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FREIGHT VEHICLES PAYLOAD AND DESIGN ANALYSIS

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SAŽETAK

Preopterećenja građevinskih kamiona oštećuje ceste i mogu uzrokovati probleme sigurnosti prometa. Proveli smo istraživanja problema i razjasnili problematiku osovinskog opterećenja teretnih vozila. Analizirali smo suvremena tehnička svojstva i specifikacije podvozja kamiona i koncepte oblikovanja kiper nadogradnje. Pitanje razmještaja osovina je vrlo važno kao i pitanje aktiviranja podiznih osovina. Formirali smo dijagrame raspodjele opterećenja kamiona u tovarnom sanduku te opisali potrebna vučna svojstva višeosovinskog kamiona. Brojna teretna vozila nisu samo sredstva prijevoza nego i predmet korištenja cesta i sigurnosti prometa, zato je važno kako se poduzetnici i inspekcija nose s ovim izazovom radi povjerenja javnosti.

Ključne riječi: *teretna vozila, građevinski kamioni, kiper kamioni, nosivost kamiona, dijagram raspodjele opterećenja kamiona*

ABSTRACT

Construction trucks overloading damages roads and can cause traffic safety problems. We conducted research on the problem and clarified the issue of axle load of freight vehicles. We have analyzed the modern technical properties and specifications of the truck chassis and the design concepts of the tipper superstructure. The issue of axle placement is very important, as is the issue of activating the lifting axles. We formed diagrams of truck load distribution in the cargo box and described the necessary traction properties of a multi-axle truck. Numerous freight vehicles are not only means of transport but also the subject of road use and traffic safety, so it is important how entrepreneurs and the inspection deal with this challenge for the sake of public trust.

Keywords: *freight vehicles, construction trucks, tipper trucks, truck payload, truck load distribution diagram*

1. PROBLEMI I IZAZOVI
1. PROBLEMS AND CHALLENGES

Overloaded trucks cause damage to roads and can generate road safety problems. It is primarily for the drive to increase transport productivity that trucks get overloaded. Such overloaded vehicles are a frequent cause of accidents and casualties, as the accidents involving heavy vehicles has almost doubled [1]. Trucks are the lifeblood of any healthy market economy and a measure of economic success, therefore the state must ensure quality traffic control and regulation.

The problem of a large number of heavy trucks passing through settlements, where, in addition to damage to roads and damage to houses, the safety of citizens, especially children, peace, cleanliness of the environment and violation of traffic regulations is unacceptable, so citizens appeal for more frequent controls of their cargo, inspections. Under the threat of the traffic blockade, local communities and carriers request the state to come up with better transport solutions. For this reason, on certain sections of state roads, for example, during the tourist season, a ban on the movement of commercial vehicles with a maximum permissible weight of more than 7.5 t is introduced. In general, cargo transportation must comply with the requirements of the *Road Traffic Safety Act* [2].

At specially organized points, checks are carried out under the name "Trucks and Buses Monitoring" which are coordinated with activities throughout the European Union (RoadPol - European Traffic Police Network). The activities

carried out include checking the vehicle speed, testing the driver for alcohol and drugs, weighing the vehicle, the driver's work and rest time, evenly loading the cargo on the vehicle, properly securing the cargo in the vehicle, and the technical condition of the vehicle. Employees of Croatian roads monitor the axle load, while using the vehicle technical inspection mobile station of the Centre for Vehicles of Croatia.

For example [3], in the territory of the Primorsko-Goranska Police Department during 13th May and 19th May 2024, 114 trucks were inspected, of which 96 had Croatian registration plates. Out of the total number of controlled trucks, 28 were in violation. The largest number of violations refers to violations of technical provisions - eight, ***vehicles overloads - six***, exceeding the driving time - seven, etc. Perpetrators of violations are sanctioned in accordance with the provisions of the *Act* [2] and other regulations regulating violations.

The aim of this research is to analyse the key performance of heavy construction trucks and to form axle load models. The purpose is to provide a comprehensive understanding of the problem and how to solve it, and to point out the importance of protecting people and road infrastructure in order to respond more successfully to practical challenges. The analysis, calculation, synthesis and description methods were used in the preparation of the work, along with expert sources and publications specific to construction trucks.

2. GRAĐEVINSKI KAMIONI
2. CONSTRUCTION TRUCKS

Construction trucks belong to the cargo vehicles category. They are classified as the category N of road motor vehicles, and their trailers and semi-trailers in the category O of road vehicles. Construction operatives mostly use trucks for the transport of bulk cargo, concrete mixer trucks, concrete pumps, tankers and others. Construction trucks are often used in combination with a trailer or in combination with a towing vehicle and a semi-trailer (tractor).

The paper considers the most numerous construction trucks used for transporting bulk cargo and other construction materials, Figure 1. These are self-unloading trucks, i.e., tipper trucks equipped with an open or closed box, with a rectangular or oval tipper box for bulk cargo. They are loaded with backhoes, loaders or cranes. They can also be used for transporting palletized goods (with a crane) or transporting containers.

Slika 1 *Građevinski kiper kamioni 8x4, 6x4*

Figure 1 *Construction tipper trucks 8x4, 6x4*

Standard dump trucks

The most used trucks in construction, especially when building roads and communal infrastructure, are four-axle trucks. These are tipper trucks with four axles (8x4, two rear axles driven), which have off-road capabilities (8x6 and 8x8).

Four-axle tipper trucks are considered representative trucks in construction operations. This stems from the fact that two 8x4 tipper trucks can transport more cargo than three classic 6x4 or 4x2 trucks. Compared to three trucks, this means lower maintenance costs due to one less vehicle and one less driver. The advantage is that one less vehicle on the road leaves more space for other road users. Therefore, the standard multi-axle chassis provides a variety of options for upgrading construction equipment, from concrete mixers and pumps, truck cranes, etc., to military superstructures [4].

Slika 2 *Standardni kiper kamioni*
Figure 2 *Standard tipper trucks*

The maximum permissible mass of an 8x4 tipper truck is 32 tons, about 50% of which is the empty vehicle itself. This means that the carrying capacity of the vehicle is equal to the weight of the empty vehicle. By using lighter materials of higher strength in the design, the weight of the truck is reduced and a higher payload is achieved. Thus, the payload of modern 8x4 tipper trucks increases to 20 t. For example, the dump truck *Iveco Trakker 440 8x4* has a declared curb weight of 14.8 t, a payload of 17.45 t, so the total permissible weight is 32.25 t. Tipper trucks are powerful machines, the power of the drive diesel engine is in the range of 250-450 kW, for a four-axle vehicle (32 t), the power-to-weight ratio ranges from 8 to 14 kW/t.

Examples of construction tipper trucks 8x4 with the maximum permissible mass of up to 32 tons: *Mercedes-Benz Arocs 4145K, MAN TGS 35.440, IVECO Trakker 360, VOLVO FMX 460, RENAULT Kerax 460. DAF FAD CF 460, Figure 2.*

2.1. PODVOZJE KAMIONA
2.1. TRUCK CHASSIS

The truck's undercarriage (chassis) takes over the entire load of the vehicle. It consists of a basic frame on which all circuits and power transmission systems from the engine to the wheels, steering and stopping devices and electronic devices are located.

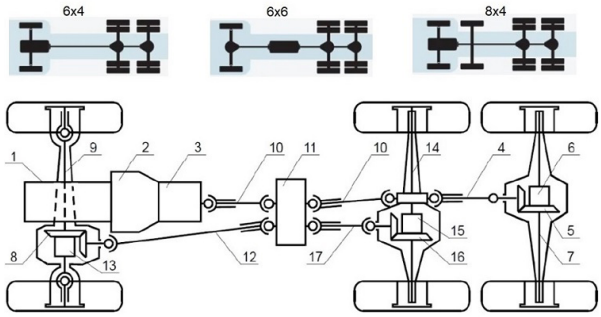
Diesel engines are the source of power, enabling the truck to negotiate the most difficult conditions of use. 6- or 8-cylinder engines, in-line or V-shaped, with Common Rail injection, turbocharging and 4-valve technology are used. The basic performance indicators of the engine are the speed characteristic, i.e., power, torque and fuel consumption as a function of the number of revolutions at full engine load. The engines of standard trucks develop a power of around 300 kW and a torque of around 2000 Nm, whereby the torque is constant in a wide range of engine rotation and the road fuel consumption is 20-40 l/100 km.

The truck *transmission* is mostly semi-automatic or automatic, which includes the gearbox, the power distributor between the front and rear axles, axle reducers and differentials, and a planetary reducer in the wheels, Fig. 3. The driver has a choice of manual or automatic gear changes, for road or off-road driving. Automatic gear shifting processes depend on driving conditions and the position of the gas pedal.

In some versions of trucks with air suspension, in order to achieve optimal traction, variable axle load is used by way of the variable axle load ratio function of the two rear drive axles (MAN, ...). The first drive axle is loaded up to the point of the prescribed axle load. Beyond that, the additional load is taken up by the second drive axle. The total axle load is therefore not fixed but variably distributed between the rear drive axles. Before that, the inter-axle differentials are blocked, so that the driving torque remains on the loaded axle. In this way, the drive axle provides the necessary traction for a certain load of the truck. Some trucks and tractors have the option of a front axle with a hydrostatic drive HydrDrive for safe pulling out in difficult terrain (mud, gravel, ...).

The *gearboxes* offer a large selection of gears (9-18), which also include off-road driving. For example, the 32-ton *Mercedes Arocs* has an automated G 280-16 *powershift* transmission (16 gears) that changes gears quickly and precisely; in *off-road* mode, it reduces the number of changes to a quarter, which ensures easier driving with a cargo and on uneven ascents. The trucks have double wheels on the drive axles (less tire wear

compared to single wheels). The markings on the tires show the dimensions, type of tire and its performance. The designation 315/80 R 22.5 154M determines the width of 315 mm, the height of the tire profile is 80% of the tire width, R - radial design of the tire, rim diameter 22.5 inches, load index of double wheels 154/154 at pressure of 8.5 bar and M vehicle speed index (130 km/h).



Slika 3 *Shema transmisije kamiona*
1-motor, 2-spojka, 3-mjenjač, 4,10, 12, 17 - kardanska vratila, 5, 8, 16 - reduktori, 6, 13, 15 - diferencijali, 7, 9, 14 - pogonska vratila kotača, 11- razdjelnik snage

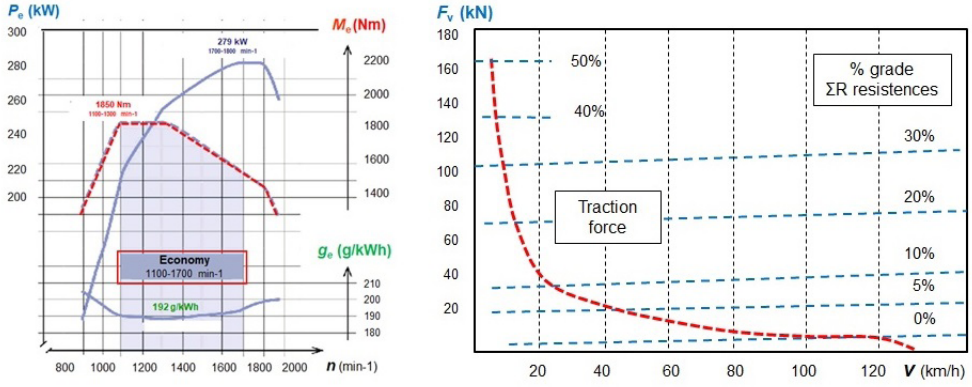
Figure 3 *Truck transmission scheme*
1-engine, 2-clutch, 3-gearbox, 4,10, 12, 17 - cardan shafts, 5, 8, 16 - reducers, 6, 13, 15 - differentials, 7, 9, 14 - wheel drive shafts, 11 - power distributor

Truck users use the traction diagram to estimate its efficiency. The traction diagram is the result of the joint operation of the engine, transmission and wheels and is a graphic representation (F-v) of the traction forces on the drive wheels on the one hand and the movement resistance on the other as a function of the speed of movement, Figure 4.

For example, using the traction diagram of a 36-ton tipper truck, for instance *FH12/380 8x4* (*engine D12D380, gearbox VT221 4B*), the performance of the vehicle under full cargo conditions can be evaluated, which allows construction operations to optimally utilize the vehicle. The truck can achieve a high traction force (160 kN on a 50% grade) on the drive wheels. The economic speed of the vehicle on the road is 70-105 km/h, at an engine speed of 1200-1700 min-1. The maximum speed is 125 km/h on a straight road and 25 km/h on a 10% gradient.

Truck *suspension* can be made with leaf parabolic springs (or semi-elliptical) or air springs. The air suspension system provides automatic regulation of the box height and ground clearance, as well as greater comfort. VASC (*Vehicle Air Suspension Control*) electronically controlled air suspension allows the vehicle frame to be raised and lowered to suit a specific application, for example to maintain a constant ground clearance, regardless of vehicle load. *Steering* of the four-axle truck 8x4 is performed with the wheels of the two front axles. The powered system makes for easy steering, with a turning radius of about 21 m.

Truck *braking* is pneumatic. Braking force is developed by way of compressed air. The air is compressed into the tanks with the help of a compressor powered by the engine. Modern trucks also use additional systems such as hydrodynamic brakes, electromagnetic brakes and engine brakes, as well as active braking systems. The electronically regulated brake system (EBS) ensures optimal matching of braking forces between the wheels, as well as between the towing and trailer vehicles. An advanced feature of the EBS-system is the speed of response of the braking system, which gives the shortest stopping distance of the vehicle.



Slika 4 *Brzinska karakteristika motora i vučni dijagram kamiona [5]*

Figure 4 *Engine speed characteristic of the engine and traction diagram of the truck [5]*

2.2. KIPER NADOGRADNJA
2.2. TIPPER SUPERSTRUCTURE

Computerized *vehicle superstructure software packages* enable truck and trailer designing, with the ability to add equipment such as cranes (front/rear), and more. The basic versions of cargo box superstructures are: open cargo box with sides, open cargo box with self-unloading, cargo box with tarps and tarpaulin, and closed cargo box with rear (and/or side) doors. In addition to the overall dimensions of freight vehicles, trucks differ in the length of their cargo boxes. The length of cargo boxes is determined according to the type of cargo to be transported and the wheelbase (number of axles).

Design concepts of tipper boxes for bulk cargo:

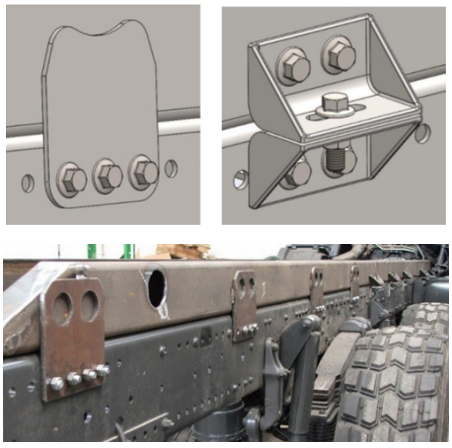
1. *K1 concept* - three-sided dump truck upgrade of rectangular shape
2. *K2 concept* - rear tipper upgrade with box, rectangular and oval shape

The basic versions of tipper boxes are open or closed structures (open with tarpaulin and self-unloading). The tipper box is designed in a rectangular or oval shape (*Half Pipe*), Figure 5.

Slika 5 *Kiper kamion s pravokutnim i ovalnim sandukom*

Figure 5 *Tipper truck with rectangular and oval box*

The box is connected to the chassis of the vehicle via a subframe. The auxiliary frame withstands complex stresses caused by the load. The place of the greatest moment determines the critical point, so a rigid connection is placed at that place. From that place, elastic connections are placed towards the front of the vehicle, and rigid connections towards the rear. By using rigid connections between the main and auxiliary chassis, an interacting substructure is obtained where the interconnected elements behave as a whole. Such a construction has the necessary resistance to deformations (bending, twisting) and enables taking on greater loads and increasing the carrying capacity of the vehicle, Figure 6.

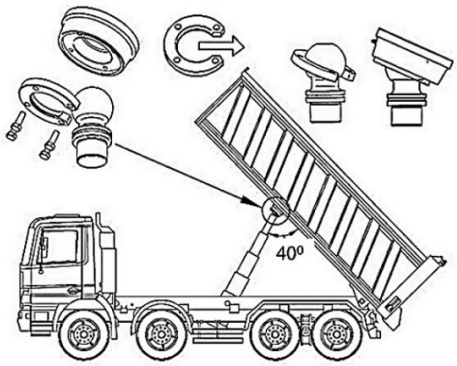


Slika 6 *Oblici veza dva okvira: kruta i elastična veza [8]*

Figure 6 *Connection forms of two frames: rigid and elastic connection [8]*

When the truck is unloaded, the hydraulic telescopic cylinder lifts the crate to an unloading angle of maximum 450. For heavier tipper cargo beds, scissors are installed to stabilize the bed, which ensure lifting stability. The hydraulic cylinder is most often connected in the middle of the bed and secured by a connection of a specific shape into which the ball fits, Figure 7.

The gear pump of the hydraulic installation is powered by the transmission output (PTO - *Power Take-Off*). The raising or lowering of the cylinder is provided by an oil distributor, which is controlled by an air control valve. The hydraulic cylinder is selected according to the force required to lift the tipper bed with the cargo and according to the length of the cylinder. The required force of the hydraulic cylinder is performed for the case of rear tilting of the box. In the case of lateral tilting, the required force is less than in the case of rearward tilting.



Slika 7 *Spajanje hidrauličnog cilindra na okviru sanduka*

Figure 7 *Connecting the hydraulic cylinder to the box frame*

3. NOSIVOST KAMIONA I OSOVINSKO OPTEREĆENJE

3. TRUCK CAPACITY AND AXLE LOAD

The carrying capacity of trucks is their basic characteristic. Vehicle payload is the difference between the maximum permissible vehicle weight and the empty vehicle weight in driving condition. The maximum permissible mass is the mass of the vehicle along with its payload. The axle load is part of the total mass of the vehicle in a horizontal position with which its axle loads the horizontal surface when the vehicle is at rest. The limitation of axle load is related to the protection of roads from overloading.

The payload of the vehicle depends on the permissible axle load and the number of axles. The maximum permissible load of the vehicle at rest on a horizontal surface [6] is:

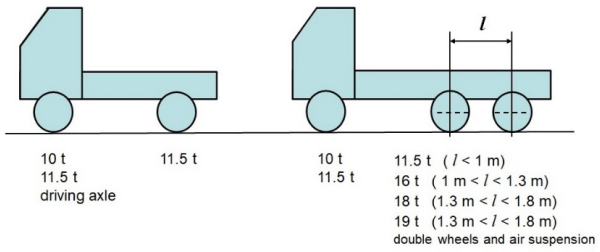
• For a two-axle vehicle 18 t

• For a three-axle vehicle 25 t (26 t)

• For a four-axle vehicle 31 t (32 t)

Exceptionally, three-axle and four-axle motor vehicles may have a maximum permissible mass of 26 t or **32 t** respectively if the drive axle of the motor vehicle is equipped with double tires and air suspension or if the drive axle is equipped with double tires and the maximum permissible mass of each axle does not exceed 9.5 t. The maximum permissible mass of a combination of vehicles with 5 or 6 axles is **40 t** (this includes a two- or three-axle tractor and a two- or three-axle semi-trailer, but also includes a two- or three-axle towing vehicle and a two- or three-axle trailer). In the case of a combination of 4 axles, the maximum permissible weight of the set of vehicles is 36 t (two-axle tractor and two-axle semi-trailer or two-axle towing vehicle and two-axle trailer).

In the case of a statically loaded vehicle, the axle load at rest on a horizontal surface for single (individual) axles must not exceed **10 t** for free axles and **11.5 t** for driven axles. The following is the permissible load of multiple axles, while respecting the load of one axle, Figure 8:

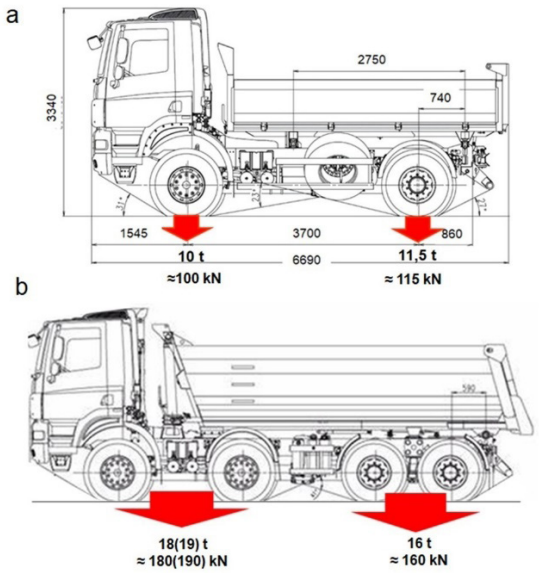


Slika 8 *Najveće dopušteno osovinsko opterećenje kamiona*

Figure 8 *The maximum permissible axle load of the truck*

A single axle is defined as any individual axle that is at least 1.80 m away from the adjacent axle. The payload is expressed by mass (kg or t) which is appropriate from the point of view of use. Axle loads determine the permissible weight of the vehicle and thus the maximum weight of the cargo.

For example, the maximum permissible load of a two-axle and four-axle truck is shown in Figure 9.



Slika 9 *a - Najveće dopušteno opterećenje dvoosovinskog kamiona*
b - Najveće dopušteno opterećenje četveroosovinskog kamiona

Figure 9 *a - Maximum permissible axle loading of a two-axle truck*
b - Maximum permissible axle loading of a four-axle truck

3.1. PODIZNE OSOVINE KAMIONA

3.1. TRUCK LIFTING AXLES

When there is a need to transport more cargo in order to increase the productivity of the truck, there is the possibility of adding lifting non-

driven axles and thus preventing overloading of the truck. Lifting axle means an axle that can be raised from its normal position and lowered again by means of an axle lifting device. There are two such lifting axles: Pusher Axle and Tag Axle, which are first of all distinguished by their position in the vehicle chassis and the way they help distribute the load. Both the push and tag axles are used to increase the payload of the truck in accordance with the legal limits allowed. The thrust axle is placed in front of the rear drive axles, and the supporting axle behind them, so that when transporting larger cargo, they can relieve the rear drive axles.

According to [6], lifting axles are referred to vehicles equipped with air suspension systems, because the air cushions provide easy lifting and lowering of the axles. Advanced systems offer automatic lifting and lowering of the lifting axle independent of the driver, in accordance with the load on the axles. On the same vehicle, both a pusher and a trailing axle can be used, or more of them. In fact, raising the axles is used when driving an empty vehicle in order to reduce rolling resistance, thereby saving fuel, reducing the wear of tires, bearings and all other parts. Figure 10 shows the use of lifting axles on trucks.

The installation of a thrust axle shortens the wheelbase between the first and the centre of the rear axles, which provides additional vehicle stability. By installing a trailing axle, the same wheelbase is increased, which means that the cargo box can be extended. When the vehicle is fully loaded, even during unloading, the weight is transferred to the trailing axle, offering support at the rear of the vehicle, thereby taking some of the load off the drive axles.

Lifting axles have a positive effect on the road infrastructure. There are disadvantages to using lift axles. Additional axles in the chassis take up space, increase the weight of the vehicle, make the truck more complex and expensive. When cornering, there is a "scrubbing" effect, which negatively affects the handling of the vehicle. By raising the trailing axle, the vehicle's handling is improved.

4. RASPODJELA OPTEREĆENJA KAMIONA
4. TRUCK LOAD DISTRIBUTION

The cargo distribution inside the cargo space of the truck is of great importance because it directly affects the load on the axles, the safety of moving and stopping the vehicle. The cargo in the cargo box should be distributed in such a way that the permissible axle loads are not exceeded. The axle load is affected not only by the cargo, but also the mass distribution of the base vehicle. Therefore, it is necessary to know the load distribution on the cargo space platform. Modern truck upgrade computer packages offer truck and trailer technical calculations (e.g., *TrailerWin, Axle Weight Calculator*) [7].

Construction tipper trucks can carry different types of cargo beds for bulk cargo (**10-30 m^3**) according to work in a certain soil category or material density (larger box volume for lighter material 1000-1800 kg/m^3, smaller volume for heavier material 1800-3000 kg/m^3). It is important to use the adequate bed according to the purpose of transport, because an underutilized truck is not economical. For example, a truck with the bed volume of 10 m^3 for transporting gravel with a

Slika 10 *Pozicije podiznih osovina na kamionima (10x4 i 10x2), a - potisna osovina u sredini, b - prateća osovina straga, c - potisna osovina i prateća osovina na istom podvozju*

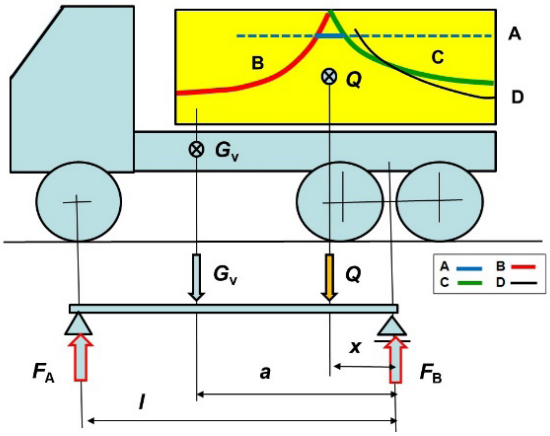
Figure 10 *Positions of lifting axles on trucks (10x4 and 10x2), a - push axle in the middle, b - tag axle at the back, c - pushing axle and tag axle on the same chassis*

a b c

density of 2000 kg/m^3 should have a payload of 20 t. A truck with the bed of 20 m^3 should have the same carrying capacity of 20 t for transporting humus with a density of 1000 kg/m^3.

The mass of the vehicle and the mass of the cargo when moving and stopping affects the load on the axles, that is, the longitudinal and transverse stability of the truck. In accordance with the upgrade regulations, the manufacturer recommends the centre of gravity be located in front of the rear axle of the vehicle. Rarely, but sometimes for certain superstructure configurations (e.g., a crane behind the cab and a smaller box at the rear of the vehicle with a short wheelbase truck) the centre of gravity of the cargo area is in the centre of the rear axle or slightly behind it. It is important that the permissible axle loads are not exceeded and that the load on the front axle is sufficient to maintain vehicle steering.

Depending on the permissible payload and the position of the centre of gravity of the empty vehicle, each type of vehicle has a ***load distribution diagram***, so that there is no excess axle load and unsafe driving. The centre of gravity of the cargo should be within the permissible load curves, Fig. 11.



Slika 11 Model opterećenja troosovinskog kamiona
A - ograničenje najveće dopuštene nosivosti kamiona, B - ograničenje dopuštenog opterećenja prednje osovine, C - ograničenje dopuštenog opterećenja stražnje osovine (osovina), D - omjer opterećenja prednje osovine prema ukupnoj masi vozila

Figure 11 Three-axle truck load model
A - limitation of the maximum permissible payload of the truck, B - limitation of the permissible load of the front axle, C - limitation of the permissible load of the rear axle (axles), D - ratio of the load of the front axle to the total weight of the vehicle

4.1. ODREĐIVANJE DIJAGRAMA RASPODJELE OPTEREĆENJA

4.1. DETERMINATION OF THE LOAD DISTRIBUTION DIAGRAM

It is practical to include the mass of the tipper superstructure with the bed in the mass of the vehicle (the position of the centre of gravity is determined through weighing and calculation) because this superstructure is permanently attached to the vehicle. Then a load distribution diagram is created and the permissible position of the centre of gravity of the cargo and the permissible mass of the cargo in relation to the position inside the cargo space are obtained.

a –Position of the centre of gravity of the empty vehicle from the rear axle (ΣMB=0)

$a = F_{A,v}\, l / G_v \quad [mm]$

$F_{A,v}$ – Vehicle front axle load – without cargo (manufacturer's data)

G_v - Empty vehicle mass, including the tipper superstructure (manufacturer's data)

b – Position of the centre of gravity of the cargo from the rear axle (ΣMB=0)

$x = (F_{A,max}\, l - G_v\, a) / Q \quad [mm]$

$F_{A,max}$ – Vehicle front axle load (calculation, N)

Q – Vehicle maximum load, truck payload (N)

The cargo centre of gravity position (x) should be in front of the axis of the rear axle. At the same time, the front axle must be loaded with at least 20% of the total load.

Axle load

Front axle load at maximum cargo (ΣMB=0)

$F_{A,max} = (G_v\, a + Q\ x) / l \quad [N]$

Rear axle load at maximum cargo (ΣMA=0)

$F_{B,max} = [G_v\, (l-a) + Q\, (l-x)\ ] / l \quad [N]$

Formation of load curves, A, B, C, D [8,9]

A - Maximum permissible payload of the truck limit

$m_{max,A} = m_{v,dop} - m_v \quad [kg]$

$m_{v,dop}$ – Gross weight

m_v – Curb weight (G_v – Curb weight with the tipper superstructure)

B – Maximum permissible front axle load

$m_{max,B} = (m_{p,dop}\ l - m_p\ a\ ) / x \quad [kg]$

$m_{p,dop}$ – Maximum permissible front axle mass

m_p – Empty vehicle mass on the front axle

C – Rear axle(s) permissible load limit

$m_{max,C} = [m_{s,dop}\ l - m_v\ (l\text{-}a)\ ] /\ l - x \quad [kg]$

$m_{s,dop}$ – Rear axle maximum permissible mass

m_v – Empty vehicle mass

D - minimum front axle load ratio, as the ratio of the front axle load to the total vehicle weight (to ensure vehicle controllability)

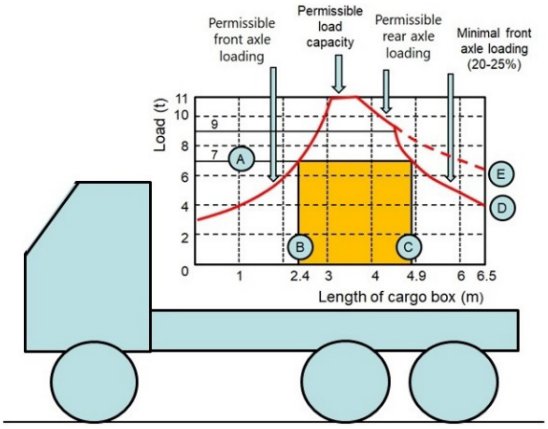
Front axle load in percentage, for certain distances from the front axle

$(F_{A,max} /\ G_v + Q\ )100 \geq 25\%$

The relationship between the front axle load and the distance of the centre of gravity of the superstructure and the cargo from the rear axle (x), in the formula below %m = 25.

$m_{max,D} = m_v\ (a / l - \%m /100) / (\%m /100 - x / l\ ) \quad [kg]$

Construction trucks carry different types of concentrated cargo (*load blocks*). An example of a load distribution diagram, as well as the correct and the incorrect cargo position methods, is shown in Fig. 12.



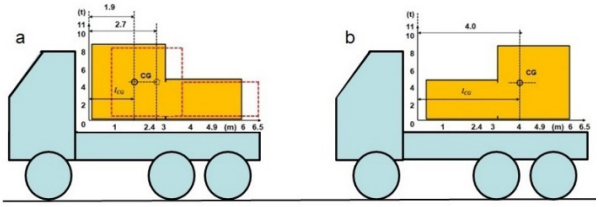
Slika 12 *Dijagram raspodjele opterećenja kamiona*

Figure 12 *Truck load distribution diagram*

The curves show the permissible axle loads and the position of the cargo. As can be seen in the picture, the permissible payload of 11 t can only be used if the centre of gravity of the cargo is in a small range of 3.1 m to 3.7 m distance from the front side of the loading area. For example, for hauling a cargo weighing 7 t (direction A). Vertical lines B and C limit the position within which a cargo can be placed and secured that meets the front and rear axle load limits and the minimum front axle load requirement. For the safety of driving the vehicle, the front axle must not be overloaded or unloaded (at least 20% of the total load, D).

The following is an example of three ways of positioning the cargo with the aim of finding the optimal position, Figure 13.a. Let the mass of the cargo be 9 t, with the length of 6 m, while the distance of the cargo's centre of gravity from the front end of the cargo area is 1.9 m. When the position of its centre of gravity is compared with the diagram in Figure 12, the conclusion follows that a cargo weighing 9 t must not be so set because for that position of the centre of gravity of the cargo, the maximum payload is approximately 5.8 t.

A good position is achieved by moving the cargo in relation to the first position by, for example, 0.8 m backwards, which places the centre of gravity of the cargo within the given limits (between 2.6 m and 4.5 m). The optimal solution is to rotate the cargo by 180°, which positions the centre of gravity of the cargo within the axle limit curves (b).



Slika 13 *Pozicioniranje tereta unutar ograničenja osovinskog opterećenja*

Figure 13 *Positioning the cargo within the axle load limits*

So, in order to estimate the load on the front axle, it is necessary to know the position of the centre of gravity of the cargo. The cargo can be moved, which can reduce the distance of the centre of gravity from the axis of the rear axle, which at the same time relieves the front axle of the vehicle. For security against movement, unlike bulk cargo in a cargo box, cargo units must be expertly secured to the floor of the box with lashing means.

Knowing the centre of gravity of the cargo is important in order to place the cargo in the correct position. With symmetrical units, it is easier to determine the centre of gravity. In the case of multiple units, it is necessary to determine the "resulting" centre of gravity:

$l_{CG} = (m_1 l_1 + m_2 l_2 + m_3 l_3 + ---) / (m_1 + m_2 + m_3 + ...)$

m_i – Cargo mass (kg, t)

l_i – Distance of the cargo's centre of gravity from the front edge (m).

The centre of gravity of the entire cargo should be on the centre line of the vehicle, and the cargo should be evenly distributed on each side and properly secured with biding devices (straps).

5. ZAKLJUČAK
5. CONCLUSION

In the research, the problem of the axle load of freight vehicles was clarified, then the distribution and diagram of the vehicle load was modelled for practical use, in accordance with the permissible axle load. In the cargo box, the cargo must be properly distributed and secured in accordance with the traffic safety regulations.

The modern technical properties and specifications of the undercarriage of construction trucks and their tipper superstructures were analysed. Traction and braking characteristics were analysed, which show the vehicle's ability to move and stop. The role of lift driving and non-driving axles in order to increase the payload is clarified. Lift axles are recommended for vehicles equipped with air suspension systems, because the air cushions provide easy lifting and lowering of the axles. Such axles have a positive effect on the road infrastructure because they reduce the risk of violation. In order to protect roads and bridges from damage, regulations in some countries encourage the use of trucks with lift axles.

Finally, the analysis of the payload of freight vehicles and their adequate construction was carried out in accordance with regulations.
The importance of protecting people and road infrastructure was highlighted, which achieved the goal and purpose of this research.

6. REFERENCE
6. REFERENCES

[1.] Profit važniji od sigurnosti? Pretovareni kamioni počeli su sijati smrt na našim cestama, eTV, https://evarazdin.hr/etv/21.11.2016.

[2.] Zakon o sigurnosti prometa na cestama, NN 67/08 s izmjenama i dopunama, 2023.

[3.] https://kanal-ri.hr/od-114-kontroliranih-teretnih-vozila-28-je-bilo-u-prekrsaju/; 21/05/2024

[4.] Mikulić D.: Motorna vozila, Teorija kretanja i konstrukcija. VVG, Velika Gorica, 2020.

[5.] www.vbi.truck.volvo.com/portal/perfman/index.htm#010 manual/100 tractive effort.htm, 2024.

[6.] Commission Regulation (EU) No 1230/2012 o provedbi Uredbe (EZ) br. 661/2009 Europskog parlamenta i Vijeća o zahtjevima za homologaciju tipa za mase i dimenzije vozila i njihovih prikolica.

[7.] www.trailerwin.com/product, 2023.

[8.] Mikulić D., Muck D.: Construction Machines, Springer Nature Switzerland AG, 2024.

[9.] Rumbak M.: Konstrukcija nadogradnje komunalnog vozila prilagođenog manjim mjestima, Diplomski rad, Fakultet strojarstva i brodogradnje Zagreb, 2020.

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