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RESEARCH AND DESIGN OF MULTI-DIRECTIONAL DUMPING CONSTRUCTION IN TRUCKS

Summary. In the current transportation industry, especially transporting coal, sand, heavy stone, construction waste, etc., dump trucks occupy a critical position. Most traditional dump trucks can only dump goods vertically, so their manoeuvrability is not high. Especially in tight spaces such as construction sites, it causes many difficulties for loading and unloading traditional dump trucks, which takes a lot of time and effort for the driver. In this paper, we have mainly focused on solving the above difficulties. Hence a multi-dimensional dump truck model was designed. The hydraulic motor actuated by the directional valve rotates the container on the required side. This design aims to improve the features and performance of dump trucks compared to existing conventional vehicles. This concept will save operating costs & energy consumption, which leads to increased efficient working. In this study, the dump truck can rotate 1800 in both directions through a hydraulic motor and gearbox linked with slewing bearing.

Keywords: multi-dimensional dump truck, three-axis modern trailer, three direction dropping dumper

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1. INTRODUCTION

In today's industry, dump trucks are an indispensable means of transportation for any construction site. One of the problems raised is that setting the dump location of the vehicle in the desired direction to dump the material consumes too much time and energy and additionally limited working space poses challenges for efficient unloading of goods.

The reality is that there is a need for a dump truck that can dump materials in any desired direction. A multi-directional dump truck can be helpful for workers in material transfer, construction sites, garbage collection, gravel and sand material etc. It can also reduce vehicle power and fuel consumption when dumping it in multiple directions. Multi-directional dump trucks also take less time than dump trucks to do the same volume work. Trucks, dump trucks, and tippers are used to transport bulk materials from one place to another at the construction site in the mines or in the storage yards to fulfil the actual requirements of the site. Suppose someone with experience can understand the site conditions and available space in mines and on the construction site. It is tough to unload bulk material at the proper location. The trucker will have difficulty adjusting the dump truck, which takes considerable time, and effort to unload loose material.

As we all know, dump trucks are mainly used for loading and unloading bulk materials on construction sites, mines, and warehouses. The usual system available is the unloading of the material at the rear. We propose a new multidimensional dump truck with a 3D Solidworks model to solve the above difficulties. It is also a field that has received a lot of research attention.

Many scientists have studied the problem of multidimensional dump trucks. Deshmukh et al. [1] present a design that could unload the materials in three ways. This option was used for the ball socket joint to unload the material in the left or right direction and use the hydraulic cylinder on the backing side. For the container to move in three movements, the solution of this paper using a spherical joint is quite suitable. However, a pin must be used to fix one side of the ball joint when pouring on the left or the right. Prasath et al. [2] used an optional hydraulic cylinder and jacking mechanism to unload the trailer in three axes without external force. This option used a directional valve to activate the hydraulic cylinder. Along with the arrangement of suitable knee joints on the trailer and the linkage of the hydraulic cylinder, they could unload the trailer in three axes. The study of this design makes loading and unloading materials easy, saving time and effort for the driver. Rani. [3] proposed a plan for a dumper that can unload in any direction desired. This option used a pneumatic cylinder and sprocket mechanism. The pneumatic cylinder is responsible for lifting the container to dump the material, and the sprocket mechanism rotates the container to the desired pouring position. With this design, the vehicle can operate in limited working spaces and have applications in more than three directions. Pal et al. [4] rated dump trucks in three directions dropping dumpers. The reasons for this evaluation are attributed to problems encountered during material unloading in confined areas at construction sites or situations where the process of material dismantling is time-consuming. Therefore, this study evaluates the previous solutions for multidimensional dump trucks, which improve existing conventional vehicles. It helps prevent traffic congestion because dump trucks work quickly and efficiently. Hence, this option can save material unloading time and operating costs. Patel et al. [5] introduced a three-way tipper mechanism. This tipper can unload the materials in three directions without needing external force. This design is used for ball-socket joints and pneumatic cylinders to unload goods on the back, right, or left sides. The mechanism is designed to lift the tipper to unload the material in three directions. This project helps to unload goods safely, quickly, and effectively. It will be easier to dump goods in a limited area. Khilari et al. [6] and Shinde et al. [7] presented a design using the direction control valves, activating the hydraulic cylinder's ram and lifting the trailer cabin on the required side. Shashidar et al. [8] used the worm screw and worm wheel to rotate the trolley to a suitable unloading position and lift it by the hydraulic cylinder. Toke et al. [9] studied the unloading process in three axes with the help of locking arrangement and the pneumatic system. The direction control valve was used to control the flow direction of the pneumatic cylinder.

2. MULTI-DIMENSIONAL DUMP TRUCK DESIGN

We pose the problem of the method of dumping materials in a relatively narrow space, making it difficult to put the vehicle in the appropriate pouring position. Therefore, to solve the above problem, we offer a design plan for a dump truck that can quickly rotate the container in many different directions to dump materials. With this option, we use a hydraulic motor, reducer, and slew drive to rotate the container and lift the container using a telescopic cylinder. The chassis truck in our design is Kamaz 65115 [10]. The hydraulic pump is driven from the power take-off of the chassis truck and supplies oil to the telescopic cylinder and the hydraulic motor. The oil from the hydraulic pump will be connected to the direction valve. Through this valve, we can control the lifting and rotary of the container by the requirements set forth. Most of the studies on multidimensional dumpers used mechanical links, which have many advantages over traditional dump trucks. However, they also make it difficult to unload horizontal goods or can only be loaded and unloaded in three dimensions. Our research not only saves the installation of quick-release pins compared to the studied multidimensional dump trucks, but also can be dumped in more than three directions to improve the working efficiency of the vehicle.

2.1. Modern multi-directional dumping

The complex assemblies of the multidimensional dump truck are arranged as shown in Fig. 1. The hydraulic cylinder is responsible for lifting and lowering the dump truck, and the slewing bearing combines with the hydraulic motor and the reducer to reduce the load. Rotate the barrel to the desired pour position.

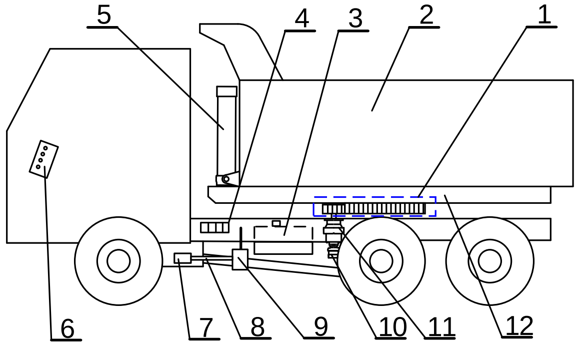


Fig. 1. General layout diagram of modern multi-directional

The proposed design model of the dump truck with its components is listed below:

1	Slew drive bearing	2	Dumping container
3	Hydraulic oil tank	4	Directional control valve

5	Hydraulic cylinder	6	Control panel
7	Power take-off	8	Propeller shaft
9	Hydraulic pump	10	Hydraulic motor
11	Gearbox	12	Sub-frame

Fig. 2 shows the distance from the center of gravity of components such as the lifting cylinder, subframe, hydraulic oil tank, bearing etc., to the centerline of the rear axle assembly (ROH line) in the direction of longitudinal and height of the vehicle design.

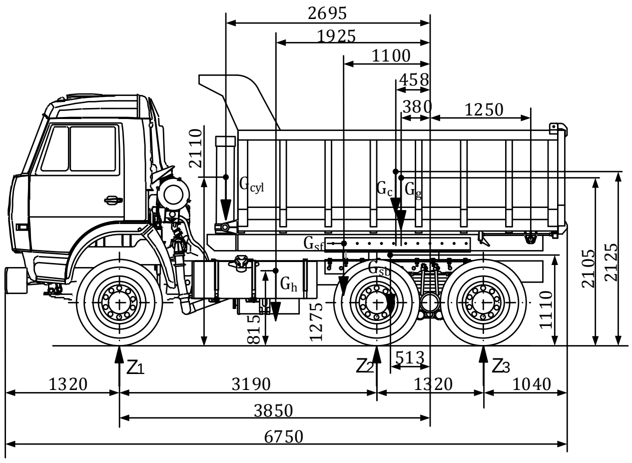


Fig. 2. The weight's center of gravity position

The general layout parameters of the design vehicle's mass, including the chassis truck, the subframe, the container, the lifting cylinder, Slew bearing and linkage base, pay-load and trucker, are shown in Table I.

Tab. 1

Dump truck axle weight distributions

Components	Total weight (kg)	Front axle (kg)	Rear axle (kg)
Chassis (G_{ch})	7725	4030	3695
Sub-frame (G_{sf})	350	100	250
Container (G_c)	1680	200	1480
Cylinder (G_{cyl})	200	140	60
Slew bearing and linkage base (G_{sb})	750	100	650
Hydraulic oil tank (G_h)	100	50	50
Trucker (G_{tr})	195	195	0
Pay-load (G_g)	13000	1285	11715
No-load (G_{nl})	10805	4620	6185
Full-load (G_{fl})	24000	6100	17900

2.2. Calculation of hydraulic cylinder

Fig. 3 describes the moving process from horizontal state to the vertical state driven by a telescopic hydraulic cylinder, the lifting angle of the container is 55°, corresponds to the lifting stroke of the container, $S = 3505\,mm$. The normal minimum dump angle is 45° and the normal maximum dump angle is 57°[11].

If the container is to be lifted when, the moment generated by the hydraulic cylinder must be greater than the resisting moment caused by the weight of the mass components for the center of rotation K.

Calculation of the minimum thrust force of telescopic cylinder with moment equilibrium about point K is shown as follows:

$$\sum M_K = 0 \quad (1)$$

or

$$-l_3F_{cyl} + g(l_2G_c + l_1G_g) = 0 \quad (2)$$

Where M_K is the moment of each component force about the point K, F_{cyl} is the thrust force of the hydraulic cylinder, g is the gravitational acceleration. Distance from the set point of the gravity of the goods, the gravity of load, and the thrust force to the center of rotation of the dumping container correspond to l_1, l_2, l_3.

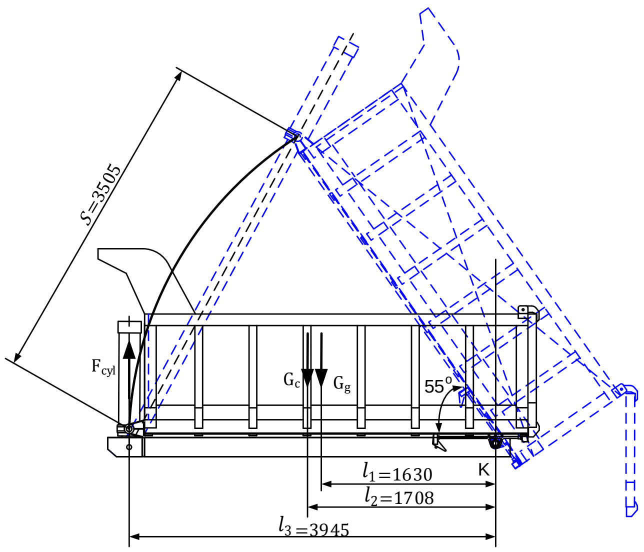


Fig. 3. Erection diagram driven by telescopic cylinder

The required thrust force is maximum at the starting position of the dumping container, and then decreases as the container is raised higher [12].

The following formula can calculate the thrust force of hydraulic cylinder:

$$F_{cyl} = p\frac{\pi D^2}{4.10^6} \quad (3)$$

Where p is the pressure of the hydraulic cylinder, D is the inner diameter of the hydraulic cylinder. The pressure of the hydraulic cylinder is selected $90\ bar$, because the max pressure of the hydraulic cylinder is approximately $200\ bar$ [11], and the max pressure constantly drop of the hydraulic motor about $100 - 140\ bar$ [13]. So it is necessary to choose the working pressure of the hydraulic system to be less than 100 bar.

From equation (2) (3), the minimum diameter of the cylinder can be calculated according to the following equation:

$$D = 2000\sqrt{\frac{F_{cyl}}{p\pi}} = 2000\sqrt{\frac{g(l_2G_c + l_1G_g)}{l_3p\pi}} \tag{4}$$

From formula (4), it is possible to determine the minimum diameter of the hydraulic cylinder $D = 92\ mm$, calculation for the first stage is also the smallest stage of the telescopic cylinder.

Therefore, we choose the hydraulic cylinder to lift the container, a telescopic cylinder with the parameters given in Tab. 2.

Tab. 2

Technical specifications of hydraulic cylinder [11]

MODEL NO. 5.5-3-138-B00				
Extension	1	2	3	Number of Stages: 3
Diameter (mm)	129	111	95	
Stroke (mm)	1164	1169	1172	Total Stroke: 3505 mm
Thrust (kN)	258	196	142	Thrust based on 220 bar
Oil (l)	15	11.2	8.2	Total Oil: 34.4 l

Besides, the maximum extension speed is less than 0.2 m/s[11], so the lifting time of the hydraulic cylinder is more than 17.5 seconds. Therefore, choose the lifting time of the hydraulic cylinder to be 30 seconds.

The flow of oil supplied to hydraulic cylinders:

$$Q_{cyl} = \frac{V}{t} = 68.8\ l/min \tag{5}$$

Where V is the total volume of hydraulic oil required for the telescopic cylinder, t is the lifting time of the hydraulic cylinder.

Minimum hydraulic pump power for lifting cylinder:

$$P_{cyl} = \frac{Q_{cyl}.p}{600} = 10.32\ kW \tag{6}$$

2.3. Calculation of slew bearing

The slewing bearing of the multi-directional dump truck is subjected to the equivalent axial load F_{ax}, the radial force F_{rad} and the bending moment M_k with the diagram shown in Fig. 4. Vertical loads acting on a slewing bearing is caused by weight components mounted above it.

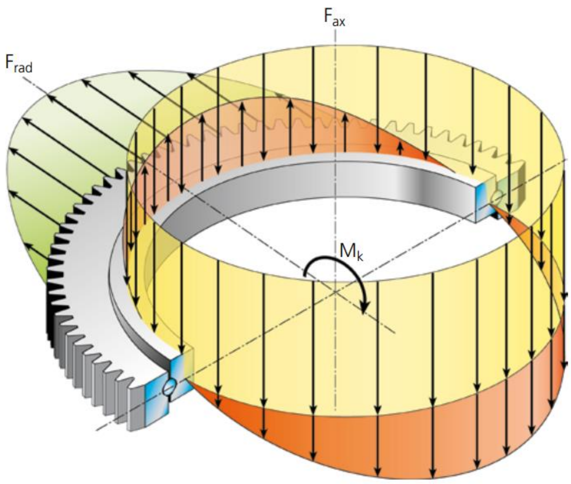


Fig. 4. Diagram of force and moment components acting on slewing bearings [14]

Therefore, the vertical load acting on the slewing bearing are given by the following equation:

$$F_{ax} = (G_{cyl} + G_{sf} + G_c + G_g)g = 149{,}4\ kN \tag{7}$$

Where F_{ax} is the equivalent axial load including all occurring impact loads and required safety factors, calculated from all axial forces.

From Fig. 5, it is possible to calculate the tilting moment on the slew bearing given by the following formula:

$$M_k = (-x_1 G_{sf} + x_2 G_c + x_3 G_g)g = 208.65\ kNm \tag{8}$$

Where M_k is the equivalent tilting moment including all occurring impact loads and required safety factors, calculated from all axial and radial forces causing tilting.

When the dumping container is at the maximum angle, the hydraulic cylinder has gone all the way, and the slewing bearing is subject to the maximum tilting moment. The distance from the set point of the gravity of the goods and the container to the center of the slewing bearing is shown in Fig. 5.

The equivalent radial load is given by the following equation:

$$F_{rad} = (G_{cyl} + G_{sf} + G_c + G_g)j = 17.51\ kN \tag{9}$$

Where F_{rad} is the equivalent radial load including all occurring impact loads and required safety factors, calculated from all axial forces.

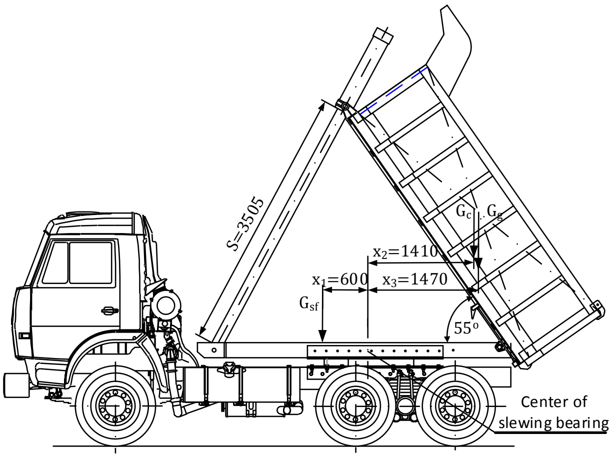


Fig. 5. Schematic diagram of the moment acting on the slewing bearing

According to research by Yang et al. [15] and Bokare et al. [16], the type of truck identified in this study is a medium truck. The maximum acceleration or deceleration rate of medium trucks is approximately $j = 1.15\ m/s^2$ ($3.78\ ft/s^2$).

The safety factors should be taken into account in the following equations for the prevailing loads [14]:

$$F_{axD} = F_{ax}.f_a \tag{10}$$

$$M_{kD} = \left(M_k + 1{,}73.F_{rad}.\frac{D_L}{1000}\right).f_a \tag{11}$$

Where F_{axD} is the equivalent axial load, equivalent tilting moment including equal radial load and application service factor for determining the load point in the limiting load diagram, M_{kD} is the equivalent tilting moment including equivalent radial load and application service factor for determining the load point in the limiting load diagram. The application service factor $f_a = 1.5$ for special vehicles [14]. Pre-selected slew drive SP-H 0855/2-05914 for dump truck with raceway diameter of the rolling elements is $D_L = 855\ mm$.

Tab. 3

Technical specifications of slew drive [14]

MODEL NO. SP-H 0855/2-05914	
Module (mm)	8
Number of teeth, wheel	122
Number of teeth, pinion	15
Slew drive gear ratio	8.13
Overall gear ratio incl. gearbox	147.21
Maximum torque (Nm)	47180
Static load rating, radial (kN)	1037

Static load rating, axial (kN)	2777
Dynamic load rating, radial *(kN)*	354
Dynamic load rating, axial *(kN)*	414
Weight, incl. 10 kg for hydraulic motor OMS125 *(kg)*	289

Table III has given the specifications of slewing bearing SP-H 0855, such as overall gear ratio, maximum torque, and static load rating etc. These are the main specifications of slewing bearings.

The radial load must satisfy the following equation [14]:

$$F_{rad} \leq 220.\frac{M_k}{1000} + 0{,}5F_{ax} \quad (12)$$

From equations (7) (8) (9), it is shown that equation (12) satisfies. According to equation (10) (11), we can calculate $F_{axD} = 224.1\ kN, M_{kD} = 351.82\ kN$.

Because Fig. 6 is the limit load diagram of slewing bearing SP-H 0855/2-05914. At point (F_{axD}, M_{kD}), check the limit load diagram, and see that the preselected slew drive is statically adequate.

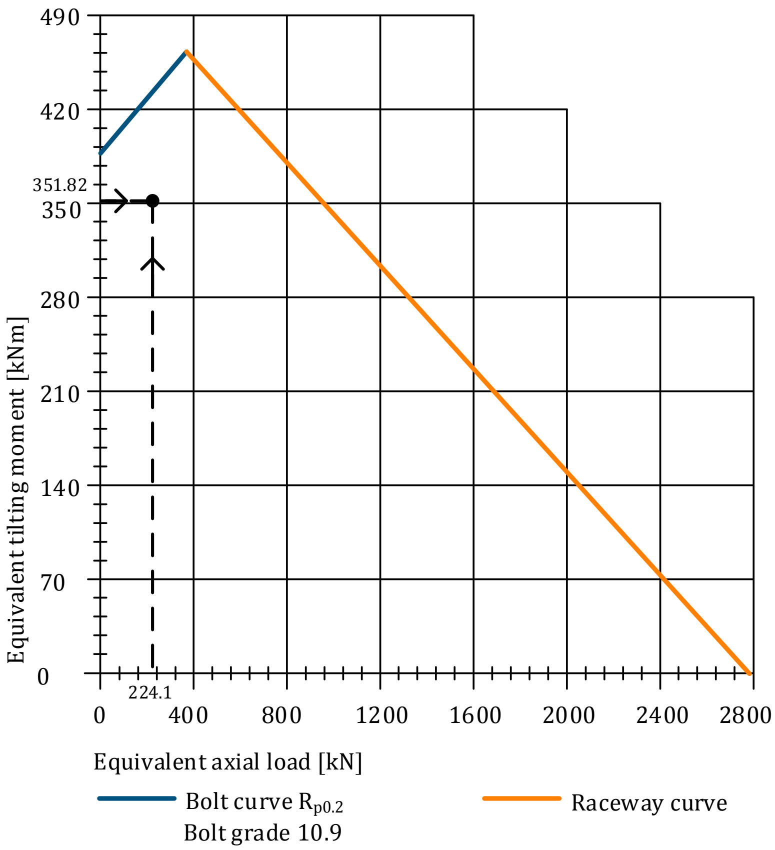


Fig. 6. Limiting load diagram for compressive loads for slew drive SP-H 0855/2-05914 [14]

It is clear that with a service factor of 1.5 by calculating the test and from the graph in Fig. 6, the load acting on the bearings still satisfies the allowable limit. Because the operating load point is below the limiting load curve, the slew drive is statically adequately dimensioned.

Determine the friction torque of an unloaded slew drive [14]:

$$M_{WA} = 0{,}2.\frac{D_L^2}{2000} \quad (13)$$

$$= 0.073\ kNm$$

The friction torque for a slew drive under load can approximately be determined using the following formula [14]:

$$M_W = 0{,}005.(4400.M_K + 4.D_L.F_{rad} + D_L.F_{ax}) + M_{WA} \quad (14)$$

$$= 5602\ Nm = 5.602\ kNm$$

Minimum torque on the shaft of hydraulic motor:

$$M_m = \frac{M_W}{\eta i_{tot}} \quad (15)$$

$$= 0.0625\ kNm$$

Where η is overall efficiency for hydraulic motor and mechanical system, i_{tot} is overall gear ratio including gearbox. The efficiency is selected $\eta = 0.55$[17], and i_{tot} is shown in table III.

Minimum power of hydraulic motor:

$$P_m = \frac{n i_{tot} M_m}{9{,}55} \quad (16)$$

$$= 0{,}963\ kW$$

Where n is the speed of slewing bearing, it is $n = 1\ rpm$.

The flow to be supplied to the hydraulic motor of the slewing bearing:

$$Q_m = \frac{600 P_m}{p} \quad (17)$$

$$= 6{,}42\ l/min$$

The speed of the hydraulic motor is $n_m = 147{,}21\ rpm$. Therefore, the geometric displacement of the hydraulic motor is given the following equation:

$$D_m = \frac{1000 Q_m}{n_m} \quad (18)$$

$$= 43{,}61\ cc/rev$$

Therefore, we choose the hydraulic motor OMP 40 with the specifications given in Table 4.

Tab. 4

Technical specifications of hydraulic motor [15]

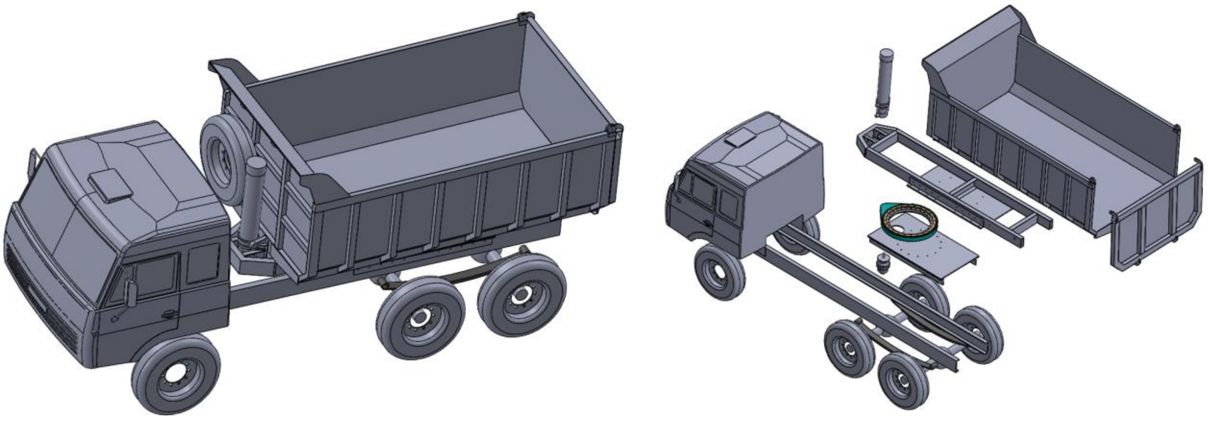
MODEL NO. OMP 40	
Max speed cont (rpm)	1500
Max pressure drop cont (bar)	100
Max pressure drop peak (bar)	225
Geometric displacement (cc/rev)	40
Max oil flow cont (l/min)	60
Max torque cont (Nm)	74
Max output power cont (kW)	7
Min speed (rpm)	10

The technical specifications of the hydraulic motor in Table IV, such as torque and power, satisfy the calculated values in equations (15) and (16). This hydraulic motor will transmit torque to the slewing bearing through the gearbox.

2.4. 3D model

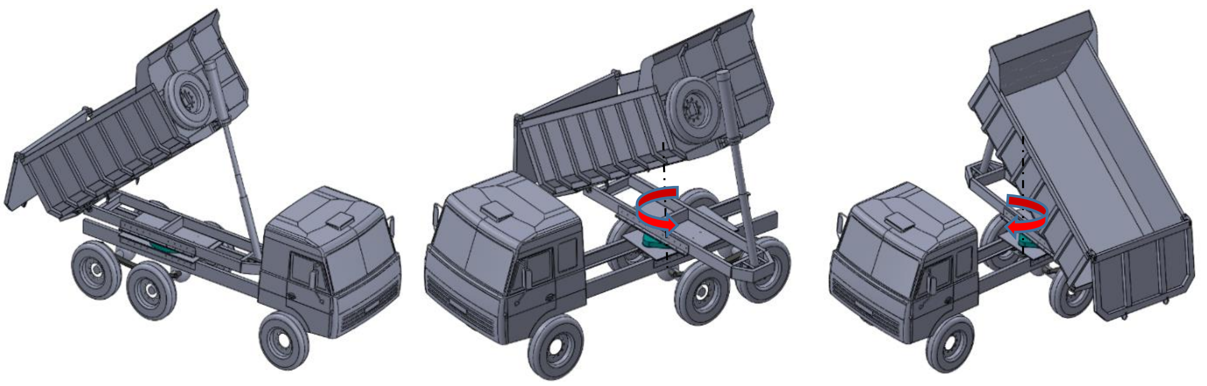
Fig. 7a is the state of the vehicle moving with no-load or full-load on the road. In which, hydraulic cylinders and slewing bearings in the initial state do not work.

The body parts of the dump truck are important components that support the total weight of the dump truck. Fig. 7b shows the assemblies of the dump truck. The container is lifted by a hydraulic cylinder and rotated to the unload position using slewing bearing and hydraulic motor. With slewing bearings and a hydraulic motor, the vehicle can be unloaded in many desired positions quickly.

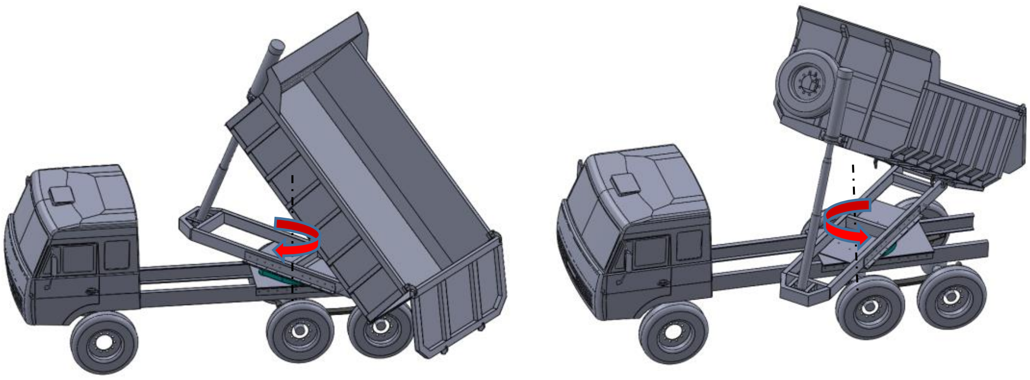


(a) Moving on the road (b) Separation assemblies

Fig. 7. The 3D model of multidimensional dump truck



(a) Slewing bearing rotary 0^0 b) Slewing bearing rotary 90^0 (c) Slewing bearing rotary -90^0



d) Slewing bearing rotary -45^0 e) Slewing bearing rotary 45^0

Fig. 8. The dump truck unloads according to the angle of the slewing bearing

Unloading options are shown in Fig. 8 to help the vehicle quickly get into the position of loading and unloading goods and become more efficient in the working process.

3. CONCLUSIONS

This paper presents the design of a multidimensional dump truck to increase the vehicle's mobility when working. From there, Dump trucks will save time and operating costs. Stage cylinders and slewing bearings are calculated to satisfy allowable load limits. The feasibility of the proposed solution has been demonstrated by building multidimensional dump trucks using the Solidworks model and related calculations.

With this design option, we want to improve the flexibility and mobility of this dump truck to improve work productivity, especially since the designed vehicle can load and unload goods easily in different locations.

The advantage of this study is that the dump truck can unload goods in more than 3 directions. We propose a multidimensional option but still unloading in the rear, so the structure of the loading container remains the same compared to the traditional dump method. Especially with this option, the dump truck can work in limited space.

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