in welded zone caused by the cyclic fatigue loads in vertical direction. After the reason has been established, reconstruction was done in such a way that prevents the occurrence of the cracks on a new wagon. With reconstruction completed, new wagon with the modified support structure was analyzed in accordance with appropriate standards in the freight wagon industry for all of the load cases. Results with optimized support structure showed improvement, especially of stress reduction in critical areas.

Keywords – Optimization, FEM, Freight Wagon, Fatigue, Coil Sheet

1. INTRODUCTION

The Shimmns wagons are used for transportation of the metal sheet coils (primarily steel), which can have different diameter, width, and subsequently mass, as well as different placement on the wagon saddles, therefore a wagon must be able to withstand a wide range of load cases set by the International Union of Railways (UIC). Particular standards used are TSI [1] and BS EN 12663-2 [2].

Numerical analysis for 134 load cases, according to standards [1] and [2] was performed using the Finite Element Method (FEM) [3]. FEMAP software [4] is used as pre and post-processor for the FEM mesh generation and display of the results. FEM analysis itself was done using NX Nastran solver, which is built in FEMAP. The initial results show that for all of the static load cases, wagon satisfies safety criteria, i.e. maximum calculated stresses are lower than permissible stress. However, according to

Eurocode 3 [5], in order to insure fatigue strength for important structural segments, permissible stress is reduced using the scale factor for safe life, and for some load cases, there are small areas of the wagon structure that have stress concentration above permissible limit, those spots are located in the characteristic welds of the saddle support structure. By analyzing similar wagons of the same type from other manufacturers and collecting the information about their behavior in exploitation, it is confirmed that these are common characteristic critical areas where the initial crack occurs.

Detail modelling of these zones is conducted, including mesh convergence testing in several iterations. Optimization performed in FEMAP reduces stresses in these areas, and the proposed modifications ensures safety in exploitation with minimal and cost effective changes in the wagon design.

¹ University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, vladicka@kg.ac.rs

² University of Kragujevac, Institute for Information Technologies, Jovana Cvijića bb, aleksandardisic@gmail.com

³ University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, ing.jovanovic.nikola@gmail.com

⁴ University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, zile@kg.ac.rs

⁵ University of Kragujevac, Institute for Information Technologies, Jovana Cvijića bb, topalovic@kg.ac.rs

2. THE SHIMMNS WAGON MODEL

A technical description of four-axle bogie wagon type Shimmns is given in [6]. The wagon is designed for transportation of sheets coils that are loaded in the horizontal position onto five cradles. Transported coils need to be protected from weather conditions as it can be seen in the Fig. 1.



Fig.1. Partially uncovered Shimmns wagon

The main characteristics of the Shimmns wagon, according to [6] are given in Tab. 1.

Tab. 1. Technical data of wagon type Shimmns

Track width	1435mm
Gauge	TSI G1
Number of wheelsets	4
Length over buffers	12040mm
Central bolts distance between	7000mm
Load opening width	2400mm
Wagon height from the rail	~4275mm
Tare weight	22t±2%
Max. cargo weight	68t
Max. axle load	22.5t
Max. speed (empty/loaded)	120/100km/h
Bogie type	Y25 Lsi(f) - C
The smallest curve radius	35m

Technical drawing, and FEM model of Shimmns wagon are shown in Fig. 2. and Fig. 3. respectively.

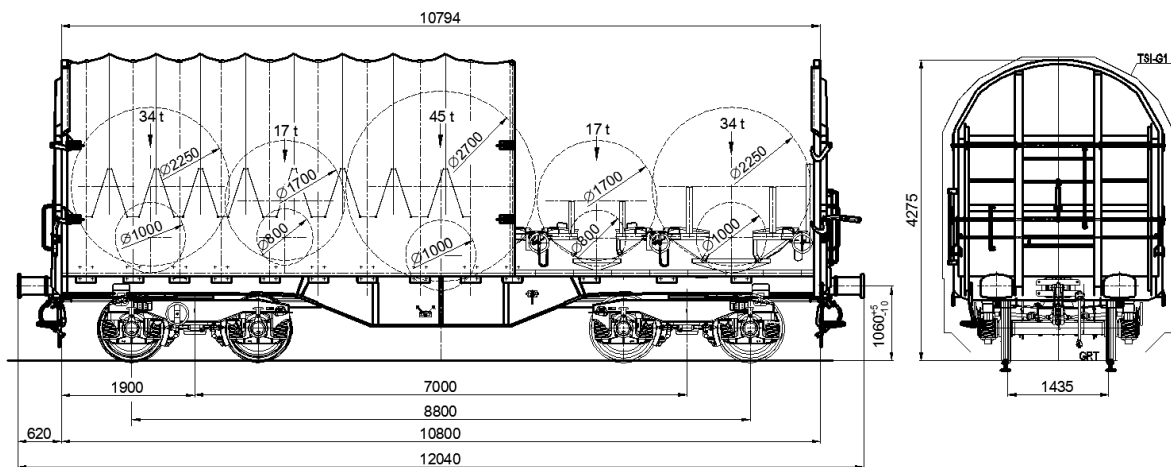


Fig.2. Technical drawing of Shimmns wagon

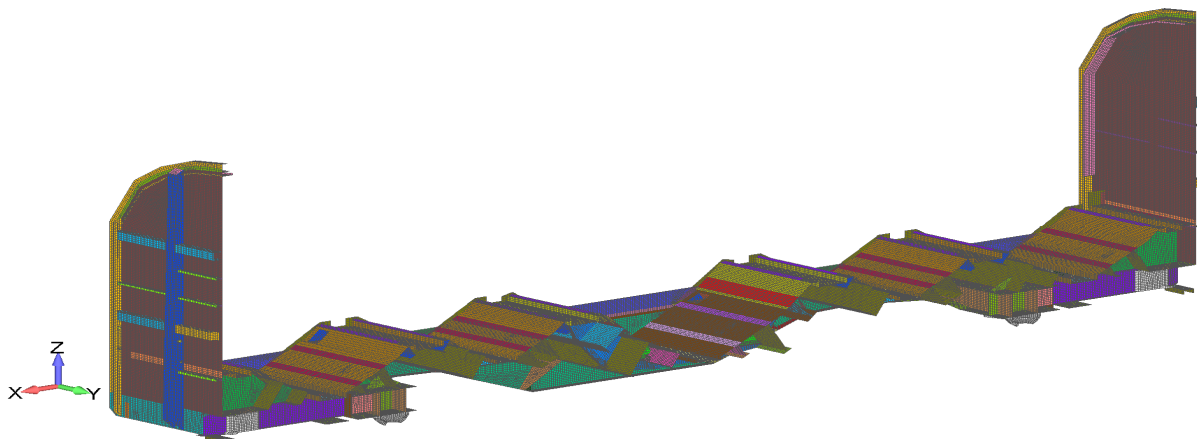


Fig.3. FEM model of Shimmns wagon

The FEM model is used to analyze wagon support structure, and does not include bogies, cover and other additional elements, which are represented in the model as loads and constraints. Due to symmetry, one half of the wagon is modeled in FEM. Shell elements of the appropriate thickness and 3D elements (for modeling of support elements) were used for creating the finite element mesh. The structure is modeled in details with 212991 elements and 218890 nodes and within the calculation there is a system of about one million and three hundred thousand equations being solved. General element side length is about 20 mm, with local mesh refinement in area of interest, (Fig. 4).

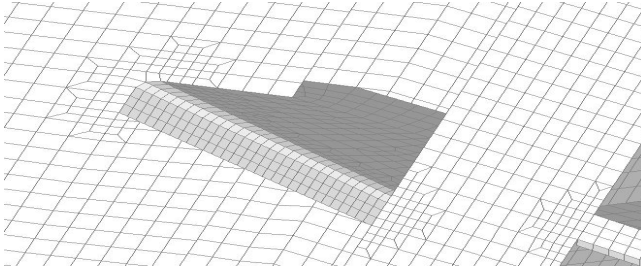


Fig.4. Mesh refinement around welded joints

The wagon is made of steel S355J2+N [6], with the following characteristics, shown in Tab. 2.

Tab. 2. S355J2+N material characteristics

Physical Characteristics		
E [N/mm ²]	ρ [kg/mm ³]	ν
$2.10 \cdot 10^5$	$7.85 \cdot 10^{-6}$	0.3
Mechanical Characteristics		
R _e [N/mm ²]	R _m [N/mm ²]	KV [J] ¹
355	490-630	27

The Table 3 shows range of diameters and weight of the steel coils for each cradle [5].

Tab. 3. Maximum loading of the cradle and dimensions of the steel coils

Cradle no.	Coil diameter [mm]	Load [t]
1	1000 – 2250	34
2	800 – 1700	17
3	1000 – 2700	45
4	800 – 1700	17
5	1000 – 2250	34

Total weight of steel coils that one wagon can carry is 68 tons (see Tab. 1.) and this weight can be attained using the combination of different diameter and width of the coils shown in Tab. 3.

¹ KV – material fracture toughness at -20°C

Not all combinations are simulated, instead the focus was on boundary cases with the maximum width or maximum diameter of coils as it is assumed they are most critical. For these extremes, we analyzed different combination of coil size and placement, examples of some considered load cases are shown in Fig. 5 and Fig. 6.

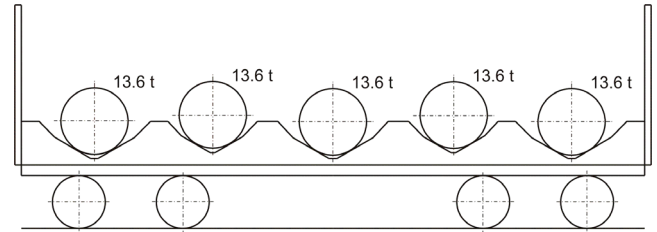


Fig.5. Evenly distributed load on all 5 cradles

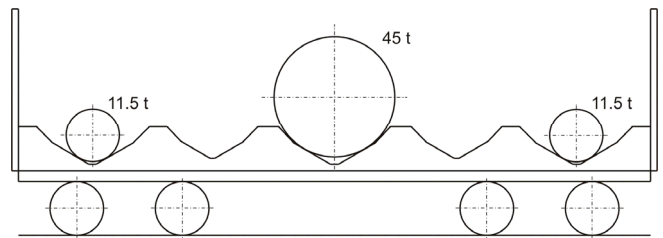


Fig.6. Big coil in the middle. smaller on front and back cradle

These are just 2 examples of the vertical load scenarios, which are analyzed for both maximum width and maximum diameter cases. The final report also includes longitudinal load cases for buffers and the coupling areas, lifting, jacking, as well as load combinations and service fatigue loads. In total 134 load cases were analyzed, and since the initial shape failed to meet safety criteria for some load cases, several iterations were made until final design was obtained.

These changes were performed using engineering experience and FEM analysis in FEMAP, adopting the different design approaches, adding the reinforcement ribs, for example.

3. OPTIMIZATION USING FEMAP AND EXPERIENCE

3 types of optimization are shown in Fig. 7.

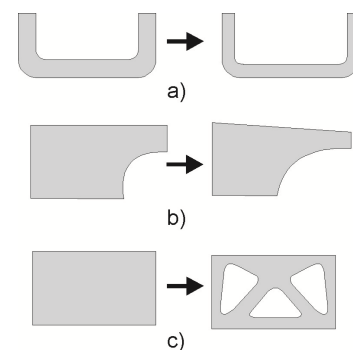


Fig.7. Different optimization types: a) parametric; b) shape; c) topology

Parametric optimization changes only properties of the structures while the geometry remains the same, this primarily means changing the plate thickness until the stress is reduced below permissible levels [1]. This optimization improved overall behavior of wagon for certain load cases, however, dynamic loads, such as buffing test and loading, create stress concentration in small areas, that needed to be addressed differently.

Shape optimization changes dimensions and layout of existing features, and it is more complex since it requires changes in FEM mesh, so it's usually done only when necessary. We used the shape optimization for the wagon design to alleviate the stress concentration.

Topology optimization implies the creation of the new features, mostly free shape openings for even stress distribution, but in this case, added features are strengthening ribs and plates.

4. OPTIMIZATION RESULTS

In this section we will show design improvements and stress reduction achieved by the optimization. In Fig. 8. the actual crack on a wagon in exploitation is shown. FEM model of the initial design is shown in Fig. 9., and the new optimized model in Fig. 10. Von Misses stress for the vertical load shown in Fig. 5., for central saddle support structure, viewed from below the wagon is shown in Fig. 9. and Fig. 10.



Fig.8. Crack in the welded joint on the actual wagon

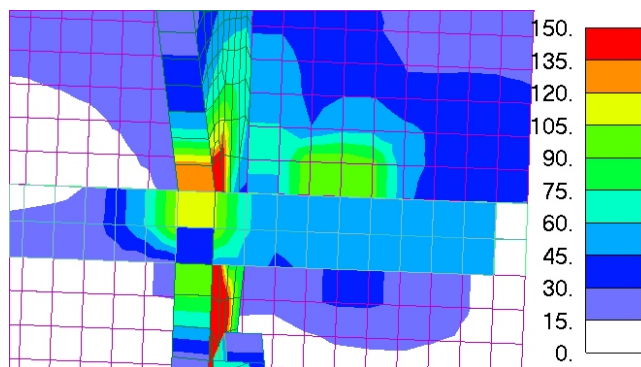


Fig.9. Stress concentration in the initial model

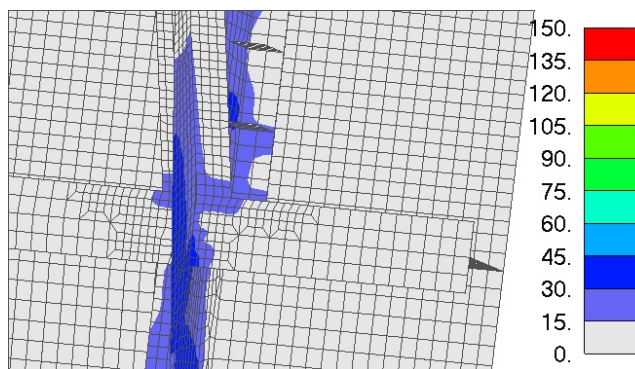


Fig.10. Stress reduction in the optimized design

As it can be seen from Fig. 10., mesh needed to be refined, U profile bar (bottom of Fig. 8. and Fig. 9.) was removed, and strengthening ribs were added in the final model.

5. CONCLUSION

The purpose of this paper is to demonstrate the methodology used for the analysis of fatigue crack formation, and reconstruction of wagon structure which will prevent recurrence of the cracks in the refurbished wagons, and to make the new wagons impervious to cracks. The analysis was conducted for 134 load cases, according to the standards defined in [1],[2] and during the process of design improvement, several iterations of mesh refinement and geometry changes were made resulting in an optimized wagon which satisfy all safety criteria and is more resilient to fatigue crack formation.

ACKNOWLEDGEMENT

This research is supported by the Ministry of Education, Science and Technological Development, Republic of Serbia, Grants TR32036 and 451-03-68/2020-14/200378.

REFERENCES

- [1] 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.
- [2] BS EN 12663-2:2010 - Railway applications – Structural requirements of railway vehicle bodies, Part 2: Freight wagons, European Standard.
- [3] Kojić, M., Slavković, R., Živković, M., Grujović, N., Finite Element Method I - Linear Analysis (in Serbian), Faculty of Mechanical Engineering, University of Kragujevac, Serbia, 1998.
- [4] Femap with NX Nastran user manual.
- [5] Eurocode 3: Design of steel structures Part 1.9: Fatigue
- [6] Technical description of the Shimmns wagon.pdf