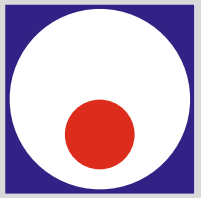




FACULTY OF MECHANICAL AND CIVIL ENGINEERING
IN KRALJEVO
UNIVERSITY OF KRAGUJEVAC



XI TRIENNIAL
INTERNATIONAL CONFERENCE
**HEAVY
MACHINERY**
HM 2023
Proceedings

VRNJAČKA BANJA, SERBIA
June 21– June 24, 2023



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

THE ELEVENTH TRIENNIAL INTERNATIONAL CONFERENCE

**HEAVY MACHINERY
HM 2023**

PROCEEDINGS

ORGANIZATION SUPPORTED BY:

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

Vrnjačka Banja, June 21–24, 2023



PUBLISHER:

Faculty of Mechanical and Civil Engineering in Kraljevo

YEAR:

2023

EDITOR:

Prof. dr Mile Savković

PRINTOUT:

SATCIP DOO VRNJAČKA BANJA

TECHNICAL COMMITTEE

Doc. dr Aleksandra Petrović – Chairman

Bojan Beloica – Vice-chairman

Miloš Adamović

Goran Bošković

Vladimir Đorđević

Marina Ivanović

Marijana Janićijević

Aleksandar Jovanović

Stefan Mihajlović

Predrag Mladenović

Stefan Pajović

Anica Pantić

Nevena Petrović

Mladen Rasinac

Vladimir Sinđelić

Marko Todorović

Đorđe Novčić

Jovana Bojković

Tanja Miodragović

Jovana Perić

Slobodan Bukarica

No. of copies: 60

ISBN-978-86-82434-01-6

REVIEWS:

All papers have been reviewed by members of scientific committee



CONFERENCE CHAIRMAN

Prof. dr Mile Savković, FMCE Kraljevo, Serbia

INTERNATIONAL SCIENTIFIC PROGRAM COMMITTEE

CHAIRMAN

Prof. dr Radovan Bulatović, FMCE Kraljevo, Serbia

VICE-CHAIRMAN

Prof. dr Milan Bižić, FMCE Kraljevo, Serbia

MEMBERS

Prof. dr M. Alamoreanu, TU Bucharest, Romania

Prof. dr D. Atmadzhova, VTU “Todor Kableskov”, Sofia, Bulgaria

Prof. dr M. Banić, FME Niš, Serbia

Prof. dr M. Berg, Royal Institute of Technology-KTH, Sweden

Prof. dr G. Bogdanović, Faculty of Engineering Kragujevac, Serbia

Prof. dr H. Bogdevicius, Technical University, Vilnius, Lithuania

Prof. dr N. Bogojević, FMCE Kraljevo, Serbia

Prof. dr I. Božić, FME Belgrade, Serbia

Prof. dr S. Bikić, Faculty of Technical Sciences, Novi Sad, Serbia

Prof. dr M. Bjelić, FMCE Kraljevo, Serbia

Prof. dr M. Blagojević, Faculty of Engineering Kragujevac, Serbia

Prof. dr S. Bošnjak, FME Belgrade, Serbia

Prof. dr A. Bruja, TU Bucharest, Romania

Prof. dr S. Ćirić-Kostić, FMCE Kraljevo, Serbia

Prof. dr I. Despotović, FMCE Kraljevo, Serbia

Prof. dr M. V. Dragoi, Transilvania University of Brasov, Romania

Prof. dr B. Dragović, Faculty of Maritime Studies Kotor, Montenegro

Prof. dr Lj. Dubonjić, FMCE Kraljevo, Serbia

Prof. dr R. Durković, FME Podgorica, Montenegro

Prof. dr Z. Đinović, ACMIT, Wiener Neustadt, Austria

Prof. dr R. Đokić, Faculty of Technical Sciences, Novi Sad, Serbia

Prof. dr K. Ehmann, Northwestern University, Chicago, USA

Prof. dr I. Emeljanova, HGTUSA Harkov, Ukraine

Prof. dr O. Erić Cekić, FMCE Kraljevo, Serbia

Prof. dr V. Gašić, FME Belgrade, Serbia

Prof. dr D. Golubović, FME East Sarajevo, Bosnia and Herzegovina

Prof. dr P. Gvero, FME Banja Luka, Bosnia and Herzegovina

Prof. dr B. Jerman, FME Ljubljana, Slovenia

Prof. dr R. Karamarković, FMCE Kraljevo, Serbia

Prof. dr M. Karasahin, Demirel University, Istanbul, Turkey

Prof. dr I. Kiričenko, HNADU Kiev, Ukraine

Prof. dr K. Kocman, Technical University of Brno, Czech Republic

Prof. dr S. Kolaković, Faculty of Technical Sciences, Novi Sad, Serbia

Prof. dr M. Kolarević, FMCE Kraljevo, Serbia

Prof. dr M. Kostić, Northern Illinois University, DeKalb, USA

Prof. dr M. Krajišnik, FME East Sarajevo, Bosnia and Herzegovina

Prof. dr M. Králik, FME Bratislava, Slovakia

Prof. dr E. Kudrjavcev, MGSU, Moscow, Russia

Prof. dr Đ. Lađinović, Faculty of Technical Sciences, Novi Sad, Serbia

Prof. dr D. Marinković, TU Berlin, Germany

Prof. dr G. Marković, FMCE Kraljevo, Serbia

Prof. dr A. Milašinović, FME Banja Luka, Bosnia and Herzegovina

Prof. dr I. Milićević, Technical Faculty Čačak, Serbia

Prof. dr V. Milićević, FMCE Kraljevo, Serbia

Prof. dr Z. Miljković, FME Belgrade, Serbia



Prof. dr D. Milković, FME Belgrade, Serbia
Prof. dr B. Milošević, FMCE Kraljevo, Serbia
Prof. dr V. Milovanović, Faculty of Engineering Kragujevac, Serbia
Prof. dr G. Minak, University of Bologna, Italy
Prof. dr D. Minić, FME Kosovska Mitrovica, Serbia
Prof. dr V. Nikolić, FME Niš, Serbia
Prof. dr E. Nikolov, Technical University, Sofia, Bulgaria
Prof. dr V. Nikolov, VTU “Todor Kableshkov”, Sofia, Bulgaria
Prof. dr M. Ognjanović, FME Belgrade, Serbia
Prof. dr J. Peterka, FMS&T, Trnava, Slovakia
Prof. dr D. Petrović, FMCE Kraljevo, Serbia
Prof. dr M. Popović, Technical Faculty Čačak, Serbia
Prof. dr J. Polajnar, BC University, Prince George, Canada
Prof. dr D. Pršić, FMCE Kraljevo, Serbia
Prof. dr N. Radić, FME East Sarajevo, Bosnia and Herzegovina

Prof. dr B. Radičević, FMCE Kraljevo, Serbia
Prof. dr V. Radonjanin, Faculty of Technical Sciences, Novi Sad, Serbia
Prof. dr D. Sever, Maribor, Civil Engineering, Slovenia
Prof. dr V. Stojanović, FMCE Kraljevo, Serbia
Prof. dr I. S. Surovcev, VGSU, Voronezh, Russia
Prof. dr S. Šalinić, FMCE Kraljevo, Serbia
Prof. dr J. Tanasković, FME Belgrade, Serbia
Prof. dr LJ. Tanović, FME Belgrade, Serbia
Prof. dr D. Todorova, VTU “Todor Kableshkov”, Sofia, Bulgaria
Prof. dr R. Vujadinovic, FME Podgorica, Montenegro
Prof. dr K. Weinert, University of Dortmund, Germany
Prof. dr N. Zdravković, FMCE Kraljevo, Serbia
Prof. dr N. Zrnić, FME Belgrade, Serbia
Prof. dr D. Živanić, Faculty of Technical Sciences, Novi Sad, Serbia

ORGANIZING COMMITTEE

CHAIRMAN:

Prof. dr Goran Marković, FMCE Kraljevo

VICE-CHAIRMAN:

Doc. dr Miljan Marašević, FMCE Kraljevo, Serbia

MEMBERS:

Doc. dr M. Bošković, FMCE Kraljevo, Serbia
Doc. dr V. Grković, FMCE Kraljevo, Serbia
Doc. dr V. Mandić, FMCE Kraljevo, Serbia
Doc. dr A. Nikolić, FMCE Kraljevo, Serbia
Doc. dr M. Nikolić, FMCE Kraljevo, Serbia

Doc. dr A. Petrović, FMCE Kraljevo, Serbia
Doc. dr B. Sredojević, FMCE Kraljevo, Serbia
Dr N. Pavlović, FMCE Kraljevo, Serbia
Doc. dr N. Stojić, FMCE Kraljevo, Serbia

PLENARY SESSION

WAREHOUSING 4.0 Boris Jerman, Jurij Hladnik	1
DEVELOPMENT OF A DOMESTIC 4-AXIS SCARA ROBOT Zoran Miljković, Nikola Slavković, Bogdan Momčilović, Đorđe Milićević	9
30 YEARS OF THE INTERNATIONAL SCIENTIFIC CONFERENCE "HEAVY MACHINERY" Mile Savković, Goran Marković, Milan Bižić, Nataša Pavlović	17

SESSION A: EARTH-MOVING AND TRANSPORTATION MACHINERY

STRENGTH OF FILLET-WELDED JOINT CONNECTIONS: COMMENTS ON CORRELATION BETWEEN CLASSICAL AND PARTICULAR FINITE ELEMENT APPROACH Vlada Gašić, Aleksandra Arsić, Nenad Zrnić	1
CONTINUOUSLY VARIABLE TRANSMISSION FOR CONSTRUCTION MACHINES TO INCREASE EFFICIENCY AND PRODUCTIVITY Jasna Glišović, Vanja Šušteršič, Jovanka Lukić, Saša Vasiljević	9
ARTIFICIAL INTELLIGENCE (AI) AND THE FUTURE OF THE MACHINE ELEMENTS DESIGN Marko Popović, Nedeljko Dučić, Vojislav Vujičić, Milan Marjanović, Goran Marković	17
A STUDY OF EMERGING TECHNOLOGIES SCHEDULING AT CONTAINER TERMINALS USING CONCEPTUAL MAPPING Branislav Dragović, Nenad Zrnić, Andro Dragović	23
FEM RECOMMENDATION FOR SHUTTLE RACKING TOLERANCES AND CLEARANCES Rodoljub Vujanac, Nenad Miloradovic, Snezana Vulovic	29
COMPARATIVE ANALYSIS OF A LARGE SPAN GANTRY CRANE STRUCTURE SUBJECTED TO SKEWING FORCE CALCULATED USING JUS AND EUROCODE 1 STANDARDS Marko Todorović, Goran Marković, Nebojša Zdravković, Mile Savković, Goran Pavlović	37
THE OPTIMIZATION OF THE LOADING RAMP MECHANISM OF A HEAVY-WEIGHT TRAILER Predrag Mladenović, Radovan Bulatović, Nebojša Zdravković, Mile Savković, Goran Marković, Goran Pavlović	45
MULTI-AISLE AUTOMATED RACK WAREHOUSE SIMULATION FOR AVERAGE TRAVEL TIME Goran Bošković, Marko Todorović, Goran Marković, Zoran Čepić, Predrag Mladenović	53
FRAMEWORK AND REASONABLENESS OF APPLICATING THE CONCEPT OF CRANE STRUCTURAL HEALTH MONITORING IN INLAND WATER HARBOURS Atila Zelić, Ninoslav Zuber, Dragan Živanić, Mirko Katona, Nikola Ilanković	59
MEASURING THE KINEMATIC CHARACTERISTICS ON A REDUCED-SIZE ZIPLINE MODEL Tanasije Jojić, Jovan Vladić, Radomir Đokić	67

TESTING OF CONVEYOR BELTS AND FORMATION OF VERIFICATION MODEL USING FEM Dragan Živanić, Nikola Ilanković, Nebojša Zdravković	73
ANALYSIS HYBRID DRIVES OF MOBILE MACHINES Vesna Jovanović, Dragoslav Janošević, Jovan Pavlović	81
DETERMINATION OF RESISTANCE FORCES IN THE WHEEL LOADER USING DISCRETE ELEMENT METHOD Jovan Pavlović, Dragoslav Janošević, Vesna Jovanović, Nikola Petrović	87
A HYBRID MCDM MODEL FOR WASTE OIL TRANSFER STATION LOCATION SELECTION Jelena Mihajlović, Goran Petrović, Danijel Marković, Dragan Marinković, Žarko Čojbašić, Dušan Ćirić	93

SESSION B: RAILWAY ENGINEERING

PROOF TESTS OF GEOMETRIC-KINEMATIC CALCULATIONS OF RAILWAY VEHICLES Dragan Milković, Goran Simić, Vojkan Lučanin, Saša Radulović, Aleksandra Kostić Miličić	1
NETWORK MODEL AND VIBRATION SIMULATION OF A RAILWAY TRACK Mustafa Berkant Selek, Erol Uyar, Mücahid Candan	7
VIBRATION MEASUREMENT WITH WIRELESS HETEROGENEOUS INTEGRATED DISPLACEMENT SENSOR AND DETERMINATION OF DYNAMIC DEFLECTION OF SLEEPERS AND STIFFNESS OF RAILWAY TRACKS Branislav Gavrilović, Vladimir Aleksandrovich Baboshin, Zoran Pavlović	13
STUDY OF THE CONTACT BETWEEN DESIGN PROFILES OF RAILS AND RIMS USED IN THE TRAM TRACK OF THE CITY OF SOFIA Vladimir Zhekov	19
INVESTIGATION OF THE BEHAVIOUR OF A FREIGHT WAGON BRAKING SYSTEM ON A BRAKE SYSTEMS BENCH Vasko Nikolov, Georgi Nikolov	25
TECHNICAL CONDITION OF RAILWAY VEHICLES AS A SAFETY FACTOR IN TRAFFIC Marija Vukšić Popović, Jovan Tanasković, Ivan Krišan	33
REQUIREMENTS OF UIC STANDARDS FOR BRAKE TRIANGLES OF RAILWAY VEHICLES Milan Bižić, Dragan Petrović	39
APPLICATION OF METAL-RUBBER ELEMENTS IN THE SPRING SUSPENSION OF ROLLING STOCK Emil Kostadinov, Nencho Nenov	45
DEVELOPMENT OF LABORATORY FOR TESTING OF RAILWAY VEHICLES AND STRUCTURES Dragan Petrović, Milan Bižić	55
CHALLENGES FOR TECHNICAL SPECIFICATIONS FOR INTEROPERABILITY (TSI) IN THE EUROPEAN UNION (EU) Miltcho Lepoev	61

DETERMINING THE PARAMETERS FOR PERFORMING PUBLIC PASSENGER RAIL TRANSPORT OF THE CARRIERS	65
Mirena Todorova, Kostadin Trifonov	
POSSIBILITY OF REPLACING LOW-CARBON STRUCTURAL STEEL WITH HIGH-STRENGTH STEELS, FOR PRODUCING WELDED STRUCTURES IN INDUSTRY OF HEAVY MACHINES	71
Đorđe Ivković, Dušan Arsić, Radun Vulović, Vukić Lazić, Aleksandar Sedmak, Srbišlav Aleksandrović, Milan Đorđević	
INVESTIGATION OF THE OCCURRENCE OF FAILURES IN THE AXLE BOX AND PRIMARY SPRING SUSPENSION OF PASSENGER BOGIES	79
Vanio Ralev	
APPLICATION OF AGILE PROJECT MANAGEMENT METHODOLOGY IN RAILWAY TRANSPORT	89
Irena Petrova, Dimitar Dimitrov	
COMPARATIVE ANALYSIS OF THE EFFECT OF LATERAL SWINGING OF THE TRAM BODY ON DIFFERENT TYPES OF ELECTRICAL CURRENT COLLECTORS	95
Emil M. Mihaylov, Emil Iontchev, Rosen Miletiev, Metodi Atanasov, Rashko Vladimirov	
A SENSOR NETWORK-BASED MODEL FOR INCREASING SAFETY ON HIGH-SPEED RAILWAYS	101
Zoran G. Pavlović, Veljko Radičević, Branislav Gavrilović, Marko Bursać, Miloš Milanović	
METHODOLOGY FOR CALCULATING THE PROCESS OF EMERGENCY COLLISION IN RAILWAY VEHICLES	109
Venelin Pavlov	
 SESSION C: PRODUCTION TECHNOLOGIES	
ADDITIVE MANUFACTURING – A VIEW THROUGH THE PRISM OF STANDARDIZATION	1
Pavle Ljubojević, Tatjana Lazović, Snežana Ćirić-Kostić	
ANALYSIS OF SPECIFIC CUTTING ENERGY IN LONGITUDINAL TURNING OF UNALLOYED STEELS	7
Milan Trifunović, Miloš Madić	
STATE OF THE ART IN THE FIELD OF COLD FORGING TOOLS	13
Ilija Varničić, Miloš Pjević, Mihajlo Popović	
APPLICATION OF THE POKA-YOKE METHOD IN SMALL WOOD PROCESSING COMPANIES	19
Jovana Perić, Milovan Lazarević, Mitar Jocanović, Vladan Grković, Mišo Bjelić	
DEVELOPMENT A SYSTEM FOR DESIGNING OPTIMAL TECHNOLOGICAL PROCESSING PARAMETERS AT MACHINING CENTERS	27
Zvonko Petrović, Milan Kolarević, Radovan Nikolić, Milica Tufegdžić, Nikola Beloica	
APPLICATION OF THE ANFIS METHOD TO SUPPORT DECISION-MAKING IN THE PREDICTION OF THE FACTORS THAT MOST INFLUENCE THE PRODUCT PRICE	33
Marija Mojsilović, Radoje Cvejić, Goran Miodragović, Snežana Gavrilović, Selver Pepić	
SUPPLEMENTARY ELEMENTS OF TRAFFIC NOISE BARRIERS	39
Vladan Grković, Violeta Đorđević, Milan Kolarević, Branko Radičević, Tanja Miodragović	

IDENTIFICATION OF NOISE SOURCE BASED ON SOUND INTENSITY IN VERTICAL CNC MILLING MACHINE	45
Tanja Miodragović, Branko Radičević, Stefan Pajović, Nenad Kolarević, Vladan Grković	
SURFACE TREATMENTS FOR TRAFFIC NOISE BARRIERS	51
Violeta Đorđević, Jovana Perić, Tanja Miodragović, Stefan Pajović, Mladen Rasinac	
COMPARISON OF MECHANICAL BEHAVIOUR OF TIG AND MIG WELDED JOINT DISSIMILAR ALUMINUM ALLOYS 2024 T351 AND 6082 T6	57
Dragan Milčić, Miodrag Milčić, Tomaž Vuherer, Aleksija Đurić, Nataša Zdravković, Andreja Radovanović	
TAGUCHI-BASED DETERMINATION OF DOUBLE-ELLIPSOIDAL HEAT SOURCE PARAMETERS FOR NUMERICAL SIMULATIONS OF GMAW PROCESS	63
Mišo Bjelić, Mladen Rasinac, Aleksandra Petrović, Marina Ivanović, Jovana Perić	
OPTIMIZATION OF GMA WELDING PARAMETERS USING THE GRASSHOPPER OPTIMIZATION ALGORITHM	69
Mladen Rasinac, Mišo Bjelić, Aleksandra Petrović, Marina Ivanović, Stefan Pajović	

SESSION D: AUTOMATIC CONTROL AND FLUID TECHNIQUE

EVENT-TRIGGERED ADAPTIVE DYNAMIC PROGRAMMING BASED OPTIMAL CONTROL FOR HYDRAULIC SERVO ACTUATOR	1
Vladimir Djordjević, Vladimir Stojanović, Hongfeng Tao, Xiaona Song, Shuping He, Weinan Gao	
DESIGN AND IMPLEMENTATION OF AN AEROPENDULUM CONTROLLER VIA LOOP SHAPING	7
Luka Filipović, Milan Ristanović, Dušan Božić	
H^∞ CONTROL OF AEROPENDULUM	15
Dušan Božić, Luka Filipović, Milan Ristanović	
ANALYSIS OF THE CURRENT SITUATION IN SERBIA RELATED TO THE EDUCATION IN THE FIELD OF APPLIED ARTIFICIAL INTELLIGENCE	21
Anđela Đorđević, Marko Milojković, Miodrag Spasić, Dejan Rančić, Saša S. Nikolić, Miroslav Milovanović	
CONCEPTUAL MODELING OF HYSTERESIS IN PIEZO CRYSTALS USING NEURAL NETWORKS	27
Lazar Kelić, Dragan Pršić	
ADVANCED ELECTRO-HYDRAULIC SYSTEMS FOR DRIVING THE MOVEMENT OF RADIAL GATES	31
Dragan Nauparac	
MODELING AND SIMULATION HYDRAULIC EXCAVATOR'S ARM	39
Almir Osmanović, Elvedin Trakić, Salko Ćosić, Mirza Bećirović	

SESSION E: APPLIED MECHANICS

INFLUENCE ON THE SUPPORT RESISTANCE OF A MOBILE PLATFORM DUE TO THE EFFECT OF HIGH-INTENSITY IMPULSIVE FORCE	1
Aleksandra B. Živković, Slobodan R. Savić, Nebojša P. Hristov, Damir D. Jerković,	

Andjela G. Mitrović, Marija V. Milovanović, Lazar M. Arsić

METHODS FOR MODELING BOLTED CONNECTIONS USING FEM 7
Vladimir Milovanović, Miloš Pešić, Rodoljub Vujanac, Marko Topalović, Milan Stojiljković

OPTIMAL DYNAMIC BALANCING OF PLANAR MECHANISMS: AN OVERVIEW 15
Marina Bošković

MODIFIED 2D ARC-STAR-SHAPED STRUCTURE WITH NEGATIVE POISSON'S RATIO 21
Vladimir Sinđelić, Aleksandar Nikolić, Nebojša Bogojević, Olivera Erić Cekić,
Snežana Ćirić Kostić

SESSION F: THERMAL TECHNIQUE AND ENVIRONMENT PROTECTION

CARBON DIOXIDE EMISSIONS CALCULATION OF THE TRANSPORT PROCESS IN ROAD FREIGHT TRANSPORT 1
Nikola Petrović, Vesna Jovanović, Dragan Marinković, Jovan Pavlović

POLLUTANTS IN THE AIR 7
Svetlana K. Belošević, Maja B. Djukić

DETERMINATIONS OF EQUATION IN 1D CONDUCTION: EXPERIMENTAL INVESTIGATION FOR WALL HEATING 13
Aleksandar Vičovac

THE PROPOSAL OF THE RECUPERATOR DESIGN FOR THE ROTARY KILNS WITH A DRIVING MECHANISM IN THE CALCINATION ZONE 21
Nenad Stojić, Nebojša Bogojević, Miljan Marašević, Dragan Cvetković, Aleksandar Nešović

THE USAGE OF NATURAL GAS HHV FROM SMALL COGENERATION SYSTEMS IMPLEMENTED IN A 3RD GENERATION DH PLANT 27
Milan Marjanović, Miloš Nikolić, Rade Karamarković, Anđela Lazarević, Đorđe Novčić

SESSION G: CIVIL ENGINEERING

MASONRY DEVELOPMENT OF BUILDING CONSTRUCTION ON THE TERRITORY OF SERBIA 1
B.Milosevic, V. Mandić, D. Turina, A. Kostić, K. Krstić

KRIGING INTERPOLATION OF PRECIPITATION FOR LAKE ĆELIJE CATCHMENT 9
V. Mandić, S. Kolaković, M. Stojković, B. Milošević, I. Despotović

MANUFACTURING TECHNOLOGIES FOR GFRP'S WITH THERMOSETTING POLYMERIC BINDERS 17
C. Sescu-Gal, C. Frâncu, C. Dobrescu, P. Bălan

METHODS FOR DETERMINING THE CHARACTERISTICS OF BIOCOMPOSITES 23
J. Bojković, V. Bulatović, B. Radičević, N. Stojić, M. Mrašević

STATIC ANALYSIS OF THE RC MULTI-STOREY BUILDING DEPENDING ON MODEL AND SOIL PARAMETERS 29
S. Mihajlović, M. Šešljija, V. Mandić, I. Despotović, M. Janićijević

Influence on the support resistance of a mobile platform due to the effect of high-intensity impulsive force

Aleksandra B. Živković^{1*}, Slobodan R. Savić¹, Nebojša P. Hristov², Damir D. Jerković², Andjela G Mitrović¹, Marija V Milovanović³, Lazar M Arsić³

¹Faculty of Engineering, University of Kragujevac, Serbia
²Military Academy, University of Defence, Belgrade, Serbia
³Military Technical Institute, Belgrade, Serbia

In this study, a Finite Element Method (FEM) analysis was performed to evaluate the support resistance of a vehicle's chassis under the effect of a high-intensity, impulsive force of very short duration. The FEM model of the chassis was created, and material properties were defined to simulate the actual scenario. The model was subjected to the impulsive force, and the results were analysed to determine the support resistance of the vehicle's base. The findings of the analysis can help enhance the structural integrity of the vehicle's chassis under impulsive loading conditions, thus improving the safety and reliability of the vehicle. In conclusion, the study provides valuable insights into the support resistance of a vehicle's chassis under impulsive loading conditions. The results of the analysis can help improve the design and performance of the vehicle's base, ensuring the safety and reliability of the vehicle under different loading conditions.

Keywords: Simulation, FEM, Support Resistance

1. INTRODUCTION

System stability is an important aspect of vehicle design, particularly in heavy-duty vehicles and mobile platforms. The resistance offered by the support structure of the vehicle is a critical factor that affects its stability and performance under different loading conditions. In this context, the development of mathematical and mechanical models to determine the support resistance of a vehicle's base is essential for ensuring its stability and reliability.

The main objective of this study is to establish a mathematical and mechanical model to evaluate the stability of the mobile wheel platform of a vehicle. To accomplish this objective, Finite Element Method (FEM) analysis was conducted to simulate the impact of an impulsive force on the vehicle's chassis [1, 2].

Figure 1 depicts the schematic of the vehicle with the forces acting on its chassis, along with the support resistances that the vehicle experiences due to the impact force. The support structure of the vehicle is critical to ensuring its stability and reliability under varying loading conditions. The impulsive force acting on the vehicle's base causes stresses and strains that influence the performance of the vehicle. Therefore, it is vital to evaluate the support resistance offered by the vehicle's base to ensure its stability and prevent any damage or failure of the vehicle's structure.

The schematic in Figure 1 shows the different forces acting on the vehicle, including the inertial force, the reaction force, and the weight force. These forces induce stress and strain in the support structure, leading to deformations and potential damage to the vehicle. However, the support resistance of the vehicle's base provides the necessary stability to counteract the forces and maintain the vehicle's structural integrity. Therefore, it is essential to determine the support resistance of the vehicle's base under varying loading conditions, including impulsive forces, to ensure its stability and reliability.

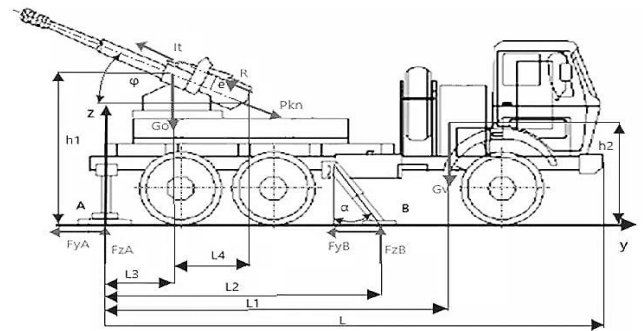


Figure 1: Vehicle with acting forces and support resistance

The forces acting on the vehicle as shown in Figure 1 are as follows: Pkn is the tractive force, It is the inertia force of the moving mass, R is the resistance force due to traction, Go is the weight force of the Pkn source, Gv is the weight force of the vehicle Nc, Nb is the longitudinal component of the reaction force of the support arms C and B, and Xc and Xb are the vertical components of the reaction force of the supports C and B.

In detail, Pkn represents the force exerted on the vehicle by the towing vehicle or the ground during acceleration, while It represents the force that resists the change in motion of the vehicle's recoiling mass. R is the force that opposes the motion of the vehicle due to the friction between the tires and the ground. Go is the force that results from the weight of the tractive force source acting on the vehicle. Gv is the weight force of the vehicle itself, which acts vertically downwards.

Furthermore, Nb and Nc are the reaction forces that occur at the contact points of the support arms B and C, respectively. Nb is the force acting in the longitudinal direction of the vehicle, while Nc acts vertically upwards. Xc and Xb are the components of the reaction force acting

*Corresponding author: Sestre Janjić 6, 34000 Kragujevac, e-mail: aleksandra.zivkovic.bm@gmail.com

vertically downwards due to the support arms C and B, respectively.

Understanding these forces and their magnitudes is essential in designing the vehicle's support structure to ensure stability and prevent failure or damage under impulsive loading conditions. The FEM analysis can help in evaluating the impact of these forces on the vehicle's base and optimize the support resistance to maintain the vehicle's structural integrity [3, 4].

In addition to the forces shown in Figure 1, geometric distances relative to the coordinate origin located at support A are also depicted. The angle φ represents the elevation angle of the forces P_{kn} , I_t , and R , while the angle ψ represents the direction angle of these forces.

2. THE MATHEMATICAL MODEL OF STABILITY

The mathematical model of stability for the FAP 2026 vehicle involves analysing the effects of forces acting on the vehicle's supports under the influence of a high-intensity, short-duration impulsive load. Due to the nature of the problem, certain limitations and assumptions need to be established before setting up the model. These include factors such as the structural properties and material behaviour of the vehicle, as well as the geometry and orientation of its components. Additionally, it is necessary to consider the dynamic effects of the impulsive load on the vehicle, including its magnitude, duration, and direction, as well as the response of the vehicle's supports to these forces [5]. By taking these limitations and assumptions into account, a more accurate and reliable mathematical model can be developed to analyse the stability of the vehicle:

1. The vehicle body is placed on a flat and horizontal surface.
2. Wheel support is excluded.
3. The point of action of the weight force G_o of the source P_{kn} is located on the axis of the source.
4. The last two wheels of the vehicle share a common axle, and the system behaves like a 4x4.
5. The system is considered as a rigid body placed on rigid supports, i.e., beams.
6. Two stability limit cases are considered: the effect of the tractive resistance force along the longitudinal axis of the vehicle and perpendicular to it.
7. The inertia and displacement of the vehicle's driving axles are neglected.
8. The platform on which the device is mounted is symmetric with respect to the longitudinal and vertical planes of symmetry of the vehicle.
9. The position of the centre of mass of supported parts does not change during the movement of the recoiling mass.

The simplified mathematical-mechanical models of the lateral and longitudinal stability of the vehicle are shown in Figure 2 and Figure 1, respectively. All forces acting on the vehicle are marked on the figures, with their respective positions of action.

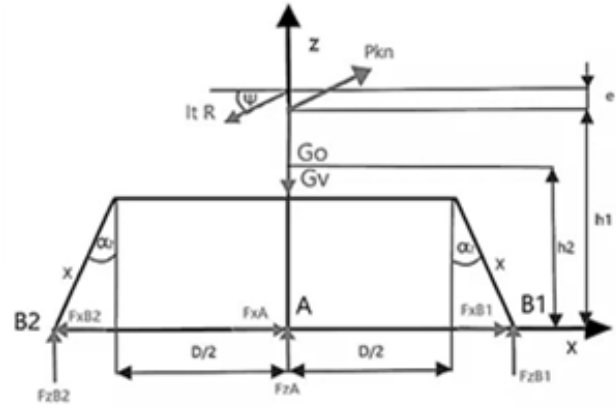


Figure 2: The model of the lateral stability of the vehicle

The equations of equilibrium for the longitudinal stability model, shown in Figure 1, are given in expressions 1, 2 and 3.

$$\sum y_i = R \cdot \cos \varphi - F_{yA} - F_{yB} = 0 \quad (1)$$

$$\sum z_i = F_{zA} + F_{zB} - R \cdot \sin \varphi - G_o - G_v = 0 \quad (2)$$

$$\sum M_A = P_{kn} \cdot \cos \varphi \cdot h_1 - R \cdot \cos \varphi \cdot h_1 - R \cdot \cos \varphi \cdot e + P_{kn} \cdot \sin \varphi \cdot L_3 - R \cdot \sin \varphi \cdot L_3 - P_{kn} \cdot \sin \varphi \cdot L_4 - G_o \cdot L_3 + F_{zB} \cdot L_2 - G_v \cdot L_1 = 0 \quad (3)$$

The equations of equilibrium for the lateral stability model, shown in Figure 2, are given by equations 4, 5 and 6.

$$\sum x_i = R \cdot \cos \psi + F_{xB1} - F_{xB2} + F_{xA} = 0 \quad (4)$$

$$\sum z_i = F_{zA} + F_{zB2} + F_{zB1} + R \cdot \sin \psi - G_o - G_v = 0 \quad (5)$$

$$\sum M_A = F_{zB1} \cdot (D/2 + x \cdot \sin \alpha_2) + P_{kn} \cdot e \cdot \cos \psi - R \cdot (h_1 + e) - F_{zB2} \cdot (D/2 + x \cdot \sin \alpha_2) = 0 \quad (6)$$

Table 1 presents the values of geometric and other variables depicted in Figures 1 and 2.

Table 1: Values of geometric and variables of the system

Mass of the P_{kn} source (mo):	1800 kg
Vehicle mass (mv):	16200 kg
Maximum value of the recoiling force (P_{knmax}):	3037.8244 kN
Maximum value of the resistance force (R_{max}):	173.09 kN
Acceleration due to gravity (g):	9.81 m/s ²
Total vehicle length (L):	7.720 m
X-coordinate of the vehicle's center of gravity (L_1):	5 m
Distance from support A to support B (L_2):	4 m
X-coordinate of the P_{kn} source center of gravity (L_3):	2.5 m
Distance from the center of gravity P_{kn} source to the its end (L_4):	0.400 m
Height of P_{kn} source in position (h_1):	1.420 m + 0.580 m = 2 m
Y-coordinate of the vehicle's center	1.2 m

of gravity (h2):	
Total vehicle width (D):	7.720 m
Length of arm B (x):	1.5 m
Elevation angle (φ):	-5°+70°
Heading angle (ψ):	-25°+25°
Angle of arm B in the longitudinal section (α1):	15°-20°
Angle of arm B in the transverse section (α2):	10°
Dynamic arm (e):	0.0005 m

3. DETERMINATION OF SUPPORT REACTION BY FEM ANALYSIS

The goal and essence of this work is FEM analysis of the resistance in the supports for 21 combinations of the direction angle and elevation angle of the Pkn force. For the purpose of this calculation, additional restrictions and assumptions were adopted through FEM analysis:

1. The force R and the force Pkn act in the same direction, and the value of e is neglected due to its small magnitude.
2. The weight force of the cause of the force Pkn is also neglected, as its value is much smaller compared to the force Pkn, the resistance force R, and the weight force of the vehicle Gv.

In addition to the above, it is necessary to find the unit vector of forces Pkn and R. As assumption 1 states that the forces act in the same direction, the unit vector for both of them is identical.

3.1. Determining the unit vector

The determination of the unit vector of the force Pkn and the resistance force R is performed in order to obtain the cosines of the angles, which are the input data in the computer simulation. The figure shows the action of forces Pkn and R in space, with respect to the coordinate system. The line OS represents the axis of the Pkn force generator. Point S represents the point of action of the force in space, while point S' represents its projection.

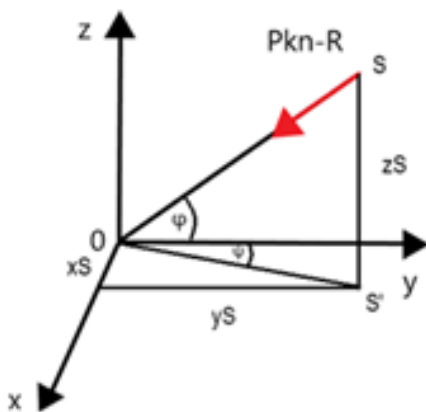


Figure 3: The spatial representation of the force action

The vector of the force is calculated based on equations 7, 8, 9, and 10.

$$\vec{OS} = \vec{r}_0 - \vec{r}_s \tag{7}$$

$$OS_x = x_s - x_0 \tag{8}$$

$$OS_y = y_s - y_0 \tag{9}$$

$$OS_z = z_s - z_0 \tag{10}$$

The magnitude of vector (OS) \vec{OS} is calculated based on equation 11.

$$|\vec{OS}| = \sqrt{OS_x^2 + OS_y^2 + OS_z^2} \tag{11}$$

The unit vector \vec{OS}_0 , whose direction coincides with the direction of forces Pkn and R, is calculated based on equation 12.

$$\vec{OS}_0 = \frac{\vec{OS}}{|\vec{OS}|} \tag{12}$$

The coefficients next to the vectors $i \vec{}$, $j \vec{}$, $k \vec{}$ represent the cosines of the angles that the unit vector makes with the x, y, and z axes. Table 2 shows all three components of the Pkn-R force, depending on the direction and elevation angles. The values from Table 2 represent input data in the FEM analysis model.

Table 2. Components of the Pkn-R force

Angles		Components of the Pkn-R force		
φ (°)	ψ (°)	X (N)	Y (N)	Z (N)
-5	-25	108428.1	812034.5	2745095
-5	0	0	812616.8	2747063
-5	25	-108428	812034.5	2745095
0	-25	379152.6	2839533	0
0	0	0	2864734	0
0	25	-379153	2839533	0
10	-25	-318964	-2388771	-1548786
10	0	0	-2403717	-1558476
10	25	318964	-2388771	-1548786
30	-25	58991.4	441795,7	-2829848
30	0	0	441889,4	-2830448
30	25	-58991.4	441795,7	-2829848
45	-25	200452.4	1501219	2431638
45	0	0	1504908	2437613
45	25	-200452	1501219	2431638
65	-25	-214544	-1606756	2361993
65	0	0	-1611281	2368645
65	25	214544.3	-1606756	2361993
70	-25	241394.2	1807839	2209106
70	0	0	1814291	2216991
70	25	-241394	1807839	2209106

3.2. FEM Analysis

The 3D model of the vehicle used for analysis consists of 10 nodes and 9 bars. To ensure that the model is statically determinate, the structure has been modified by adding a shell of 100 mm on each side of the bar. The simplified 3D model of the vehicle is shown in Figure 4. Using FEM analysis of the 3D model under the load of the force Gv and the difference of forces Pkn-R, the values of the support reaction at points A, B1 and B2 were obtained. The calculation was performed for 21 combinations of angles. The obtained results were used to optimize the design of the vehicle structure to ensure sufficient bearing resistance in the identified critical points.

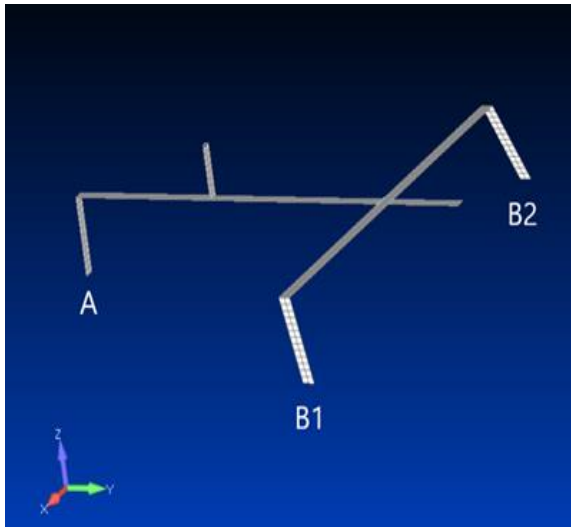


Figure 4: The 3D model of the vehicle

4. THE RESULTS

The results of the FEM analysis show the maximum support reaction force and the minimum support reaction force. These values were obtained for a specific combination of angles and elevations of the force vectors Pkn and R. Table 3 shows the magnitudes of forces in supports A, B1 and B2. The maximum force values are marked in red, while the minimum values are marked in blue.

The forces are a result of the FEM analysis of the 3D vehicle model under the influence of the Gv force and the difference between the Pkn and R forces for 21 combinations of angles. It is important to note that the model was designed as a shell structure with additional shells added to the construction of the rods on both sides of each rod, which allowed for a static determination of the model.

The analysis also revealed that the stress values in the structure are within the allowable limits, indicating that the design is structurally sound and able to withstand the applied loads. However, the analysis highlighted areas of high stress concentration, particularly in the areas where the shell was attached to the frame.

Based on the results of the FEM analysis, it can be concluded that the maximum force on support A is 1926770.638 N when $\varphi = 30^\circ$ and $\psi = \pm 25^\circ$, while the minimum force on support A is 964914.2533 N when $\varphi = 0^\circ$ and $\psi = 0^\circ$. The maximum force on support B1 is 985063.1165 N when $\varphi = 0^\circ$ and $\psi = -25^\circ$, and the minimum force on support B1 is 463081.1936 N when $\varphi = -5^\circ$ and $\psi = -25^\circ$. Finally, the maximum force on support B2 is 985062.4296 N when $\varphi = 0^\circ$ and $\psi = +25^\circ$, while the minimum force on support B2 is 463081.093 N when $\varphi = -5^\circ$ and $\psi = +25^\circ$. These results provide valuable information for further design and optimization of the vehicle model.

This means that the analyzed parts of the structure are sufficiently strong and can withstand the loads simulated in this model. However, in further development and optimization of the structure, changes may be necessary to reduce the intensity of the forces in the supports, which would increase the overall strength of the structure and reduce the risk of breakage and damage [6].

Table 3. The results

Angles		Intensities of support reactions		
φ ($^\circ$)	ψ ($^\circ$)	A (N)	B1 (N)	B2 (N)
-5	-25	1831877	463081.1936	468259.0695
-5	0	1832566	465028.1988	465028.1024
-5	25	1831877	468259.1525	463081.093
0	-25	971524.2292	985063.1165	919038.6512
0	0	964914.2533	954834.4363	954833.7319
0	25	971524.3979	919039.2477	985062.4296
10	-25	1400489.913	845926.0336	816329.9761
10	0	1401204.963	831342.0282	831341.4753
10	25	1400490.005	816330.4184	845925.4652
30	-25	1926770.638	581904.3987	570246.9936
30	0	1926587.244	575872.2749	575872.2434
30	25	1926770.638	570247.0247	581904.3899
45	-25	1695926.11	588129.0075	579788.5256
45	0	1697775.806	582702.2879	582701.9701
45	25	1695926.109	579788.6484	588128.6741
65	-25	1602871.451	682059.4282	635159.1628
65	0	1604503.958	658008.2712	658007.927
65	25	1602871.497	635159.4152	682059.1785
70	-25	1598866.831	661252.799	643742.5915
70	0	1600991.944	651351.7494	651351.3996
70	25	1598866.837	643742.9235	661252.343

5. CONCLUSION

In conclusion, the FEM analysis of a 3D vehicle model subjected to high-intensity and impulse force, namely the Pkn force, the opposing R force and the force Gv. The vehicle model consisted of 10 nodes and 9 bars, and in order to achieve static determinacy, it was added a shell of 100 mm to the construction of each bar on both sides, resulting in a shell-shaped model.

Through FEM analysis, it was obtained the values of the support reaction forces at points A, B1 and B2, which indicate the structural strength of the vehicle under the given loading conditions. The results showed that the analysed parts of the construction are strong enough to withstand the simulated loads, with the maximum reaction forces occurring at a φ angle of 30° and a ψ angle of $\pm 25^\circ$.

However, further development and optimization of the construction may require modifications to reduce the intensity of the reaction forces in the supports, which could lead to an increase in overall structural strength and a reduction in the possibility of damage and breakage [7].

It is important to note that this model is just one of the many possible configurations of the vehicle's construction, and that additional analyses and optimizations would be necessary to determine the most efficient and safe solution [8]. The FEM analysis was performed for 21 combinations of angles, with the model subjected to the force Gv and the difference in forces Pkn-R. The results of the analysis have shown that the maximum resistance forces in the supports A, B1 and B2 occur when the angles φ and ψ are within a certain range. These forces are well below the yield strength of the material used, indicating that the analysed parts of the structure are sufficiently robust to withstand the simulated loads. However, further optimization of the design may be necessary to reduce the intensity of forces in the supports, thereby increasing the overall strength of the structure and minimizing the risk of damage and breakage [9].

REFERENCES

- [1] H. Benaroya and M. Rehak, "Finite Element Method in Probabilistic Structural Analysis: A Selective Review," *Appl. Mech. Rev.* Vol. 41 (5), pp. 201-213, (1988).
- [2] R. Rajappan and M. Vivekanandhan, "Static and Model Analysis of Chassis by Using FEA" Proceedings of the National Conference on Emerging Trends in Mechanical Engineering 2013.
- [3] N. M. Ghazaly, "Applications of Finite Element Stress Analysis of Heavy Truck Chassis: Survey and Recent Development," *Journal of Mechanical Design and Vibration*, Vol. 2 (3), pp. 69-73, (2014).
- [4] W. Ehlert, B. Hug and I.C. Schmid, "Field Measurements and Analytical Models as a Basis of Test Stand Simulation of the Turning Resistance of Tracked Vehicles," *Journal of Terramechanics*, Vol. 29 (1), pp. 57-69, (1992).
- [5] L. Kwasniewski, H. Li, J. Wekezer and J. Malachowski, "Finite Element Analysis of Vehicle–Bridge Interaction," *Finite Elements in Analysis and Design*, Vol. 42 (11), pp. 950-959, (2006).
- [6] A. Kengkongan Ary, A. Rio Prabowo and F. Imaduddin, "Structural Assessment of an Energy-Efficient Urban Vehicle Chassis using Finite Element Analysis – A Case Study," *Procedia Structural Integrity*, Vol. 27, pp. 69-76, (2020).
- [7] M. Azizi Muhammad Nora, H. Rashida, W. Mohd Faizul Wan Mahyuddinb, M. Azuan Mohd Azlanc and J. Mahmud "Stress Analysis of a Low Loader Chassis," *Procedia Engineering*, Vol. 41, pp. 995-1001, (2012).
- [8] T. Han Fui, R. Abd. Rahman, "Statics and Dynamics Structural Analysis of a 4.5 Ton Truck Chassis," *Jurnal Mekanikal*, Vol. 24, pp. 56-67, (2007).

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 (11 ; 2023 ;
Vrnjačka Banja)**

Proceedings / The Eleventh International triennial conference Heavy
machinery

HM 2023, 21 – 24 June 2023, Vrnjačka Banja, Serbia ; [editor Mile Savković]. -

Kraljevo : Faculty of Mechanical and Civil Engineering, 2023 (Vrnjačka Banja :
SaTCIP). - 1 knj. (razl. pag.) : ilustr. ; 30 cm

Tiraž 60. - Str. 5: Preface / Mile Savković. - Bibliografija uz svaki rad.

ISBN 978-86-82434-01-6

a) Машиноградња -- Зборници b) Транспортна средства -- Зборници
v) Производно машинство -- Зборници g) Шинска возила -- Зборници
d) Аутоматско управљање -- Зборници

COBISS.SR-ID 120402697

Faculty of Mechanical
and Civil Engineering in Kraljevo
University of Kragujevac
Serbia, 36000 Kraljevo, Dositejeva 19
Phone/fax +381 36 383 269, 383 377

E-mail: office@mfkv.kg.ac.rs
www.mfkv.kg.ac.rs