PD.TVZ.HR
POLYTECHNIC & DESIGN Vol. 14, No. 2, 2026.
Mrežna inačica: ISSN 2459-6302
Tiskana inačica: ISSN 1849-1995
DOI: 10.19279/TVZ.PD.2026-14-2-13

ANALIZA SIGURNOSTI KAMIONSKE UTOVARNE RAMPE

TRUCK LOADING RAMP SAFETY ANALYSIS

Dinko Mikulić[1], Draško Mück[2]

[1] *University of Applied Sciences Velika Gorica*
[2] *DOK-ING d.o.o. Zagreb*

SAŽETAK

Pretovar tereta pomoću kamionske rampe mora biti siguran proces. U praksi postoje problemi havarija, padova i ozljeđivanja ljudi. Europska regulativa o obvezi implementacije zahtjeva sigurnosti stražnjih dizala nalaže praćenje sigurnosti rada i stalna poboljšanja konstrukcije. Proveli smo istraživanje na modelu standardne konzolne utovarne rampe s podiznim zglobnim mehanizmom. Pozornost smo stavili na kontrolu čvrstoće opterećenih zglobova podizne ruke. Kontrolu složenih naprezanja izvodili smo pomoću FEM analize. Otkrili smo prenapregnute dijelove rampe i procijenili radni vijek na zamor materijala. U cilju veće radne sigurnosti, predložili smo nazivnu nosivost rampe po cijeloj površini polovine platforme, što definira veće polje sigurnosti.

Ključne riječi: *kamionska stražnja rampa, sigurnost utovarne rampe, dijagram nosivosti rampe, naprezanje na čvrstoću, dinamička izdržljivost, FEM analiza rampe*

ABSTRACT

Loading cargo using a truck ramp must be a safe process. In practice, there are problems of accidents, falls and injuries to people. European regulations on the mandatory implementation of safety requirements for tail lifts require monitoring of operational safety and continuous improvements to the design. We conducted research on a model of a standard cantilever loading ramp with a lifting articulated mechanism. We paid attention to checking the strength of the loaded joints of the lifting arm. We performed complex stress control using FEM analysis. We discovered the overstressed parts of the ramp and assessed the working life for material fatigue. In order to achieve greater operational safety, we have proposed a nominal load capacity of the ramp over the entire surface of half of the platform, which defines a greater field of safety.

Keywords: *truck tail lift, loading ramp safety, ramp load capacity diagram, stress to strength, dynamic endurance, FEM ramp analysis*

1. UVOD
1. INTRODUCTION

Trucks equipped with rear loading tail lifts are used in the distribution of goods from warehouses to supply centers and other consumers. Such tail lifts contribute to increasing the efficiency and cost-effectiveness of loading operations onto high vehicles, such as trucks. Given the broad market and the rapid development of cargo-handling logistics equipment, loading tail lifts have significant market potential. The European standard for tail lifts [1] defines the safety requirements for the design of such lifts. Statistics on accidents involving truck tail lifts indicate incidents of lift collapse and worker injuries. Therefore, it is necessary to investigate safety requirements and propose improvements as a contribution to tail lift development. For vans, tail lifts typically have load capacities ranging from 300 to 800 kg, while for trucks the capacities range from 1,000 to 3,000 kg. Special designs

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Category	Permissible Gross Vehicle Weight	Number of Vehicles	Number of Vehicles with a Tail Lift	Percentage %
N_1	≤ 3.5 t	195,553	1,055	0.54
N_2	> 3.5 t ≤ 12 t	16,660	4,173	25
N_3	> 12 t	40,288	2,640	6.55
Total		252,501	7,868	3.1

Tablica 1 *Pregled broja teretnih vozila s rampom [2]*

Table 1 *Overview of the number of freight vehicles equipped with tail lifts [2]*

offer even higher load capacities. The number of vehicles equipped with tail lifts in the Republic of Croatia is shown in Table 1:

In the Republic of Croatia, the most used commercial vehicles equipped with rear tail lifts are those in category N2, with 4,173 trucks, representing 25% of the category. A significant number of trucks equipped with tail lifts are also found in category N3 vehicles. The tail lifts in use are predominantly of the cantilever type [1]. The following manufacturers' tail lifts are commonly used: *Dhollandia, MBB Palfinger, Bär Cargolift, Sörensen, Zepro, Dautel*, and *Anteo*.



Slika 1 *Kamionska utovarna rampa*

Figure 1 *Truck loading ramp*

2. PROBLEM SIGURNOSTI RAMPE
2. RAMP SAFETY PROBLEM

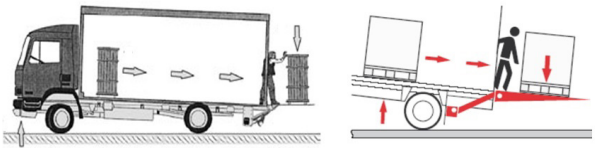
The tail lift is operated by a trained person (the truck driver) and a worker on the platform, although very often only the driver is involved. Handling multiple containers on the platform can result in worker falls. In addition to potential weaknesses in the tail lift structure, the transshipment process itself is not entirely safe and may lead to worker injuries. For example, during the delivery of groceries to a supermarket [3], involving four containers with a total mass of 1,300 kg, which was within the maximum permissible tail lift capacity of 1,500 kg, a failure occurred. While the worker was standing on the platform next to the load and lowering it, the left support of the rear tail lift fractured, causing that side of the platform to collapse to the ground and seriously injure the worker. Other accident cases have also been reported [4, 5], etc. Therefore, tail lift failures can result in serious worker injuries and property damage. This raises an important issue for further investigation. This topic has not been examined in the professional literature, and no solutions have been proposed. Based on this, the objective of this research was defined as follows: an analysis of truck tail lift safety from the perspective of structural verification and the identification of possible improvements as a contribution to the development of rear tail lifts.



Slika 2 *Primjer urušavanja stražnje rampe [3]*

Figure 2 *Example of rear ramp collapse [3]*

The selection of a specific truck tail lift is offered by tail lift manufacturers. The process begins with the requirements for handling a particular type of cargo, followed by the determination of the required tail lift capacity. This is followed by the selection of the tail lift type (cantilever, column, etc.) and the choice of an appropriate vehicle. To prevent axle overload and ensure safe driving, each truck type has a *vehicle load distribution diagram* [6]. Since the tail lift itself has a certain mass that reduces the declared permissible payload of the truck, the actual permissible payload is lower by the mass of the tail lift [13]. Truck body-building software programs provide assistance in selecting a tail lift and calculating the truck chassis configuration (e.g., TrailerWin), Figure 3.



Slika 3 *Rizik prevrtanja tereta (prilagođeno [8, 11])*

Figure 3 *Risk of cargo tipping over (adapted [8, 11])*

3. TIPOVI KAMIONSKIH RAMPI
3. TYPES OF TRUCK RAMPS

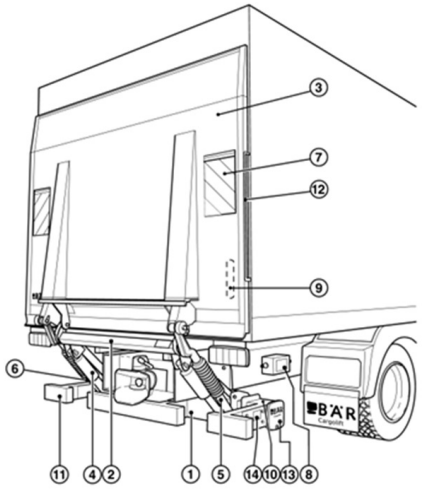
In accordance with EN, examples of tail lift mechanisms and tail lift types are presented in Annex A [1]. Several types of rear tail lifts are used in practice:

- Passenger lifts
- Lifts for factory-built panel vans
- Cantilever lifts
- Column lifts
- Slider lifts
- Tuck-away lifts
- Special lifts

The technical characteristics of a tail lift depend on the category and type of vehicle on which it is installed, Figure 4. The most common type is the cantilever tail lift. In addition to lifting cargo on trucks, the platform of a cantilever tail lift also serves as the rear door of the cargo body, eliminating the need for standard doors. However, in refrigerated truck bodies, conventional rear swing doors are used together with a cantilever tail lift for loading and unloading operations.

Basic characteristics of cantilever tail lifts:

- Platform dimensions (width × depth): 180 × 180 cm, 190 × 180 cm, 200 × 180 cm, 210 × 180 cm, 220 × 180 cm, 230 × 180 cm, 240 × 180 cm, 250 × 180 cm, 250 × 230 cm
- Rated load capacity: 1000, 1500, 2000, 2500, 3000 kg
- Tail lift assembly weight: 350–650 kg
- Platform inclination angle relative to the ground: 6°–10°
- Material: aluminium and steel (galvanized)
- Lifting height: 70 cm–160 cm
- Hydraulic lifting cylinders: pressure up to 200 bar
- Power supply voltage: DC 12 V/24 V, capacity: 120 Ah.



Slika 4 *Konzolna rampa kao stražnja vrata kamiona [11]*
1 - okvir rampe, 2 - podizna ruka (PR), 3 - platforma, 4 - cilindar za dizanje (LC), 5 - cilindar za okretanje (TC), 6 - hidraulična pumpa, 7 - oznake upozorenja, 8 - jedinica za ručno upravljanje, 9 - nožno upravljanje platforme, 10 - broj šasije, 11 - zaštita od podlijetanja, 12 - bočni držači, 13 - upravljačka jedinica, 14 - broj CU

Figure 4 *Cantilever ramp as a truck tailgate [11]*
1 - ramp frame, 2 - lifting arm (PR), 3 - platform, 4 - lifting cylinder (LC), 5 - turning cylinder (TC), 6 - hydraulic pump, 7 - warning signs, 8 - manual control unit, 9 - platform foot control, 10 - chassis number, 11 - skid protection, 12 - side supports, 13 - control unit, 14 - CU number

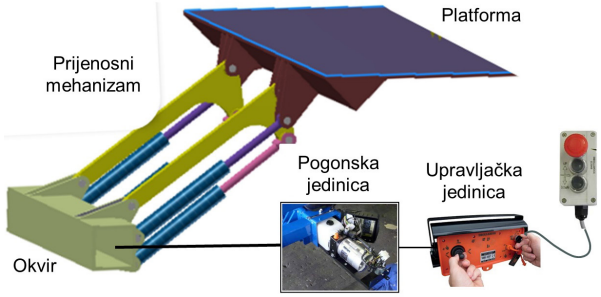
Tail lift capacity class / model *MBB Palfinger*	Vehicle manufacturer	Vehicle series N1, N2 i N3
MBB PTC 750 L / S	DAF	CF, LF, XF, XB, XD, XG
MBB PTC 1000 LLW	Iveco	Daily 4x4 SX / DX, E, S-Way, Stralis
MBB C 1000 L / S	MAN	TGA, TGL, TGM, TGS, TGX
MBB C 1500 L/ S / SZ	Mercedes-Benz	

Tablica 2 *Klase nosivosti rampi i primjena [9]*

Table 2 *Tail Lift Load Capacity Classes and their Application [9]*

Vehicle body builders offer solutions for tail lift selection (*Solution Configurator*). For example, the load capacity classes of *MBB Palfinger* tail lifts and their application on vehicles manufactured by renowned N1, N2, and N3 vehicle manufacturers are shown in Table 2:

A typical cantilever tail lift model is shown in Figure 5. It consists of a platform for accommodating pallets, supported by a lifting/lowering mechanism with four hydraulic cylinders (2+2), which are connected to the tail lift frame. The power source (*Power Pack*) is an electric motor that drives a hydraulic pump, generating the oil pressure required to actuate the cylinders, together with a control valve, oil reservoir, and control unit.

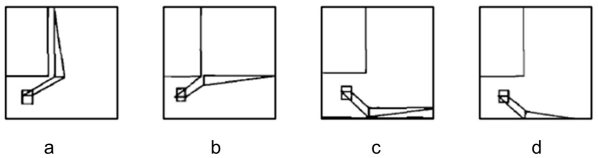


Slika 5 *Model kamionske rampe*

Figure 5 *Truck ramp model*

Functions and positions of the tail lift:

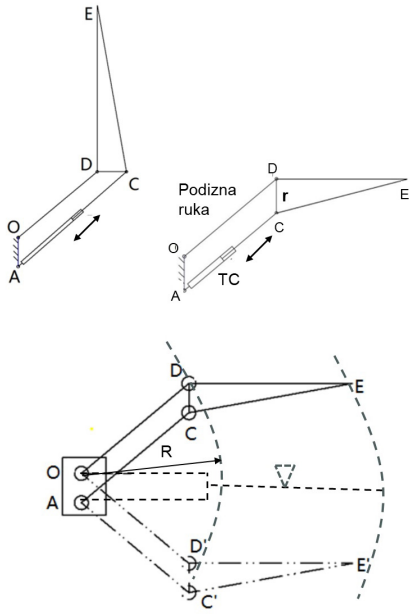
1. Platform opening: the opening of the truck's rear closure is achieved by rotating the platform through 90°, Figure 6 (a, b).
2. Platform lowering shown in Figure 6 when the platform comes into contact with the ground (c).
3. Platform adjustment to the ground surface: the underside of the platform rests with its entire surface on the ground (d), at an angle of 6°–10°.
4. Reverse process during platform lifting and closure of the truck's rear side.



Slika 6 *Funkcije i položaji kamionske rampe*

Figure 6 *Functions and positions of the truck ramp*

The rotation of the platform is achieved by means of a parallelogram mechanism, which clearly illustrates the process of positioning the platform into a horizontal orientation, Figure 7. Triangle DCE represents the working platform, while link OA forms the base, i.e., the tail lift frame. Line OD represents the lifting arm. Line AC represents the hydraulic cylinder used for platform rotation, the *Tilt Cylinder* (TC). The first movement consists of rotating the platform by 90° from the vertical to the horizontal position.

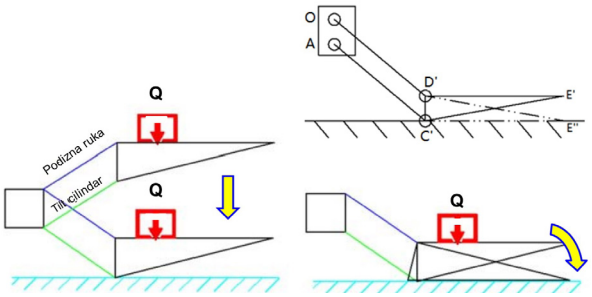


Slika 7 *Shema okretanja platforme i održavanja vodoravnog položaja [7]*
CD (r) - radijus okretanja platforme, R - radijus podizne ruke

Figure 7 *Scheme of turning the platform and maintaining the horizontal position [7]*
CD (r) - turning radius of the platform, R - radius of the lifting arm

Although there are several types of mechanisms capable of maintaining the platform in a horizontal position, the four-bar parallelogram mechanism is the standard solution. The four links are denoted as OA, AC, CD, and DO, where OA = CD, AC = OD, and OA < AC. The OA linkage is connected to the vehicle frame, while the lifting arm OD rotates about point O. As a result, AC, i.e., the Tilt Cylinder (TC), always remains parallel to link OD. At the same time, the distance between joints D and C acts as a radius that maintains the vertical orientation, allowing platform DE to remain horizontal. Joints O and A are connected to the vehicle frame. CD represents

the platform rotation radius (r), while the length of lifting arm OD constitutes the lifting radius (R). During the lifting process, the parallelogram mechanism (OACD) moves from position E to E'. When point C' encounters the ground, the platform adjustment process is initiated. The pair of TC cylinders presses the edge of the platform against the ground, Figure 8.



Slika 8 *Prilagodba platforme podlozi (6º-10º) pod teretom (Q)*

Figure 8 *Platform adjustment to the base (6º-10º) under load (Q)*

4. POGONSKI SUSTAV I HIDRAULIČKA INSTALACIJA

4. DRIVE SYSTEM AND HYDRAULIC INSTALLATION

The tail lift drive system generates the force required for:

- opening and closing the tail lift,
- raising or lowering the tail lift to the ground,
- tilting the tail lift in all positions.

The installation of the tail lift drive components is protected within the steel frame of the tail lift, Figure 9. The standard configuration uses an electric motor as the power source for driving the hydraulic pump. Other components of the drive system, namely the TC cylinder – the hydraulic cylinder for platform rotation and tilting, and the LC cylinder – the hydraulic cylinder for lifting the load, are shown in Figure 10.

Drive System Parameters:

Electric Motor (EM)

EM torque / P torque

$M_{EM} = M_P$

Hydraulic pump power, $P_P = M_P \omega_P$

Electric motor power

$P_{EM} = P_P$ (2-3 kW /24 V)

Hydraulic Pump (P)

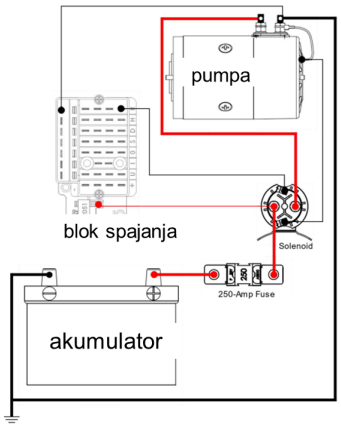
Maximum pressure, p = 200 bar

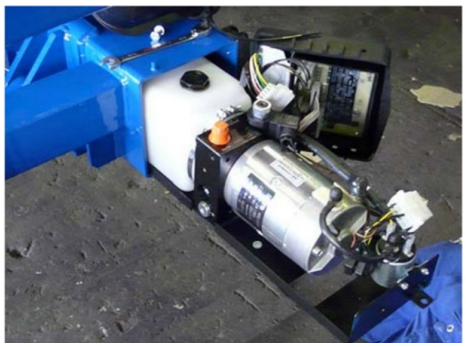
Pump power, $P_{HP} = F_{LC}\, v = p\, Q$, v = 60-80 mm/s

F_{LC} - LC cylinder force

Pump flow rate

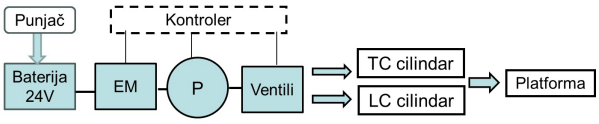
$Q = F_{LC}\, v / p$





Slika 9 *Pogonski dijelovi i napajanje [8] Akumulator DC 12V/24V, Elektromotor 2-3 kW /24 V, Hidro pumpa 1,6-3,3 cc/okret PD tipa, Spremnik ulja ISO VG 22-32, Elektronika CU, Ventilski blok*

Figure 9 *Drive components and power supply [8] Battery DC 12V/24V, Electric motor 2-3 kW /24 V, Hydraulic pump 1.6-3.3 cc/rev PD type, Oil tank ISO VG 22-32, Electronics CU, Valve block*

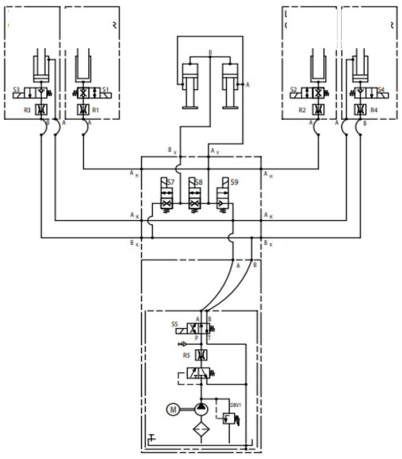


Slika 10 *Komponente pogonskog sustava*

Figure 10 *Drive system components*

A standard cantilever tail lift is equipped with four hydraulic cylinders, Figure 11. One pair of cylinders (TC cylinders) is used to maintain the

platform at a right angle and to rotate it, while the other pair of cylinders (LC cylinders) is used to raise the tail lift (tail lifts that use one cylinder for rotation and one cylinder for lifting are less safe and therefore less expensive). The cylinder lengths are determined based on the travel path of the TC and LC cylinders in the fully closed and fully lowered platform positions. Safety valves are installed on the lifting and tilting cylinders. Lifting is automatically stopped if the permissible load is exceeded, with an accuracy of ±1%. The valves also prevent uncontrolled oil discharge in the event of hose damage, protecting both the operator and the cargo by preventing platform tilting. Platform adjustment to the ground surface is achieved in one of two ways, either hydraulically or mechanically. The hydraulic system provides lifting support and platform adjustment based on synchronization between the cylinders. A standard tail lift equipped with tilt cylinders allows manual levelling (BC1000/1500 F2). Advanced tail lifts with tilt cylinders automatically maintain the platform in a horizontal position regardless of road inclination (BC1000/1500 F4), Figure 12.

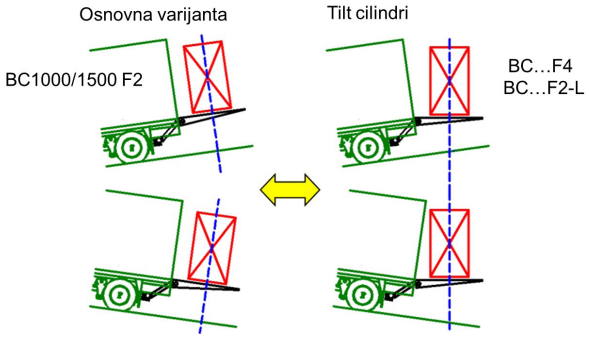


Slika 11 *Hidraulička shema [9]*

Figure 11 *Hydraulic scheme [9]*

The hydraulic characteristics of the tail lift are:

- double-acting TC cylinder,
- single-acting LC cylinder,
- cylinders protected with rubber covers,
- integrated safety/solenoid protection valves on each cylinder,
- adjustment of the horizontal platform position regardless of the angle of road inclination.

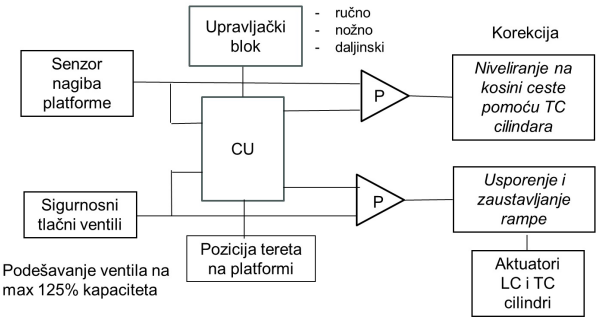


Slika 12 *Vodoravni položaj tereta na kosini [11]*

Figure 12 *Horizontal position of the cargo on the slope [11]*

5. UPRAVLJANJE RAMPOM
5. RAMP CONTROL

Figures 13 and 14 show the tail lift management diagram.



Slika 13 *Shema sigurnosti upravljanja*

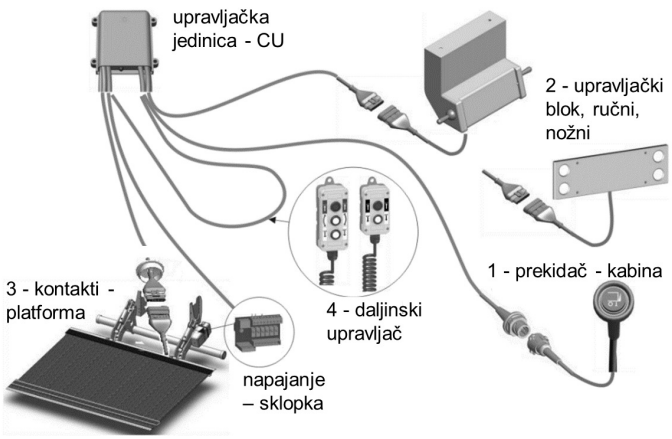
Figure 13 *Management security scheme*

Depending on the manufacturer, the control unit is designed in different ways, including manual control, foot control, or remote control. Two-foot operation is performed using a triangular foot switch located on the platform. The worker presses the switch corresponding to the desired direction of movement, one for lifting and one for lowering.

6. PARAMETRI KONSTRUKCIJE RAMPE
6. RAMP CONSTRUCTION PARAMETERS

The dimensions of the tail lift are determined according to the selected vehicle chassis (H), i.e., the height of the cargo body floor, which also corresponds to the platform height (H_0), Figure 15.

Control Unit (CU) and Components



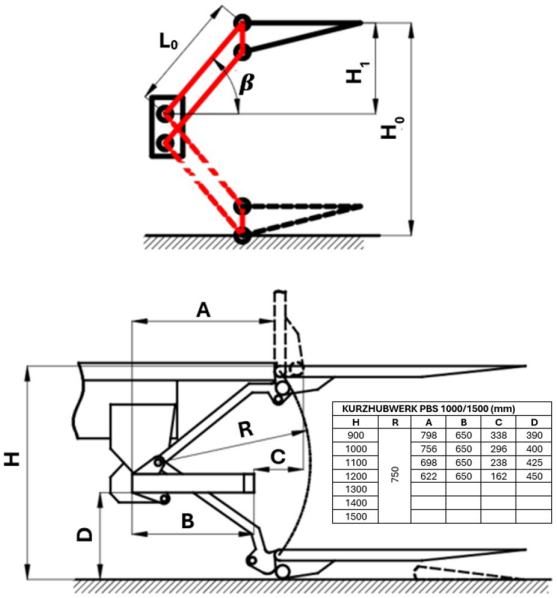
Slika 14 *Upravljačka jedinica CU i komponente (Sorensen) [10]*
1 -"On-Off" prekidač u kabini, 2 - upravljački blok, 3 - platforma, 4 - daljinski upravljač

Figure 14 *Control unit CU and components (Sorensen) [10]*
1 - "On-Off" switch in the cabin, 2 - control block, 3 - platform, 4 - remote control

H_0 – platform height (*platform vertical travel distance*)

L_0 – lifting arm length (serving as the lifting radius R)

β – lifting arm inclination angle (40º - 50º)



Slika 15 *Osnovni parametri kamionske rampe [9]*

Figure 15 *Basic parameters of a truck ramp [9]*

Lifting arm length:

$$L_0 = \frac{H_1}{Sin\ \beta}$$

H_1 – vertical distance from the platform joint to the bracket joint

$$H_1 = \frac{1}{2}(H_0 - C)$$

C – distance between the joints on the frame support member, C = 0,14 L_0 (npr. 120-140 mm)

$$L_0 = \frac{1}{2}(H_0 - C)\frac{1}{\sin\beta}$$

With the standard platform height: H_0 = 1300 mm

β = 40º ~ 50º, $sin\beta$ = 0,64~0,77

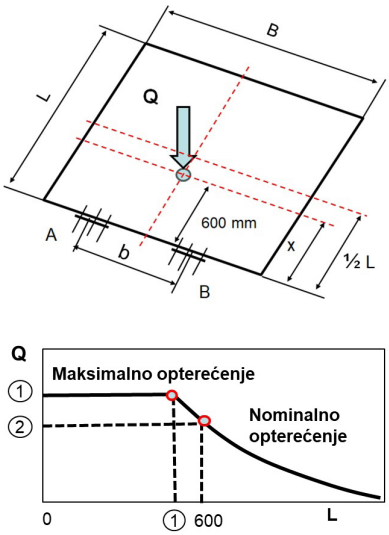
L_0 = (0,70~0,59) H_0 = 910~767 mm (e.g., 850 mm)

Tail Lift Load Diagram

In accordance with the EU standard [1], a distinction is made between the terms maximum load and nominal load, as shown in the load diagram, Figure 16. *The maximum load* is the permissible load as a function of the position of its centre of gravity on the platform, as determined by the manufacturer. *The nominal load* is the maximum load whose centre of gravity is located on the platform reference centreline. The reference load line of the platform along the longitudinal axis is defined as the distance from the vehicle edge to half of the platform depth (1/2 L) or 600 mm, whichever distance is smaller. A distance of 600 mm from the platform pivot axis conventionally defines the position of the centre of gravity of the maximum load that may be lifted.

The maximum nominal load capacity of the tail lift (load Q) includes the total load, consisting of the weight of the palletized goods being lifted, the operator, the pallet truck, and all other items located on and used on the platform. Load Q is positioned centrally between the cylinders at a platform depth x. The load moment of the tail lift about the pivot axis is: M_0 = Q x (Nm). As the position of the load centre of gravity (x) increases,

the load moment acting on the tail lift also increases. To maintain a constant moment curve, the load capacity of the tail lift must be reduced as the lever arm increases. If the permissible load is exceeded, the safety valve is activated and automatically stops the tail lift.



Slika 16 *Shema opterećenja rampe [1]*

Figure 16 *Ramp load diagram [1]*

The aluminium platform is manufactured with a standard anti-slip surface and reinforced with ribs and galvanized profiles. The upper platform plate is in direct contact with both the load and the worker handling the cargo. Therefore, it is important for worker safety to prevent slipping on the platform surface. Furthermore, the load must be protected against sliding. This is achieved through the ribbed design of the plate. The upper plate is positioned closest to the loading area when in the closed position, and care must be taken regarding the rotation radius during the opening and closing of the tail lift. The lower platform plate withstands all forces associated with supporting the platform. It is reinforced with structural profiles, welded plates, or bolted connections. The lower plate carries welded lugs for the pins through which the tail lift is supported, raised, and lowered. At the front edge, the plate is slightly bent to facilitate adaptation to the ground surface and ease of loading. Although not mandatory in all CE countries, a mechanical platform lock is installed as an additional safety feature alongside the safety valves, to prevent platform collapse in the event of a loss of hydraulic pressure.

7. ANALIZA MEHANIČKE KONSTRUKCIJE

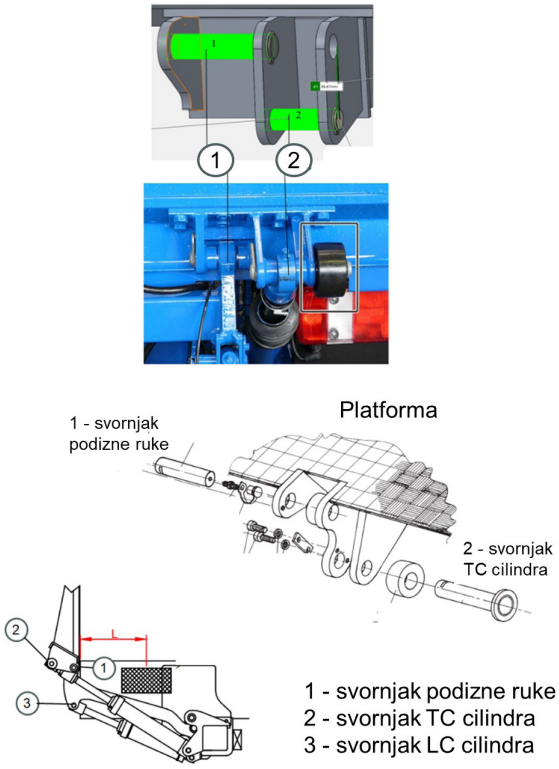
7. MECHANICAL STRUCTURE ANALYSIS

The hinged connection between the tail lift mechanism and the platform consists of plain bearings and pins installed on the flange lugs of the upper structure. The upper structure is considered first, being rigidly attached to the platform frame by means of a flange and, for example, several bolts (e.g., 4–8), Figure 17.

Assumption of static loading – load on the platform

1. The load force acting on the platform is transmitted equally by both bearings: those of the lifting arms and those of the TC cylinders.

2. The tail lift moment M_0 is transmitted through the lifting arm bearing by means of the activation of the LC cylinder.



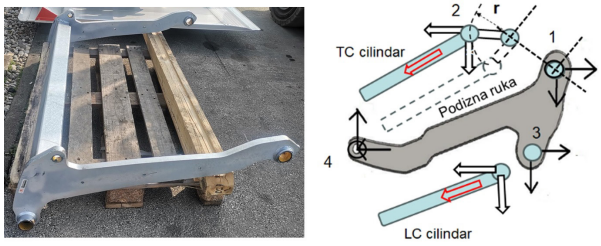
Slika 17 *Konstrukcija rampe [8, 11]*

Figure 17 *Ramp construction [8, 11]*

Lifting Arm (U-Beam)

The solid section of each side of the lifting arm carries three press-fitted bearing bushings, Figure

18. The left and right sides of the lifting arm are connected by a transverse hollow beam of either square or circular cross-section, forming the U-shaped beam structure.

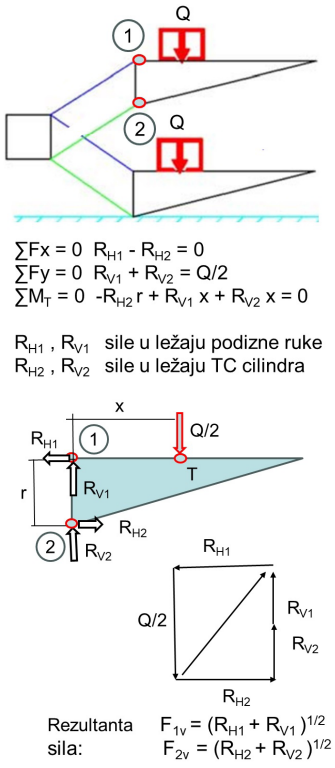


Slika 18 *Podizna ruka (U-nosač)*

Figure 18 *Lifting arm (U-beam)*

Loading of Supports for ½ of the tail lift

a) position of the load centre of gravity x, Figure 19.



Slika 19 *Sile u osloncima podizne ruke i tilt cilindra*
1 - ležaj podizne ruke (Lift arm), 2 - ležaj Tilt cilindra

Figure 19 *Forces in the lift arm and tilt cylinder supports*
1 - lift arm bearing, 2 - tilt cylinder bearing

b) TC cylinder force ($F_{TC} = F_{2v}$)

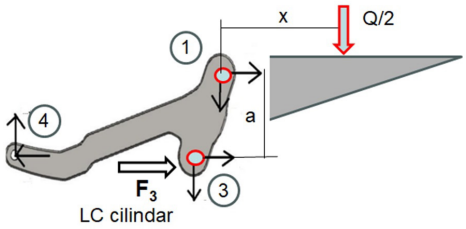
c) LC cylinder force, Figure 20.

Tail lift load torque: M = Q/2 x

LC cylinder holds equilibrium: Q/2 x = F_3 a

LC cylinder force: F_3 = Q/2 x/a

Lifting power: Pd = F_3 v_d ; v_d – *lifting speed*



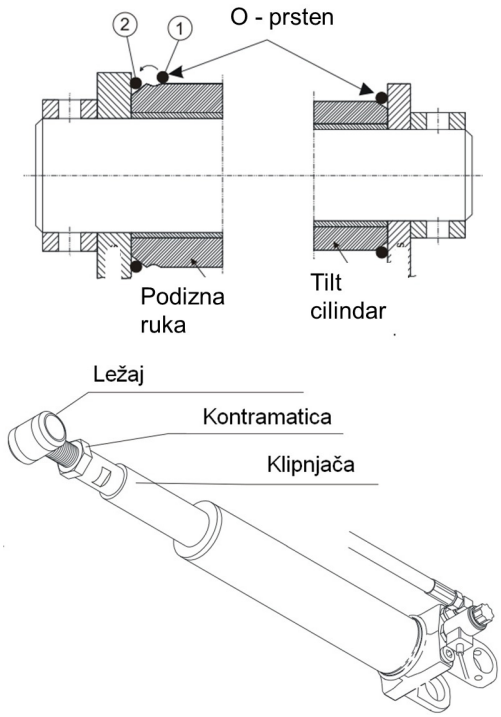
Slika 20 *Sile u zglobovima podizne ruke kod dizanja tereta*

Figure 20 *Forces in the joints of the lifting arm when lifting a cargo*

d) Bearings and Pins

Particular attention during inspection is focused on verifying the strength of the most heavily loaded bearings of the LC cylinder and TC cylinder, Figure 21. The pins are made of stainless steel, while replaceable bushings provide corrosion resistance, ease of installation, and simplified maintenance. The bearings contain press-fitted bushings installed in the openings of the lifting arm support, with bearing lugs located on either side. The lugs and bushings are connected by hardened pins, which are rigidly fixed to the lugs (without rotation). Bearing clearance is very small. The bushings may be made of *polymer* materials requiring no lubrication (self-lubricating joints) or of *sintered bronze* with lubrication. Components are lubricated with grease applied using manual grease guns through grease nipples into channels that distribute the lubricant across the sliding surface. It is important to reduce high edge pressures at the ends of the bearing by maintaining a lubricating film. Such pressures lead to excessive wear, overheating, or seizure. Therefore, an O-ring is installed at the ends of the bearing. Wear at the ends of the bushing causes misalignment of the pin axis, which can result in bearing damage. Maintenance of plain bearings ensures proper operation and durability. In some designs, instead of using a rigid bearing and measures to prevent edge pressure, a spherical joint with a press-fitted bushing is employed. This arrangement allows load adaptation but also requires greater bearing clearance. Joint maintenance is carried out either based on self-lubricating bearings or by using grease suitable for outdoor lubrication (calcium-based grease). At the ends of the tilt-cylinder pins, a freely rotating roller is mounted, allowing

the platform to rest on the ground during lowering. The lower supports of the TC and LC cylinders on the tail lift frame may be designed in various ways, for example with one or two bearings positioned between the lugs.



Slika 21 *Ležajevi podizne ruke i tilt cilindra [9]*

Figure 21 *Lift arm and tilt cylinder bearings [9]*

Pin and bearing parameters [12]:

- Surface pressure on the pin: $p_u = F / b\ d$; $p_v = F / 2\ a\ d$
- Pin bending stress: $\sigma_f = (0{,}5\ F * 0.5\ a) / 0{,}1\ d^3$
- Pin shear stress: $\tau_u = F / 2A$ (A - pin cross-sectional area)
- Surface pressure on the bearing bushing: $p = F / d\ b$, (3-10 N/m^2, sintered bronze)

  b – bearing width (b/d=0,6-1,5)

For all load-bearing components of the tail lift, the load factors are based on the yield strength of the material. The static load factor shall not be less than 2,1 for tail lifts on which persons are permitted to stand on the platform [1]. For example, assuming: $F_{1D} \approx 30$ kN, $a \approx 12$ mm, $\sigma_{f\,dop} = 300\text{-}500$ N/mm^2, St 60-2, the pin diameter is [12]:

$$d \geq \sqrt[3]{\frac{0{,}5 \cdot F \cdot 0{,}5 \cdot a}{0{,}1 \cdot \sigma_{f,dop}}}$$

$d \approx 15\text{-}20\ (30)$ mm, the actual pin diameter depends on the choice of the hydraulic cylinder.

Lower Structure – tail lift frame

The tail lift frame consists of a rectangular steel structure onto which the support lugs for the lifting arm (LA), TC and LC cylinders, as well as the underrun protection elements, are welded. Vertically upward, the tail lift frame is properly connected to the vehicle chassis frame by means of connecting plates and bolts. The drive components (electric motor, hydraulic pump, oil reservoir, controller, etc.) are housed within the frame structure.

Reactions at the three lower tail-lift supports:

- Lifting arm, lower support, position 4, load: F_4
- Load at the LC cylinder support: $F_3 = F_{LC}$
- Load at the TC cylinder support: $F_{2v} = F_{TC}$

The pins of the lower structure are assumed to be subjected to approximately the same forces as those in the upper structure, with the addition of the weight of the hydraulic cylinder or lever. This additional weight does not significantly affect the required dimensions of the pins.

8. SLOŽENO NAPREZANJE DIJELOVA I FEM ANALIZA

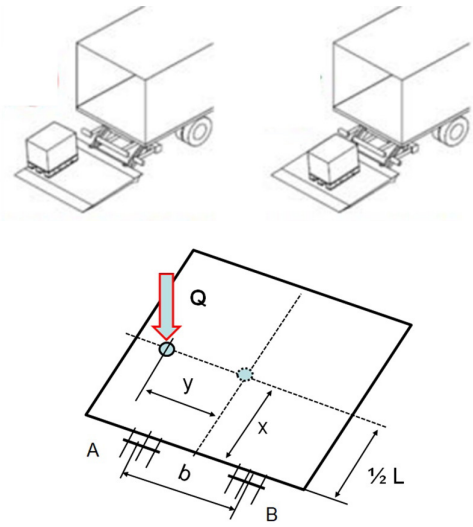
8. COMPLEX STRESS OF PARTS AND FEM ANALYSIS

The position of the load pallet and the worker on the platform is most often not symmetrical. Therefore, the structure should be checked for each case across the entire surface, particularly for asymmetric loading and the identification of critical parts of the tail lift. The maximum stress must not exceed the elastic range of the material, i.e., an acceptable safety factor must be ensured in the critical cross-sections of the structural members [1]. The conventional calculation of complex stresses for the strength verification of components is complex, slow, and uncertain. A more efficient modern calculation method using FEM analysis was therefore applied, with complex stresses presented in a 3D design.

Asymmetric or lateral overloading of the tail lift, Figure 22.

The tail lift load is placed on Euro pallets used in logistics and transport. Each of them has specific characteristics depending on its purpose and operating conditions. Euro pallets (EPAL) are defined according to the EN 13698-1 standard. They are compatible with systems for transport, storage, and cargo handling. The dimensions of a standard wooden pallet (length, width, height: 1200 × 800 × 144) are designed for a load capacity of 1000 kg, with the force centre of gravity located at the centre of the pallet.

- let the platform load limit be at one half of the tail lift depth (x = 1/2 L).
- let the position of the centre of gravity of a pallet weighing 1000 kg be laterally shifted to the left or right from the tail lift axis, i.e., the platform centreline (y, min. 300 mm).
- let the permissible deflection of the platform tip be up to 30.



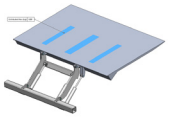
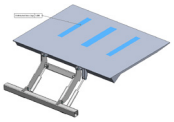
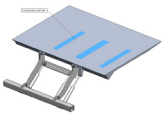
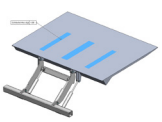
Slika 22 *Položaj palete tereta na platformi*

Figure 22 *Position of the cargo pallet on the platform*

Shifting the load pallet to the left or right of the tail lift centreline affects the type of stress acting on the tail lift mechanism. This results in complex stresses within the tail lift joints (shear, torsion, and bending). Likewise, operating the tail lift on a lateral incline, although not permitted, causes complex stress conditions. The maximum stresses in the tail lift, particularly in the lifting arm joint areas (left or right, y) relative to the position of the centre of gravity, exceed the permissible values, as does the deflection at the platform tip. When load pallets are placed only on one side, the tail lift capacity is significantly reduced according to the manufacturer's specifications (to one-half [9]). Reducing the load capacity due to structural weakness is not a practical solution; therefore, this issue can be eliminated through a redesign of the structural mechanism. The design solution is developed while ensuring the required safety factor [1]. The centre of gravity of the maximum load may be located anywhere within one-half of the tail lift depth (½L) without reducing the load capacity. This extension of the operating range of the tail lift (x, z) eliminates the risk associated with lateral loading, thereby defining a broader safety loading envelope for cantilever tail lifts. Furthermore, the stresses in the components should also be evaluated with respect to fatigue and the number of cycles to crack initiation.

Using *SolidWorks 2024 Simulations*, the calculation results are presented graphically with visible stress values [14]. Stress simulations were performed for a component with a nominal load capacity of Q = 1000 kg, with the load positioned 600 mm from the platform edge on the platform centreline and with a pin diameter of d = 20 mm. An analysis was conducted for four specific loading cases corresponding to different load positions on the platform, Table 3.

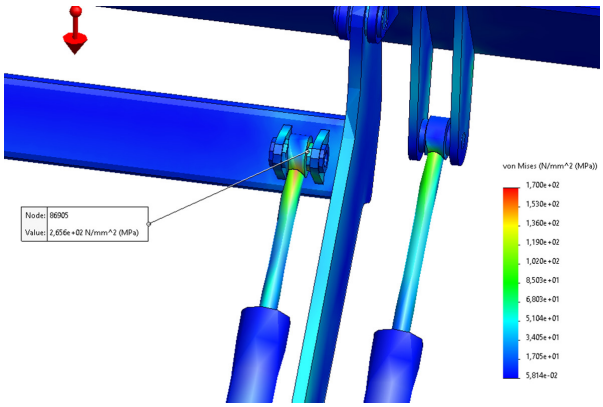
Table 3 *Load cases*

Case 1	Nominal load in the prescribed position, mass 1000 kg, x=600 mm	
Case 2	Nominal load at a greater distance, mass 1000 kg, x=1000 mm	
Case 3	Nominal load moved backwards and to the side, mass 1000 kg, x=600 mm, y=300 mm	
Case 4	Overload (150% of the nominal load), mass 1500 kg, x=600 mm	

The highest stresses occur in the lifting arm pins, Figure 23, which connect the hydraulic cylinders and the lugs of the lower and upper structures. The stresses in the remaining cross-sections of the

structure are below the material yield limit.

$$\sigma_{dop} = 170\ MPa = \frac{\sigma_{ref}}{FS} = \frac{355}{2{,}1}$$



Slika 23 *Naprezanja gornje konstrukcije i svornjaka [14]*

Figure 23 *Stresses in the upper structure and bolts [14]*

The total number of stress cycles until failure determines the durability, i.e., the service life of the components. In accordance with the expected loading spectrum over the service life, a tail lift prototype is tested for 50,000 cycles or for a durability of 10,000 operating hours (10–15 years of service).

Material fatigue behaviour equation:

$$\sigma_a = \sigma_f^{`}(N_f)^b$$

A fatigue simulation was used to estimate the fatigue strength of the pin under cyclic loading. For the stress amplitude σ_{max}, obtained from the FEM analysis, the number of cycles to failure was calculated. The constants were adopted for pin material grade S355 [15], Table 4.

σ_a - Stress amplitude

σ_f - Fatigue strength coefficient (1274,39 MPa) [15]

b - Fatigue strength exponent (-0,1264) [15]

N_f – Number of cycles to failure

Tablica 4 *Broj ciklusa do loma, čelik klase S355*

Table 4 *Number of cycles to failure, grade S355 steel*

Case	Q (kg)	x (mm)	y (mm)	σ_{max} (MPa)	N_f
1.	1000	600	0	129	$7{,}48 \times 10^7$
2.	1000	1000	0	265	$2{,}52 \times 10^5$
3.	1000	600	300	373	$1{,}69 \times 10^4$
4.	1500	600	0	383	$1{,}37 \times 10^4$

It is evident that for loading cases 3 and 4, pin failure will occur after a lower number of cycles (16,900 and 13,700, respectively) compared to the expected service life of the platform (50,000 cycles). The fatigue durability of the pin could be increased by using a higher-strength material or by increasing the pin diameter. A pin manufactured from S690-grade material would withstand 525,350 loading cycles in case 4.

9. DISKUSIJA
9. DISCUSSION

We adhered to the safety requirements of EN [1], which relate to the mechanical design of a standard cantilever tail lift and the elimination of safety-related issues. The fundamental characteristics of cantilever tail lift design are presented in the literature [7], but without exact indicators for preventing failure. This issue has not been systematically investigated, and therefore there is no direct possibility of comparing results and proposed solutions.

The obtained results of the tail lift safety analysis indicate the following:

The calculation of complex stresses in the tail lift using conventional methods is complicated, time-consuming, and unreliable. Therefore, the stress analysis of the tail lift was performed using FEM analysis, which also enables the dimensioning of overstressed tail lift joints. By ensuring the required safety factor and performing fatigue simulations in accordance with the expected loading spectrum, the service life of the pins with respect to strength was estimated.

We consider that the centre of gravity of the maximum load should not be restricted solely to the tail lift axis but may be located anywhere within one-half of the tail lift depth (½L), provided that the tail lift is redesigned accordingly. This extension of the operating range of the tail lift (x, z) may eliminate the risk of lateral loading, thereby establishing a wider operating envelope for the tail lift. The redesigned tail lift can be validated through prototype fabrication and testing under the expected loading spectrum.

10. ZAKLJUČAK
10. CONCLUSION

The widespread use of truck loading tail lifts indicates the need for greater attention to their operational safety. The cargo-handling process throughout the service life of a tail lift must be safe and free from failures, collapses, and injuries to personnel. European regulations requiring the implementation of tail lift safety requirements impose an obligation to monitor and verify tail lift safety, which essentially represents a general position regarding the entire class of rear tail lifts.

We conducted a safety assessment of a standard hydraulic truck loading tail lift equipped with a four-bar lifting mechanism. The analysis identified the highly stressed components of the tail lift and provided an estimate of the fatigue life of the pins. To improve the safety of tail lift operation, a nominal load capacity applicable across the entire area of one-half of the platform was proposed. This defines a larger safety envelope (x–y), thereby contributing to the further development of rear tail lifts. In this way, the research objective was achieved, together with the possibility of enhancing the safety of rear truck tail lifts.

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11. REFERENCES

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AUTORI · *AUTHORS*



• **Dinko Mikulić** - The author of a significant number of scientific and professional papers in the field of motor vehicle, construction machinery, and special-purpose machine design, published in domestic and international journals (CROSBI). He is the author of the books: *Motor Vehicles* (VVG, 2020), *Design of Demining Machines* (Springer, 2013), *Construction Machines* (Springer, 2024), *Građevinski strojevi* (Construction Machinery) (VVG, 2025). At the University of Applied Sciences Velika Gorica, he lectures in the courses Motor Vehicles and Construction Machinery.

Korespondencija · *Correspondence*

dinko.mikulic@vvg.hr



• **Draško Mück** - The author of scientific and professional papers in the field of motor vehicles, published at national and international conferences. He is employed at DOK-ING d.o.o. in Zagreb. He is the Head of the Design Solutions Development Group. At the University of Applied Sciences Velika Gorica, he lectures in the courses *Mechanics and Strength of Structures*.

Korespondencija · *Correspondence*

drasko.muck@dok-ing.hr