Scientific-technical journal

Volume 4 | Issue 2 Article 11

5-7-2021

GRAPHIC-ANALYTICAL METHOD FOR CALCULATING THE DISTRIBUTION OF FORCES OVER THE FRAME IN THE WORKING PROCESS OF THE UNLOADING

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CHEMICAL TECHNOLOGY AND ECOLOGY

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ТИРКАМАЛАР КЎТАРИБ-АҒДАРИШ ҚУРИЛМАСИНИНГ ИШ ЖАРАЁНИДА КУЧЛАРНИ РАМАГА ТАҚСИМЛАНИШИНИ ХИСОБЛАШНИНГ ГРАФОАНАЛИТИК УСУЛ

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ГРАФОАНАЛИТИЧЕСКИЙ МЕТОД РАСЧЕТА РАСПРЕДЕЛЕНИЯ СИЛ ПО РАМЕ В РАБОЧЕМ ПРОЦЕССЕ ПОДЪЕМНО-ОПРАКИДЫВАЮШЕГО УСТРОЙСТВА ПРИЦЕПОВ

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Abstract: *The article presents graphic-analytical method for calculating the distribution of forces along the frame and the hydraulic cylinder in the working process of the unloading device of trailers.*
Key words: Place of distribution of forces, direction of forces, platform surface, angle of rotation of the hydraulic cylinder, spar, frame cross member.

Аннотация: *Мақолада тиркамалар кўтариб-ағдариш қурилмаси иш жараёнида кучларни рама ва гидроцилиндр бўйича тақсимланишини хисоблашнинг графоаналитик усули келтирилган.*
Калит сўзлар: Кучларнинг тақсимланиш жойлари, кучлар йўналиши, платформа юзаси, гидроцилиндр бурилиш бурчаги, лонжерон, рама кашаклари.

Аннотация: *В статье приведено графоаналитический метод расчета распределения сил по раме и гидроцилиндру в рабочем процессе подъемно-опракидывающего устройства прицепов.*
Ключевые слова: Место распределения сил, направление сил, поверхность платформы, угол поворота гидроцилиндра, лонжерон, поперечина рамы.

I. INTRODUCTION

Due to the change (decrease) of the load mass and the slope of the platform during the operation of the trailer`s unloadng device, the areas of impact, direction and amount of loads falling on the trailer frame change. Since the frame is the main load-bearing and load-receiving element of the trailer, the choice of its design and calculation of strength is carried out mainly on these loads.

The analysis of the available technical literature, published scientific works and Internet data shows that this issue has not been fully researched [1-10]. The unloading device is mounted in the center of gravity of the hydraulic cylinder to be able to carry the load from one place to two sides and back. The calculation of the strength of the frame elements is carried out at the maximum value of the loads falling on it.

It is known, that during unloading process the loads slide from the platform to each other or to the supporting surfaces and the change in loads during these processes varies. When loads slide over the base surfaces, their masses do not change during the process. Therefore, the distribution of forces is carried out in this case.

In general, loads can affect the frames of trailers in three different ways.

Distribution of forces in the transport mode of the trailer. During operation of the trailer unloading device, the static resistance force is mainly formed from the masses of the load and the body, that is:

$$F_{rez} = (m_1 - m_2) \cdot g$$

here: m_1 – mass of the load; m_2 – mass of the body; g – acceleration of free fall.

Their mass forces are assumed to be evenly distributed across the platform surface and concentrated in the center of gravity, while the forces are directed perpendicular to the platform surface. In this case, the trailer is formed only when the horizontal concentration of load is evenly distributed over the surface of the platform, and in this case the resistance forces act equally on the frame through the platform on all four supports, no force falls on the hydraulic cylinder (figure 1):

$$\frac{F_{rez}}{4} = F_{T1} = F_{T2} = F_{T3} = F_{T4} = \frac{(m_1 - m_2) \cdot g}{4}$$

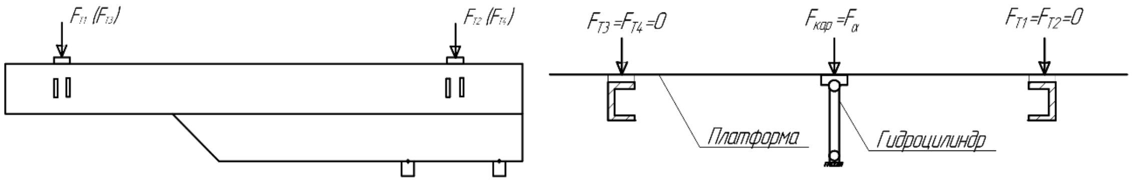

Figure 1. Scheme of the distribution of resistance forces to frame spar

Distribution of forces at the initial stage of the unloading process. In the initial stage of the process, it is assumed that the supports on the non-rolling side of the frame are free from the load, and with little effect on the supports on the rolling side, almost all the loads fall vertically on the hydraulic cylinder stock (figure 1). Because in this case the hydraulic cylinder is mounted on the center of gravity of the platform, it is almost in a vertical position to the platform:

$$F_{gc} = F_{rez} = (m_1 + m_2) \cdot g$$

here: F_{gc} - is the resistance force acting on the hydraulic cylinder.

At this stage the forces are $F_5 = F_{rez}$, $F_6 = 0$, and forces F_1, $F_1^{/}$ are not formed, (fig. 1, 4)

$$F_7 = \frac{F_5 \cdot l_2}{l_1 + l_2} = \frac{F_{rez} \cdot l_2}{l_1 + l_2}, \quad F_8 = \frac{F_5 \cdot l_2}{l_1 + l_2} = \frac{F_5 \cdot l_2}{l_1 + l_2}, \quad F_9 = \frac{F_7 \cdot L_2}{l_1 + l_2} = \frac{F_{rez} \cdot l_2 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)},$$

$$F_{10} = \frac{F_8 \cdot L_2}{L_1 + L_2} = \frac{F_{rez} \cdot l_2 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)}, F_{11} = \frac{F_7 \cdot L_1}{L_1 + L_2} = \frac{F_{rez} \cdot l_2 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)}, \quad F_{12} = \frac{F_8 \cdot L_1}{L_1 + L_2} = \frac{F_{rez} \cdot l_2 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)};$$

Distribution of forces at the main stage of the overthrow process. At this stage of the unloading process, the platform forms a slope angle ($\propto$) with respect to the frame. The resistance in this case is denoted by $F_{\propto}$ and is defined as follows:

$$F_\alpha = F_{rez} \cdot \cos\alpha = (m_1 + m_2) \cdot g \cdot \cos\alpha$$

The components of the force F_α, the normal force F_n - is perpendicular to the platform and resists its rotation, and the longitudinal force $F_{\ln}$ - is directed along the surface of the platform, pushing it to the bottom of the slope (fig. 1).

During the main and final stages of the unloading process, the center of gravity of the load shifts from the center of gravity in its horizontal position to the growth side (top of the slope) to maintain balance on the slope, as well as the direction and amount of resistance to the hydraulic cylinder moves to the center of gravity.

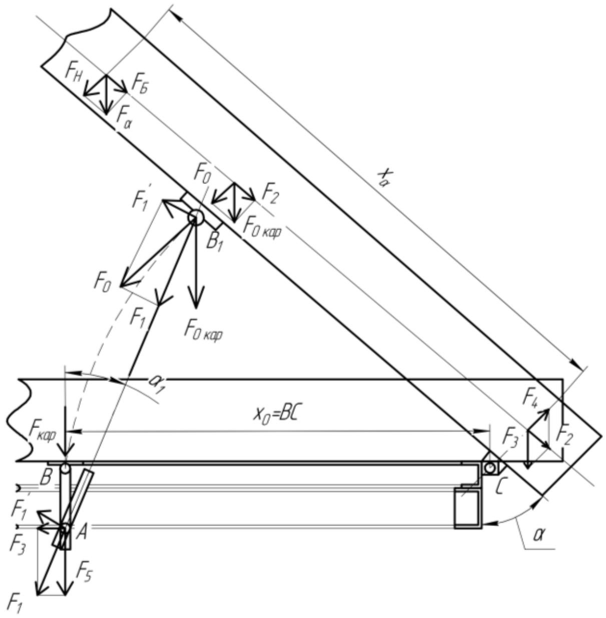

Figure 2. Scheme for calculating the resistance forces.

It follows that it is necessary to determine the coordinate of change of the center of gravity of the load on the *x* axis. It is determined relative to the axis of rotation of the platform.

The coordinate of the center of gravity at an angle of inclination $\alpha = 0$ is x_0:

$$x_0 = BC$$

Here: BC - is the distance from the center of gravity of the platform to the axis of rotation.

Determining the coordinate of the slope angle $\alpha \succ 0$ as x_α, it is determined by the condition of maintaining the equilibrium of the load on the slope:

$$x_0 = F_\alpha = x_\alpha \cdot F_n$$

Here, if is: $$F_n = F_\alpha \cdot \cos\alpha : x_0 \cdot F_\alpha = x_\alpha \cdot F_\alpha \cdot \cos\alpha$$

From this equation: $$x_\alpha = \frac{x_0}{\cos\alpha} = \frac{BC}{\cos\alpha}, \quad 0 \le \alpha \le 90^\circ \qquad (1)$$

Expression (1) is the equation of change of the center of gravity of the load in the sloping position on the x -axis with respect to the slope angle of the platform (α).To determine the resistance force acting on the hydraulic cylinder, the resistance force F_α in the x_α coordinate must be reduced to the x_0 coordinate.

To do this, using the equilibrium condition of the forces at the centers of gravity, it is determined as follows:

$$x_0 \cdot F_{grez} = x_\alpha \cdot F_\alpha = F_\alpha \cdot \frac{x_0}{\cos\alpha}$$

from this equation: $$F_{grez} = \frac{F_\alpha}{\cos\alpha} = F_\alpha \cdot \frac{x_0}{\cos\alpha}, \quad 0 \le \alpha \le 45^\circ \qquad (2)$$

where: F_{grez} - the resistance force given.

Equation (2) is a mathematical expression for the change in resistance force at an angle α.

It can be seen from the equation that the quantity of the given resistance force (F_{grez}) is directly proportional to the change in the magnitude of the center of gravity coordinate.

To determine the resistance force acting on the hydraulic cylinder, the given resistance force (F_{grez}) is divided into components (fig. 4).

Normal force perpendicular to the platform - F_0 resists the lift of the platform and is defined as follows: $$F_0 = F_{gres} \cdot \cos\alpha = \frac{F_\alpha}{\cos\alpha} \cdot \cos\alpha = F_\alpha \qquad (3)$$

Longitudinal force directed along the surface of the platform - F_2 pushes the platform towards the base *C* and is determined as follows:

$$F_2 = F_{gres} \cdot \sin\alpha = \frac{F_\alpha}{\cos\alpha} \cdot \sin\alpha = F_\alpha \cdot tg\alpha \qquad (4)$$

The force F_0 is divided into the components: in turn directed along the axis of the hydraulic

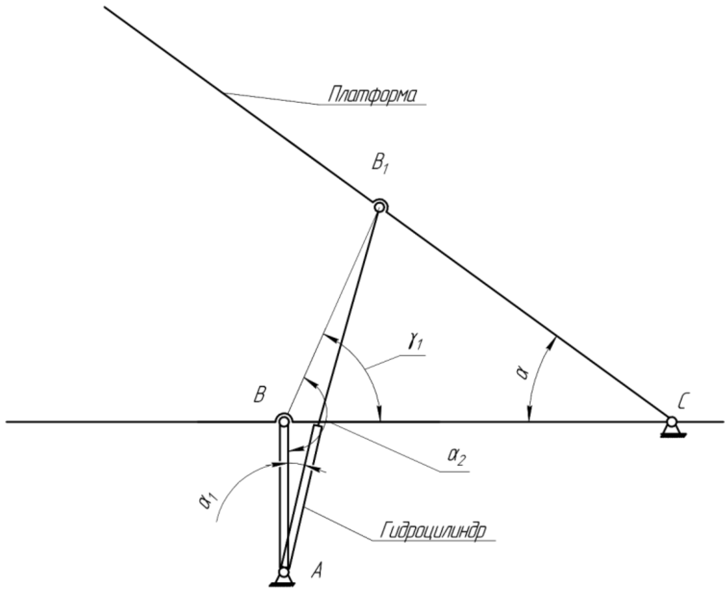

Figure 3. Scheme for calculating the angle of rotation of the hydraulic cylinder (α_1)

cylinder - F_1 and directed perpendicular to it - $F_1^/$. The force F_1 is the forward of the hydraulic cylinder rod, and $F_1^/$ is the resistance to the rotational motion of the housing, and they are calculated according to the scheme in fig. 4. To calculate the components of the force F_0 the angle of rotation of the hydraulic cylinder α_1 is determined according to the scheme in figure

1) Since the triangle BB_1C is equilateral:

$$BB_1 = 2\cdot BC\cdot\sin(0.5\cdot\alpha),\quad \gamma_1=\frac{180^\circ-\alpha}{2}$$

2) By the sine theorem from triangle ABB_1:

$$\sin\alpha_1=\frac{BB_1\cdot\sin(180^\circ-\alpha_2)}{AB_1} \tag{5}$$

$$\alpha_1=90^\circ+\gamma_1,\quad \gamma_1=\frac{180^\circ-\alpha}{2},\quad \alpha_2=90^\circ+\frac{180^\circ-\alpha}{2}=180^\circ-\frac{\alpha}{2}$$

3) By the cos theorem from triangle ABB_1:

$$AB_1^2=AB^2+BB_1^2-2\cdot AB\cdot BB_1\cdot\cos(180^\circ-0.5\cdot\alpha)$$

Here: AB - is the distance from the axis of the hydraulic cylinder (A) to the axis of the stock head (B).
Substituting the above expressions into Equation (5):

$$\alpha_1=\arcsin\left[\frac{2\cdot BC\cdot(\sin(0.5\cdot\alpha))^2}{\sqrt{AB^2+4BC^2\cdot(\sin(0.5\cdot\alpha))^2-4\cdot AB\cdot BC\cdot\sin(0.5\cdot\alpha)\cdot\cos(180^\circ-0.5\cdot\alpha)}}\right] \tag{6}$$

This equation is a mathematical expression of the change in the angle of rotation α_1 of the angle of rotation of the hydraulic cylinder jarayonida α during the operation of the unloading device.
The components of force F_0 are defined as follows:

$$F_1=F_0\cdot\cos\alpha_1=F_\alpha\cdot\cos[\arcsin\left[\frac{2\cdot BC\cdot(\sin(0.5\cdot\alpha))^2}{\sqrt{AB^2+4BC^2\cdot(\sin(0.5\cdot\alpha))^2-4\cdot AB\cdot BC\cdot\sin(0.5\cdot\alpha)\cdot\cos(180^\circ-0.5\cdot\alpha)}}\right]]$$

$$F_1^{/}=F_0\cdot\sin\alpha_1=F_\alpha\cdot\sin[\arcsin\left[\frac{2\cdot BC\cdot(\sin(0.5\cdot\alpha))^2}{\sqrt{AB^2+4BC^2\cdot(\sin(0.5\cdot\alpha))^2-4\cdot AB\cdot BC\cdot\sin(0.5\cdot\alpha)\cdot\cos(180^\circ-0.5\cdot\alpha)}}\right]]$$

The force F_1 acting on the hydraulic cylinder consists of forces F_5 and F_6.
The force F_5 acts on the hydraulic cylinder support and through it on the frame in the vertical plane:

$$F_5=F_1\cdot\cos\alpha_1=F_\alpha\cdot\cos\alpha_1\cdot\cos\alpha_1=F_\alpha\cdot\cos^2\alpha_1$$

The force F_6 acts on the frame in the horizontal plane through the hydraulic cylinder support:

$$F_6=F_1\cdot\sin\alpha_1=F_\alpha\cdot\cos\alpha_1\cdot\sin\alpha_1$$

The force acting on the hydraulic cylinder F_5 is distributed to the forces F_7 and F_8 in the vertical direction on the pulleys 3 and 4, and the force F_6 is distributed to the forces F_{13} and F_{14} (figure

5):

$$F_7 = \frac{F_5 \cdot l_2}{l_1 + l_2}, \quad F_8 = \frac{F_5 \cdot l_1}{l_1 + l_2}, \quad F_{13} = \frac{F_6 \cdot l_2}{l_1 + l_2}, \quad F_{14} = \frac{F_6 \cdot l_2}{l_1 + l_2}, \quad F_7 = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_2}{l_1 + l_2}, \quad F_8 = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_1}{l_1 + l_2},$$

$$F_{13} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot \sin \alpha_1 \cdot l_2}{l_1 + l_2}, \quad F_{14} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot \sin \alpha_1 \cdot l_1}{l_1 + l_2},$$

$$F_9 = \frac{\dfrac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_2 \cdot L_2}{l_1 + l_2}}{L_2 + L_2} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_2 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)}, \quad F_{11} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_2 \cdot L_1}{(l_1 + l_2) \cdot (L_1 + L_2)}, \quad F_{10} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_1 \cdot L_2}{(l_1 + l_2) \cdot (L_2 + L_2)},$$

$$F_{10} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot l_1 \cdot L_1}{(l_1 + l_2) \cdot (L_2 + L_2)},$$

$$F_{15} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot \sin \alpha_1 \cdot l_2 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)}, \quad F_{17} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot \sin \alpha_1 \cdot l_2 \cdot L_1}{(l_1 + l_2) \cdot (L_1 + L_2)}, \quad F_{16} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot \sin \alpha_1 \cdot l_1 \cdot L_2}{(l_1 + l_2) \cdot (L_1 + L_2)},$$

$$F_{18} = \frac{F_\alpha \cdot \cos^2 \alpha_1 \cdot \sin \alpha_1 \cdot l_1 \cdot L_1}{(l_1 + l_2) \cdot (L_1 + L_2)};$$

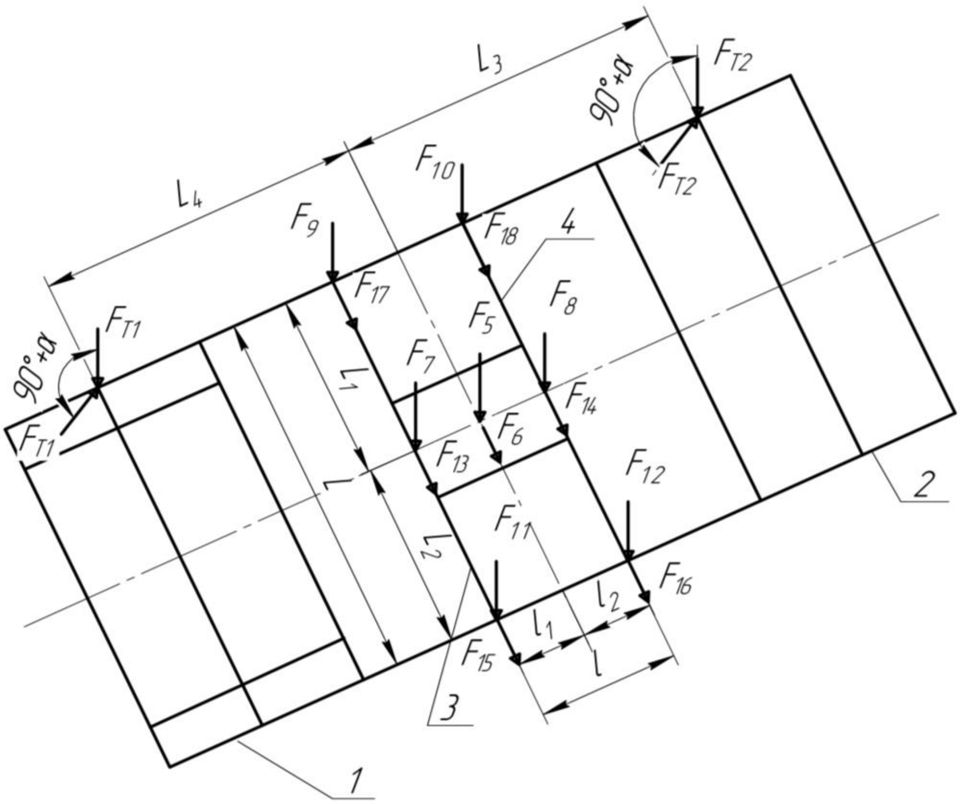

Figure 4. The scheme of distribution of external forces on the trailer frame during the overturning (1, 2 - spars, 3, 4 - pulleys)

The forces F_7 and F_8 are distributed to the springs, F_9, F_{11} and F_{10}, F_{12} and F_{13} and F_{14} respectively, to the forces F_{15}, F_{17} and F_{16}, F_{18}:

$$F_9=\frac{F_7\cdot L_2}{L_1+L_2},\quad F_{11}=\frac{F_7\cdot L_1}{L_1+L_2},\quad F_{10}=\frac{F_8\cdot L_2}{L_1+L_2},\quad F_{12}=\frac{F_8\cdot L_1}{L_1+L_2},\quad F_{15}=\frac{F_{13}\cdot L_2}{L_1+L_2},\quad F_{17}=\frac{F_{13}\cdot L_1}{L_1+L_2},$$
$$F_{16}=\frac{F_{14}\cdot L_2}{L_1+L_2},\quad F_{18}=\frac{F_{14}\cdot L_1}{L_1+L_2};$$

The longitudinal force F_2 falling on the platform is distributed to the forces F_3 and F_4 respectively. The force F_3 presses the platform horizontally down from the base C, while the force F_4 tends to separate it from the base.

$$F_3=\frac{F_2}{\sin\alpha}=\frac{F_\alpha\cdot\sin\alpha}{\cos\alpha\cdot\sin\alpha}=\frac{F_\alpha}{\cos\alpha},\quad F_4=\frac{F_2}{\cos\alpha}=\frac{F_\alpha\cdot tg\alpha}{\cos\alpha};$$

The force F_3 is distributed to the longitudinal supports in the vertical direction to the frame as follows:

$$F_{T1}=\frac{F_3\cdot L_3}{L_3+L_4}=\frac{F_\alpha\cdot L_3}{(L_3+L_4)\cdot\cos\alpha},\quad F_{T2}=\frac{F_3\cdot L_4}{L_3+L_4}=\frac{F_\alpha\cdot L_4}{(L_3+L_4)\cdot\cos\alpha}$$

The force F_4 is directed upwards in a vertical direction to the platform and is distributed to the longitudinal supports as follows:

$$F_{T1}^{/}=\frac{F_4\cdot L_3}{L_3+L_4}=\frac{F_\alpha\cdot L_3\cdot tg\alpha}{(L_3+L_4)\cdot\cos\alpha},\quad F_{T2}^{/}=\frac{F_4\cdot L_4}{L_3+L_4}=\frac{F_\alpha\cdot L_4\cdot tg\alpha}{(L_3+L_4)\cdot\cos\alpha};$$

Conclusion. The following conclusions can be drawn from the research:

1. The distribution of the resistance force during the operation of the trailer lifting device in the scheme of load - body - hydraulic cylinder - pulleys - spanners, the equations for calculating the amount and concentration of their constituents are given;
2. The mathematical expression for the calculation of the angle of rotation of the hydraulic cylinder is given;
3. Due to the change of the center of gravity of the load during the operation of the trailer lifting device, the force acting on it to the platform support decreases ($F_2=F_\alpha\cdot tg\alpha$) and the force acting on the hydraulic cylinder supports does not change ($F_4=F_\alpha$).

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