Saimaa University of Applied Sciences
Faculty of Technology, Lappeenranta
Degree Programme in Mechanical Engineering and Production Technology

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Design of hydraulic scissors lifting platform

Thesis 2016

Abstract

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The goal of this study was to apply the knowledge obtained from studying in the university and solve the substantial task of creating a design of the hydraulic scissors lifting platform.

For this purpose a research of literature and articles was made, that contain missing information of the theoretical part of the problem. The data was mainly taken from the internet, particularly from articles, digital copies of books and scientific works in a related field. The results of this research are presented in the first theoretical part of the thesis.

Then to verify the validity of the theory the practice work was accomplished. The type of the platform and the design of the structure were selected. The selection of the material and calculations of the loads and stresses were performed and explained. As the result of the work the 3D model of the lift using SolidWorks software was created.

Keywords: Hydraulic lift, scissors lift, lifting table, scissors calculations.

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List of abbreviations and symbols

$\sum F_{ox}$	Sum of forces in X-axis
$\sum F_{oy}$	Sum of forces in Y-axis
$\sum M$	Sum of moments
σ_{all}	Allowable stress
σ_n	Normal stress
n	Factor of safety
R_e	Yield strength
τ_{all}	Allowable shear stress
τ	Shear stress
σ_{eq}	Combined stress
σ_M	Bending stress
M	Maximum moment
y	Dimension from the center to the top (half of the H)
B	Width
H	Height
CCW	Counterclockwise

1 Introduction

The structure of this thesis is planned as follows: in the first part, the theory is presented. It consists of several topics concerning overall of lifting tables of scissors type, things that are needed for the design, principles of working, technical characterization and others.

The first part is needed to give a general concept of the subject and after that comes the practical part which presents and explains how to perform the knowledge. It contains the 3D model of the lift, calculations of the load, several diagrams, charts, and stress calculations, which confirm the viability and validity of the theory part.

Such a thesis structure was chosen as the most appropriate and suitable for the chosen topic. It allows increasing knowledge by appealing to the literature and adding an individuality of the author by making him solve an actual practical problem using own approach.

The scissors elevator is an elevator with a system of levers and hydraulic cylinders on which the metal platform is capable of moving in the vertical plane. This is achieved by using of linked, folding supports in a crisscross pattern, called scissor mechanism.

The hydraulic lift was chosen as a subject of the thesis because it is a perfect example of mechanical engineering field. This mechanism combines a result of several main fields of engineering and at the same time, it is simple and accessible for understanding. The construction and load distribution represent statics and strength of material subjects, the hydraulic cylinder and the control unit involve knowledge of hydraulic systems and automation. Material science is important for selection of a suitable material as well as knowledge of 3D modeling.

Also, scissors lift is an integral part of most of the workshops and building objects. The key advantage of lifts is that they even offer the best way to organise a technological and industrial process. Besides, almost all lifts give the possibility to change the place of their installation without much effort, which is important in the frequently changing conditions in the production process these days.

The need for the utilization of elevators is incredibly wide and it runs across workshops, factories, labs, fixing of billboards, residential/commercial buildings to repair street lights, etc. Expanded and less-efficient, the engineers may run into one or more problems while using(Ritchikmikie 2011).

2 Classification of lifting platforms

To start something new it is needed to look at something that already exists. On the design elevators can be divided into the following main types: permanent and portable. The permanent elevators are: scissor raise platforms, track lifting platform, launching and unloading platforms (Sinolifter.com 2011). An example is on Figure 2.1.

Figure 2.1 Launching and unloading platform (southworthproducts.com 2016).

The portable elevators divided into: several mobile lifting platform, a couple of tractor-lift platforms, improved car lifting platform, AC-DC dual-use working out with a platform, self-elevating podium, crank-type raise platform, foldable arm lift platform, packages cylinder lift platform, lightweight aluminium lift platform, working out with height from 1-30 m. array(Sinolifter.com 2011) An example is on Figure 2.2.

Figure 2.2 Mobile lifting platform (Made-in-china.com 2016).

As the drive elevators divided into: electro-hydraulic, electromechanical, pneumatic hydraulic. As the lifting devices elevators divided into: chain, screw, telescopic, lever. As the picking-up devices elevators divided into: platform, frame, and console. Stationary elevators are established in a defined place, frequently without the special foundation on a flat surface of a floor and fastened by means of anchor bolts or special pins. If the elevator is telescopic then for his installation is required the special basement is required(Stroytech-ms.ru 2016).

Elevators at which racks move belong to mobile. The main advantage of mobile elevators is their mobility - a possibility to use serially on various posts and in various technological zones of the enterprise(Stroytech-ms.ru 2016).

3 Advantage and application

The concept of a scissors lift with hydraulic power comes from Pascal's law applied in car jacks and hydraulic rams which states that "*pressure exerted anywhere in a conformed incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio remains the same*"(Hydraulicsonline 2013).

Since the emergence in the light of different cultural achievements, the individual tries to maximize their use to facilitate the work. Only a century ago, the society did not have the opportunity even to dream about what is already openly available at present. The rough labor is replaced by technology, for example lifting mechanisms.

"*A scissor lift elevator is a vertical transportation cab which is raised and lowered from underneath, somewhat like a traditional hydraulic elevator, except that instead of a hydraulic cylinder the extendable mechanism is a folding lattice of crisscrossed beams similar to a pantograph. The entire mechanism extends upward when pressure is applied to the lowest members*."(Standards.phorio.com 2013).

On Figure 3.1 below general examples of scissors elevators can be seen.

Figure 3.1 General examples (sv-e.com 2013).

People use a huge number of different lifts. The aim is also different, some are used in some situations while others are for a totally different environment. For example, there is an electro-hydraulic scissors elevator — quite a small device allowing to lift hundreds of kilograms of freight on a height of tens of meters.

Thus, in particular, the hydraulic scissor hydraulic lift has been used successfully to electrical and other works on the heights of about 2-3 floors. Also, it allows making work at a greater height than tens of meters.

Also, lifts of this type could also be applied to other conditions, such as daily loading and unloading work in warehouses. The scissor lift perfectly meets the needs for certain warehouse facilities, mainly because of the fact that above the lifting platform it has a lack of any mechanisms. This is complemented by access from all four sides, which gives the opportunity to use it for loading of objects on the top shelves of warehouse racks.

A distinctive feature of an electro-hydraulic scissor lift in comparison with other analogues is the low price due to the use of a relatively simple design. A special lifting platform is driven by a simple metal structure with levers that look like scissors connected with others in a long chain. As a lifting force is used electro-hydraulic mechanism for driving a pair of scissors in motion(sv-e.com 2013).

In addition, a scissor lift is suitable for use in situations, where movement of other types of lifts is limited. This capability makes this type of lift particularly versatile and convenient. A platform with load is movable not only vertically, but also on the meter to the side, as is for example available on some models. This feature is highly convenient in situations in the workplace where there is no possibility to put the basis of lift exactly under the desired object(sv-e.com 2013).

4 Aims/Objectives of the study

The goal of the study is to design the hydraulic scissors lift to lift up to a height of 1.2 meters and with the carrying capacity of 700 kilograms. The driving mechanism of the lift must be a hydraulic cylinder. Calculations of the inner stresses must be done and a 3D model must be created. It is also necessary to choose the material.

5 Principle of action

The general view of the elevator is presented on Figure 5.1. The elevator with the electro-hydraulic drive is performed for placement on the floor. The elevator is intended for lifting objects with the weight of hundreds and thousands of kilograms from the floor to the height of 1 meter.

Figure 5.1 General view of lift (hydraulicscissorslift.com 2016).

There are two options for installing the lift on the floor or on the level with the floor. The standard is to place the remote control for the lift to the left at a distance of 1 m. If necessary, the location of the control panel at the other distance needed lengthening of the hydraulic drive.

The main technical capabilities (Garant-techservice.ru 2016):

1. The automatic device for blocking of mechanisms for safe work in any situation;
2. The valves which are switching when hydraulic actuators are damaged;
3. Valve for control of speed of lowering;
4. The electro-hydraulic device for stopping the lowering in case of destruction of the basis of the elevator;
5. Electrically the switched-on device for protection of legs of the user;
6. The self-greased hinges.

The scissors lift has a table surface where the weight can be placed. The rising of a platform is carried out due to work of a hydraulic cylinder. The management of the elevator is carried out by the control panel which has four buttons: the main switch, lowering, rise, and blocking. As rising speed uniform and slow (on average 30 mm per second), physics behavior of the elevator corresponds to a static case(Garant-techservice.ru 2016).

The technical characteristics of the lift are shown in Table 1:

Loading capacity, kg	700
Height of rise, mm	1260
Rise time, sec.	40
Lowering time, sec.	40
Initial height, mm	125
Mass, kg	70
Power supply, volt	220

Table 1 Technical characteristic of the lift

On Figure 5.2 the main components of the lift are shown:

1. Hydraulic Cylinder
2. Leg
3. Table-top
4. Supporting tube 1
5. Supporting tube 2
6. Base plates
7. Top plates

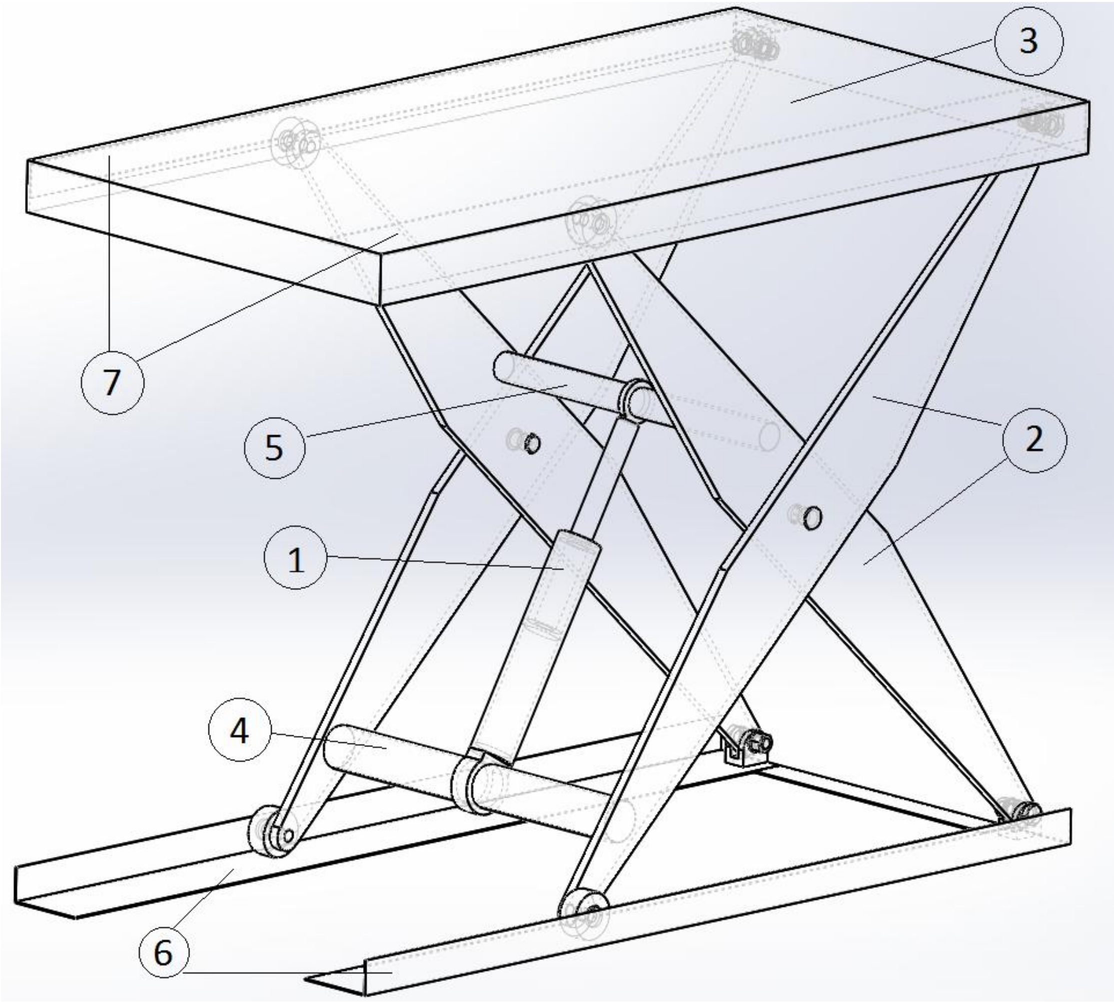


Figure 5.2 Main components

6 Actions for the maintenance of hydraulic scissors lift

Installation of the equipment:

Requirements for the floor:

1. The elevator has to be installed on a floor maintaining loading in 1.5 kN.
2. The minimum area for installation of the elevator of 1.3x0.7 m;
3. The floor has to maintain loading not lower than 1,3 kg/cm ²;

It is necessary to be convinced that the voltage in an electricity circuit corresponds to the elevator supply voltage. If the voltage does not comply it is necessary to rebuild circuit(Garant-techservice.ru 2016).

7 Main faults and methods of their elimination

Main information about faults and methods of their elimination is presented in table 2(Garant-techservice.ru 2016).

Type	Possible reasons	Method
Lift does not work	Cylinder malfunction	Remove cylinder, disassemble, and conduct the necessary repairs.
Leaks in the joints of hydraulic tubes	Loose connections	Tighten the coupling nuts. Loosen the nuts and adjust the tip end of the tube to tighten the nut.
The stock does not create the necessary pressure	Easing tightening sleeves cylinders. Maladjustment of the safety valve	Tighten bolts, adjust the spool valve.
Leak under a hydraulic cylinder cover	Weakening of an inhaling of bolts or wear of laying of a cover	Tighten coupling bolts or turn off nuts of a cover and replace laying.
The pump does not develop pressure	Malfunction of the pump	Replace the pump new

Table 2 Main faults and methods of their elimination

8 Material selection

Depending on a component and tasks that this component performs the selection of a certain material is founded. Different parts of the mechanism take different load and stress because they carry out different functions. It is important to use an individual approach to select a material for every part. It impacts on a total efficiency and benefit received from each detail and best properties which can give different materials. Thus, it is necessary to allocate the main parts of a design and to explain features of each of them separately.

The main interest is made by the legs of the lift, the greatest part of loading is shared between them and they are a basic element of the assembly. It means that the material of which they are made has to be capable of maintaining this load. This part is subjected to a normal force which might cause buckling and shear force which cause bending, which possibly cause bending deformation or even braking of the part. Then such properties as strength, hardness, and stiffness are needed. An appropriate material for these purposes is structural steel, more precisely the S355 steel.

The second basic element of a design is the cylinder. From the technical point of view, it acts as a bar with pinned ends. It is subjected to direct compressive force which leads to bending and buckling load in the rod. Also, there exists the internal pressure of the fluid, which causes circumferential and longitudinal stresses all around the wall thickness. Thereby the cylinder must have such properties as strength, toughness, ductility and hardness. An appropriate material is mild steel.

There are also such components as top plates and base plates. The top plates take the load caused by a weight of lifting goods. The main needed property here is strength and the selected material is mild steel. The base plates are subjected to the weight of the load and scissors mechanism itself – cylinder and legs, hence, hardness and stiffness are required. Mild steel is appropriate.

9 Calculations

The calculations of forces, stresses, and reactions of the structure play the most important role in the design because on the result of these calculations and its correctness depends stability, safety and successful work of the whole mechanism. The lifting table is a dynamic mechanism, but the speed of acting is relatively low, so this fact can be neglected and this system can be concerned as static. Then only two positions are needed to be considered, they are the initial position when the lift is lowered and just lying on the floor, and the highest position, when the mechanism lifted a weight on the highest possible distance. In these two positions, the highest reactions and internal forces are observed. In all the other positions the results will be between the two mentioned above.

9.1 Force acting on the cylinder

9.1.1 Lowest position

While calculation it is important to understand the behavior of the structure. For this, the simplified picture is used to focus on the main acting forces. Here is the free body diagram on Figure 9.1

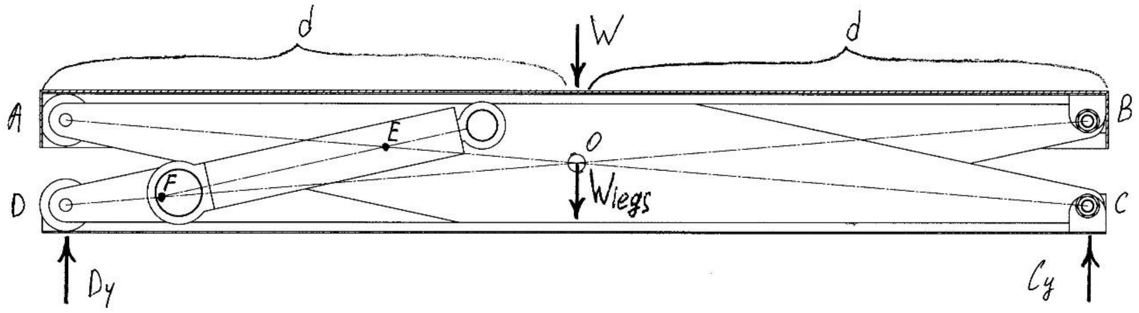


Figure 9.1 Free body diagram for the initial position

As it can be seen on Figure 9.1, A and D are roller supports and B and C are pin supports, point O is also a pin joint between two legs of the lift. Force W is applied as the weight of the load and it is acting in the middle of the table, dimension “d” shows it. Also in the other plane which is not shown, the weight is supposed to be as well in the middle. When the force acting on the middle or shared over the table, it is transmitted equally to A and B supports. The “Wlegs” is the load caused by a weight of the legs, it is also acting in the middle, but only in the initial position. Also, the total incoming forces must be equal to the total out coming, which means that whatever is happening inside the system the sum of reactions Dy and Cy would be equal to the weight. Then vertical reactions of D and C are half of the weight of the main load plus the weight of legs.

$$C_y = D_y = \frac{w + w_{legs}}{2}$$

EF from Figure 9.1 is the hydraulic cylinder and here it is acting like a truss. It is subjected a compression force, that means the cylinder acts with a certain force to the points E and F. On Figure 9.2 it can be seen how this force P is decomposed into a Y and X components according to the axes. And as a result:

$$\sin\beta = \frac{P_y}{P} \Rightarrow P_y = P\sin\beta$$

$$\cos\beta = \frac{P_x}{P} \Rightarrow P_x = P\cos\beta$$

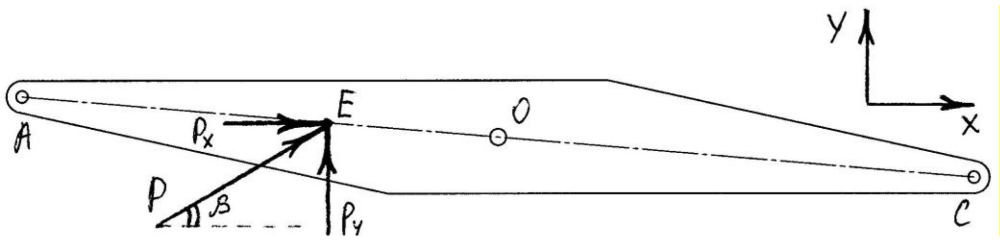


Figure 9.2 Force components at point E

Then the free body diagram is drawn for each leg separately on Figure 9.3. Fy and Fx are the components of F force acting on the pin, it is better to decompose it right now because its value and direction are not known yet.

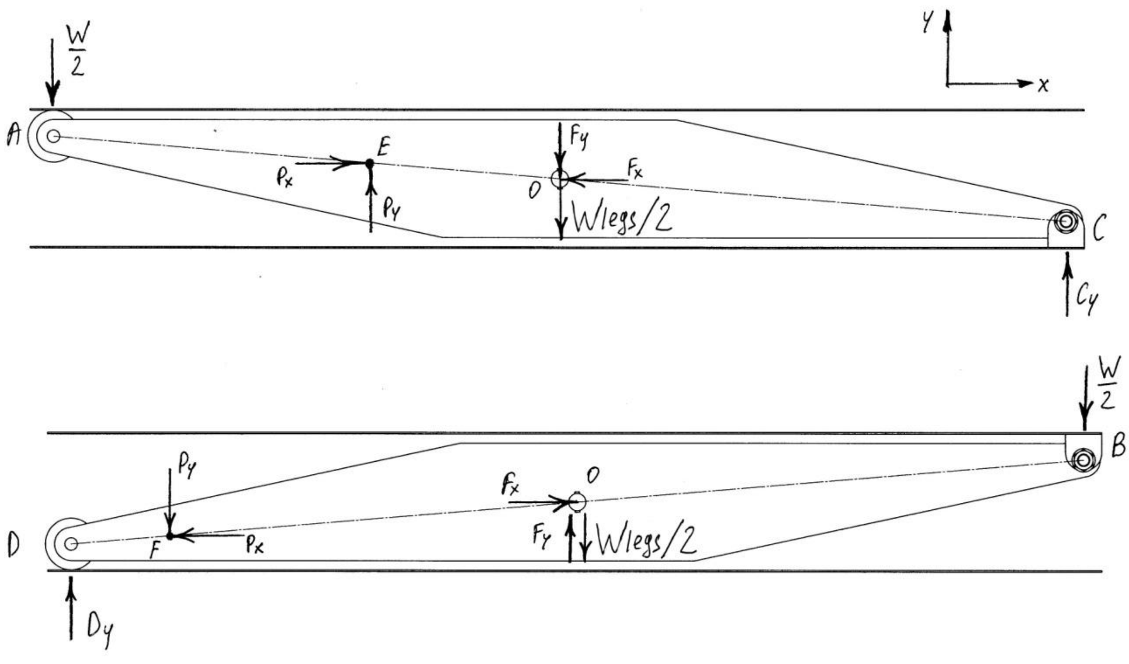


Figure 9.3 Free body diagram for each of leg separately

Also, it is needed to get the projections of the dimensions of the leg which will be called “L”, the dimension between E and O is called “a”. The analogous result may be used for projection of CE, the dimension of which is “(L/2+a)” as shown on Figure 9.4.

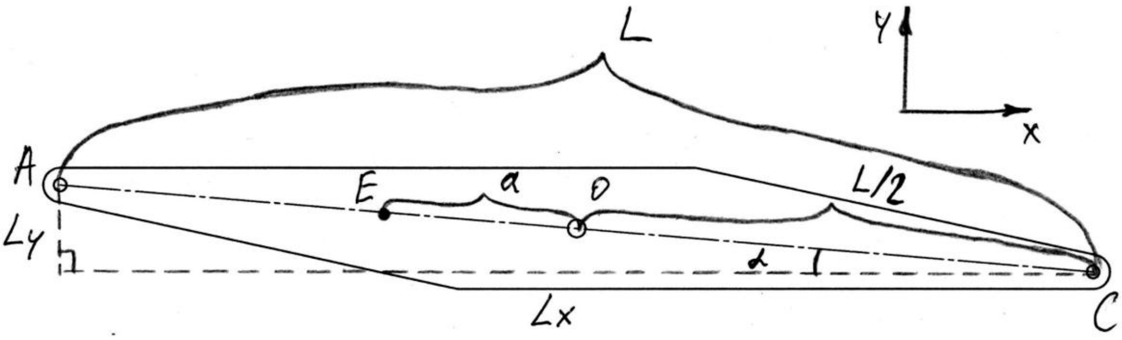


Figure 9.4 Projections of the leg

$$\cos\alpha = \frac{Lx}{L} \Rightarrow Lx = L\cos\alpha$$

$$\sin\alpha = \frac{Ly}{L} \Rightarrow Ly = L\sin\alpha$$

Then, using the diagram on Figure 9.3 it is needed to consider a balance of forces in Y and X directions and also the balance of moments created by the action of forces. It is done only for AC, but there will be an identical result on DB because dimensions are the same.

$$\sum F_{ox} = 0 \Rightarrow P_x - F_x = 0 \ \Rightarrow \ P_x = F_x$$

$$F_x = P\cos\beta$$

$$\sum F_{oy} = 0 \ \Rightarrow -\frac{w}{2} + P_y - F_y - \frac{w_{legs}}{2} + C_y = 0 \ \Rightarrow -\frac{w}{2} + P_y - F_y - \frac{w_{legs}}{2} + \frac{w+w_{legs}}{2} = 0 \ \Rightarrow P_y = F_y$$

$$F_y = P\sin\beta$$

Rotating around point C, CCW is positive direction:

$\sum M_C = 0 \Rightarrow$

$$\frac{w_{legs}}{2} \cdot \frac{L}{2} \cos\alpha + \frac{w}{2} L \cos\alpha - P \sin\beta \left(\frac{L}{2} + a\right) \cos\alpha + F_y \frac{L}{2} \cos\alpha - P \cos\beta \left(\frac{L}{2} + a\right) \sin\alpha + F_x \frac{L}{2} \sin\alpha = 0$$

$$\frac{w_{legs}}{2} \cdot \frac{L}{2} \cos\alpha + \frac{w}{2} L \cos\alpha - P \sin\beta \left(\frac{L}{2} + a\right) \cos\alpha + P \sin\beta \frac{L}{2} \cos\alpha - P \cos\beta \left(\frac{L}{2} + a\right) \sin\alpha + P \cos\beta \frac{L}{2} \sin\alpha = 0$$

$$\frac{w_{legs}}{2} \cdot \frac{L}{2} \cos\alpha + \frac{w}{2} L \cos\alpha + P \left(-\sin\beta \left(\frac{L}{2} + a\right) \cos\alpha + \sin\beta \frac{L}{2} \cos\alpha - \cos\beta \left(\frac{L}{2} + a\right) \sin\alpha + \cos\beta \frac{L}{2} \sin\alpha\right) = 0$$

$$\frac{w_{legs}}{2} \cdot \frac{L}{2} \cos\alpha + \frac{w}{2} L \cos\alpha + P \left(\sin\beta \cos\alpha \left(-\left(\frac{L}{2} + a\right) + \frac{L}{2}\right) + \cos\beta \sin\alpha \left(-\left(\frac{L}{2} + a\right) + \frac{L}{2}\right)\right) = 0$$

$$\frac{w_{legs}}{2} \cdot \frac{L}{2} \cos\alpha + \frac{w}{2} L \cos\alpha + P\left(-a(\sin\beta \cos\alpha + \cos\beta \sin\alpha)\right) = 0$$

Rule from geometry:

$\sin\beta \cos\alpha + \cos\beta \sin\alpha = \sin(\alpha + \beta)$ (Tammertekniika 2012, p. 15). (1)

$$P = \frac{L \cos\alpha \left(\frac{w}{2} + \frac{w_{legs}}{4}\right)}{\mathrm{a} \cdot \sin(\alpha + \beta)} \qquad (2)$$

In this project, there was the following order of actions: first, based on the existing examples and approximate representation what has to be the elevator, rough 3D model was drawn, which can be seen on Figure 9.5, to get the needed measurements and numbers with which calculations can be done. Then in case if the model does not correspond to the necessary result it can be changed in an appropriate way.

Figure 9.5 3D view of the lift

Having the 3D, the needed dimensions for further calculations can be obtained, which can be seen on Figure 9.6.

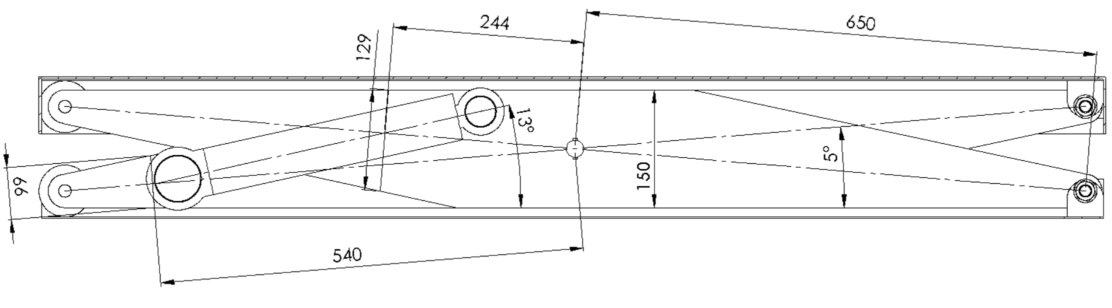


Figure 9.6 Dimensions in the lowest position

According to the design there are the following measurements:

L = 1.300 meters

a = 0.244 meters

Mass of the load is 700 kg.

Mass of the legs is 67 kg.

α = 5°

β = 13°

$$P = \frac{1.3\cos 5^\circ \left(\frac{6867}{2} + \frac{657}{4}\right)}{0.244 \ \cdot \sin(5^\circ + 13^\circ)} = 61794\text{N}$$

9.1.2 Highest position

On Figure 9.7 the free body diagram for the highest position of the lift is shown:

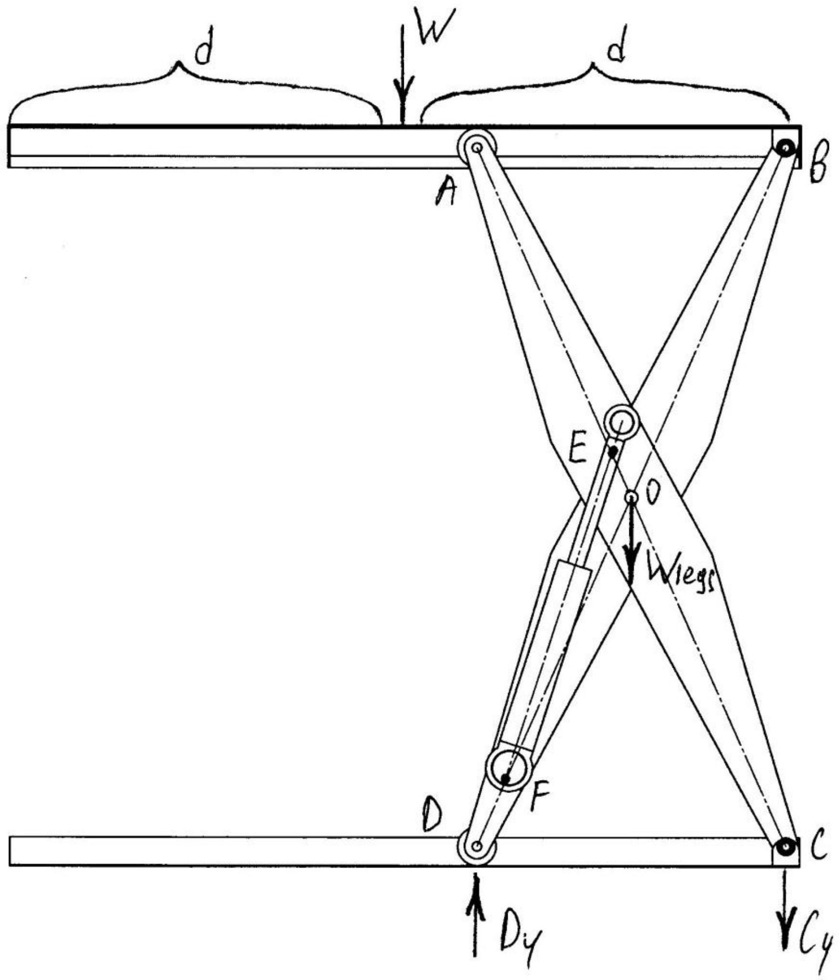


Figure 9.7 Free body diagram for the highest position

d = 0.650 meters

AB = 0.529 meters

$\sum M_C = 0 \Rightarrow w \cdot d + w_{legs}\left(\frac{AB}{2}\right) - D_y \cdot AB = 0 \Rightarrow D_y = \frac{w \cdot d + w_{legs}\left(\frac{AB}{2}\right)}{AB} = 1.23\, w + 0.5 w_{legs}$

$\sum F_{oy} = 0 \Rightarrow D_y - C_y - w_{legs} - w = 0 \Rightarrow C_y = 1.23\, w + 0.5 w_{legs} - w_{legs} - w \Rightarrow C_y = 0.23 w - 0.5 w_{legs}$

According to the behavior of the legs: $C_y = -B_y$ and $D_y = -A_y$ for the free body diagrams of the legs in the highest position which is shown on Figure 9.8. Calculations are done only for AC, but there will be an identical result on DB because dimensions are the same.

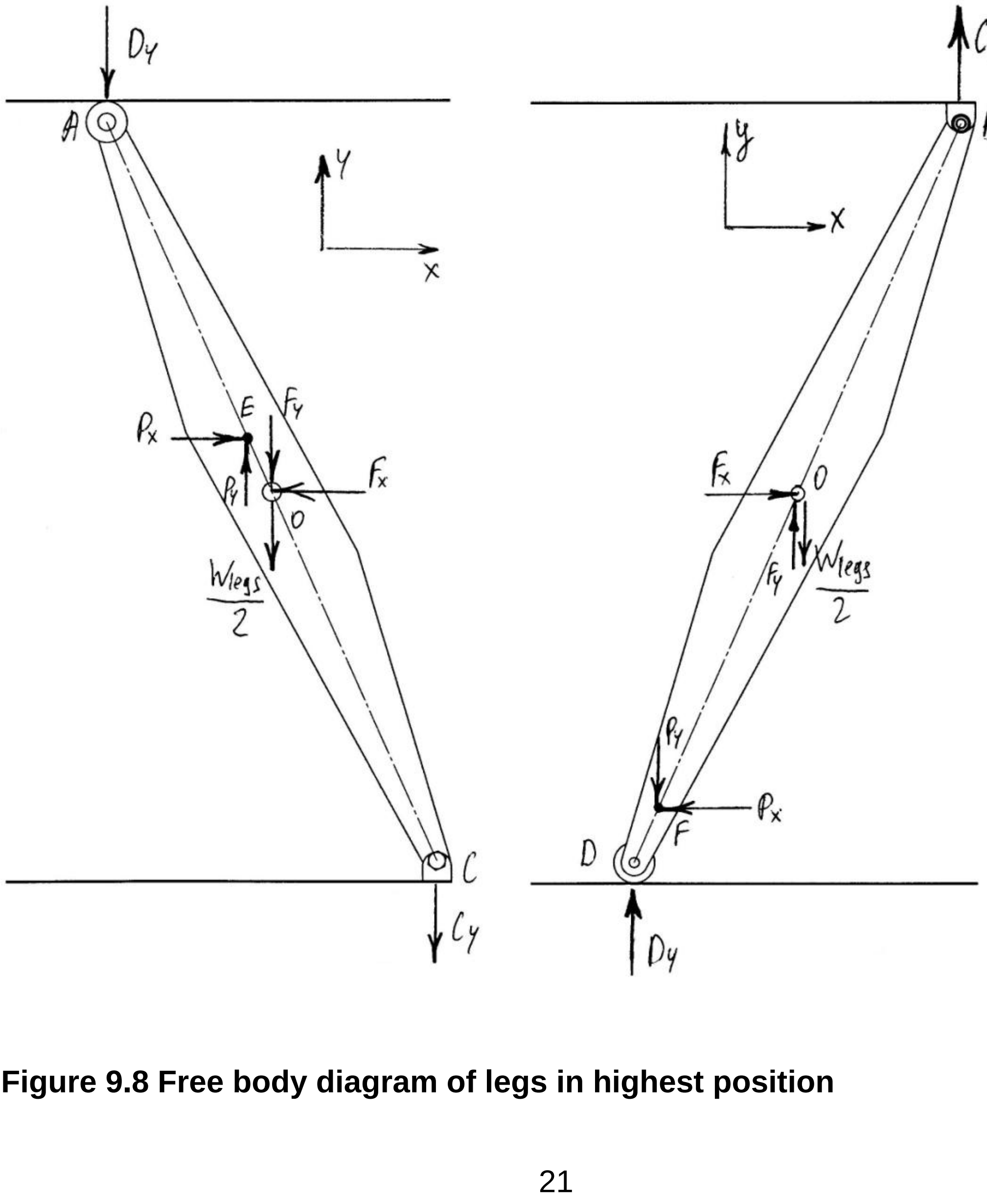


Figure 9.8 Free body diagram of legs in highest position

$$\sum F_{ox} = 0 \Rightarrow P_x - F_x = 0 \;\Rightarrow\; P_x = F_x$$

$$F_x = P\cos\beta$$

$$\sum F_{oy} = 0 \;\Rightarrow -D_y + P_y - F_y - \frac{w_{legs}}{2} - C_y = 0 \;\Rightarrow F_y = P_y - D_y - \frac{w_{legs}}{2} - C_y = P_y - 1.23\,w - 0.5w_{legs} - \frac{w_{legs}}{2} - 0.23w + 0.5w_{legs} = P_y - 1.46\,w - 0.5w_{legs}$$

$$F_y = P\sin\beta - 1.46\,w - 0.5w_{legs}$$

Rotating around point C, CCW is positive direction:

$$\sum M_C = 0 \;\Rightarrow$$

$$\frac{w_{legs}}{2}\cdot\frac{L}{2}\cos\alpha + D_y L\cos\alpha - P\sin\beta\left(\frac{L}{2}+a\right)\cos\alpha + F_y\frac{L}{2}\cos\alpha - P\cos\beta\left(\frac{L}{2}+a\right)\sin\alpha + F_x\frac{L}{2}\sin\alpha = 0$$

$$\frac{w_{legs}}{2}\cdot\frac{L}{2}\cos\alpha + 1.23\,wL\cos\alpha + 0.5w_{legs}L\cos\alpha - P\sin\beta\left(\frac{L}{2}+a\right)\cos\alpha + P\sin\beta\frac{L}{2}\cos\alpha - 1.46\,w\frac{L}{2}\cos\alpha - 0.5w_{legs}\frac{L}{2}\cos\alpha - P\cos\beta\left(\frac{L}{2}+a\right)\sin\alpha + P\cos\beta\frac{L}{2}\sin\alpha = 0$$

$$0.5w_{legs}L\cos\alpha + 0.5wL\cos\alpha + P\left(-\sin\beta\frac{L}{2}\cos\alpha - \sin\beta\cdot a\cdot\cos\alpha + \sin\beta\frac{L}{2}\cos\alpha - \cos\beta\frac{L}{2}\sin\alpha - \cos\beta\cdot a\cdot\sin\alpha + \cos\beta\frac{L}{2}\sin\alpha\right) = 0$$

$$0.5w_{legs}L\cos\alpha + 0.5wL\cos\alpha + P(-\sin\beta\cdot a\cdot\cos\alpha - \cos\beta\cdot a\cdot\sin\alpha) = 0$$

$$0.5w_{legs}L\cos\alpha + 0.5wL\cos\alpha - P\cdot a(\sin\beta\cos\alpha + \cos\beta\sin\alpha) = 0$$

$$0.5L\cos\alpha\left(w + w_{legs}\right) - P\cdot a(\sin\beta\cos\alpha + \cos\beta\sin\alpha) = 0$$

Rule from geometry:

$\sin\beta\cos\alpha + \cos\beta\sin\alpha = \sin(\alpha+\beta)$ (Tammertekniikka 2012, p. 15).

$$P = \frac{L\cos\alpha\left(\frac{w}{2} + \frac{w_{legs}}{2}\right)}{\mathrm{a}\cdot\sin(\alpha+\beta)} \quad (3)$$

The formula (3) can be used for calculating the force in the cylinder in any position where reactions Cy and Dy are not the same, it means that any position except initial – lowest position, because in that position dimension between DC is the same dimension as $2 \cdot d$.

The needed dimensions for further calculations, can be seen on Figure 9.9.

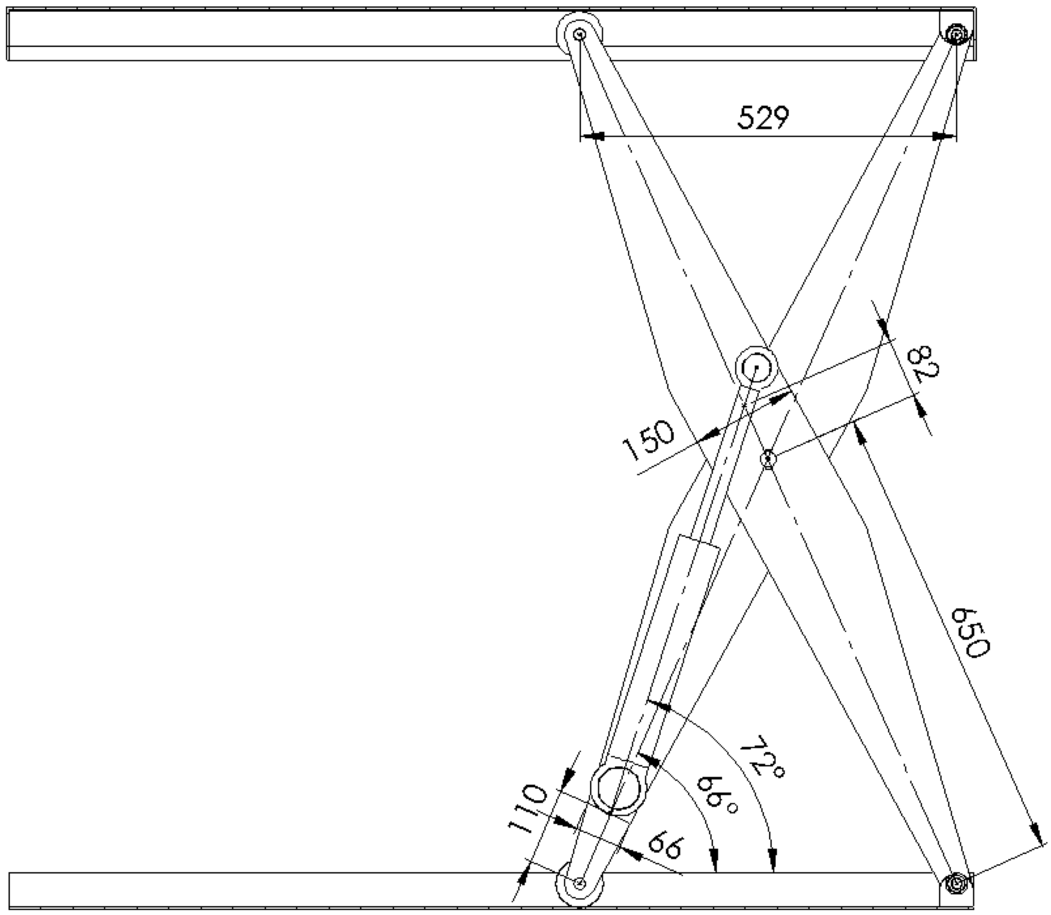


Figure 9.9 Dimensions in the highest position

According to the design there are the following measurements:

L = 1.300 meters

a = 0.82 meters

Mass of the load is 700 kg.

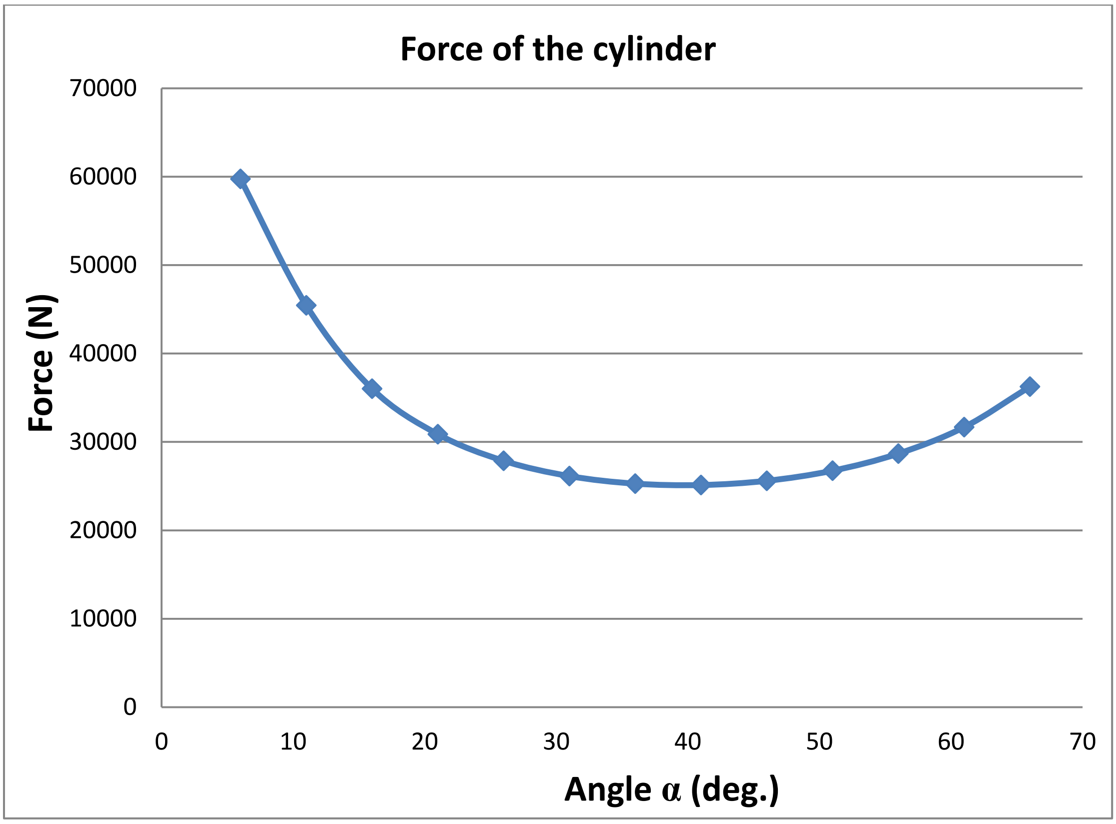
Mass of the legs is 67 kg.

α = 66°

β = 72°

$$P = \frac{1.3 \cos 66° \cdot 0.5(6867 + 657)}{0.082 \ \cdot \sin(66° + 72°)} = 36254\text{N}$$

Graph 1 and table 3, show how force depends on the angle α:



Graph 1 Cylinder force and angle

angle β(deg.)	angle α(deg.)	Force of Cylinder (N)
6	14	59751
11	17	45448
16	22	36019
21	27	30874
26	32	27867
31	37	26135
36	42	25281
41	47	25124

46	52	25602
51	57	26745
56	62	28679
61	67	31672
66	72	36254

Table 3 Cylinder force and angle

9.2 Forces acting on the leg

9.2.1 Lowest position

Now all needed forces are known. If $P_x = F_x$ and $P_y = F_y$, then P force equals to the force F in the pin and as they are acting like counter forces, their values are the same. Then it is necessary to find normal and shear forces acting on the leg in order to be able to find stresses. For that all the forces must be projected parallel to the axis of the leg, as shown on Figure 9.10, using the rules of geometry and components of the forces as it was done earlier.

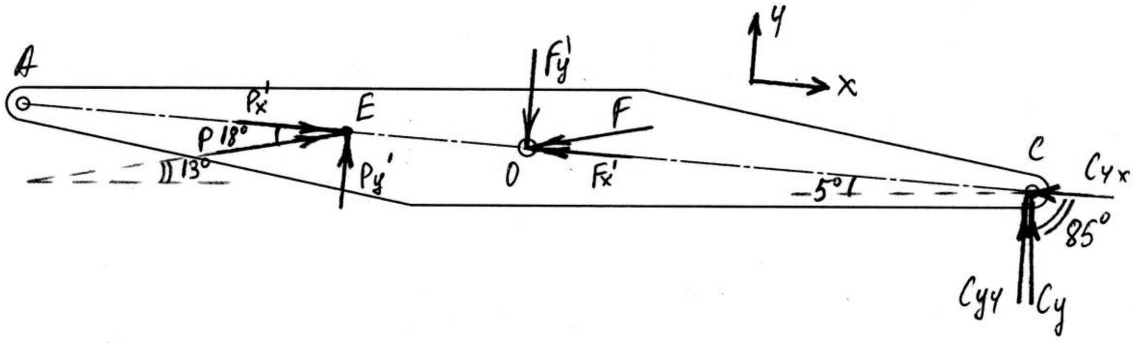


Figure 9.10 Forces components parallel to the axis of the leg

$$\sin 85° = \frac{Cyy}{Cy} \Rightarrow Cyy = Cy \sin 85° = 3748N$$

$$\cos 85° = \frac{Cyx}{Cy} \Rightarrow Cyx = Cy \cos 85° = 328N$$

$$\sin 18\,° = \frac{Py'}{P} \Rightarrow Py' = P \sin 18° = 19095N = Fy'$$

$$\cos 18° = \frac{Px'}{P} \Rightarrow Px' = P \cos 18° = 58770N = Fx'$$

$$\sin 85° = \frac{\frac{w}{2}y}{\frac{w}{2}} \Rightarrow \frac{w}{2}y = \frac{w}{2}\sin 85° = 3421N$$

$$\cos 85° = \frac{\frac{w}{2}x}{\frac{w}{2}} \Rightarrow \frac{w}{2}x = \frac{w}{2}\cos 85° = 299N$$

$$\sin 85° = \frac{\frac{w_{legs}}{2}y}{\frac{w_{legs}}{2}} \Rightarrow \frac{w_{legs}}{2}y = \frac{w_{legs}}{2}\sin 85° = 328N$$

$$\cos 85° = \frac{\frac{w_{legs}}{2}x}{\frac{w_{legs}}{2}} \Rightarrow \frac{w_{legs}}{2}x = \frac{w_{legs}}{2}\cos 85° = 29N$$

Now the free body diagram for one of the legs can be drawn as on Figure 9.11.

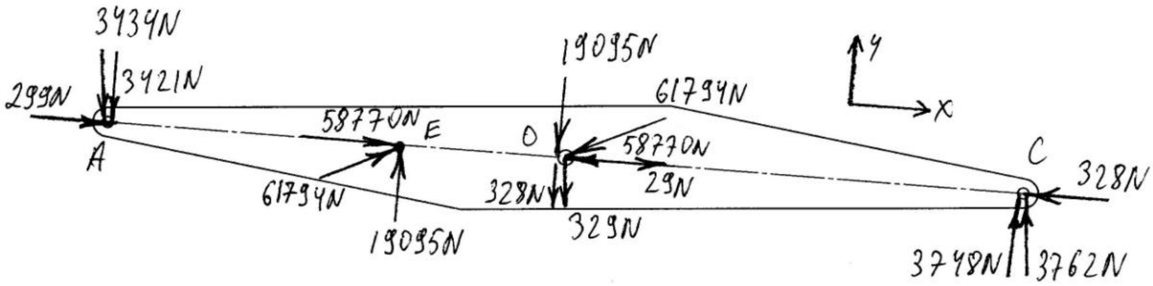


Figure 9.11 Free body diagram for the first leg in initial position

The same things are done for the second leg, where forces are the same but directions are different. Reaction forces at the points D and B are the same. It is shown on Figure 9.12.

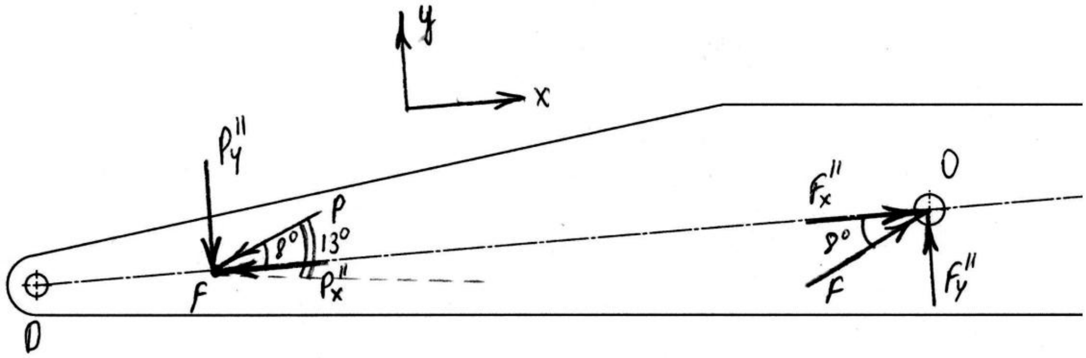


Figure 9.12 Forces components parallel to the axis of the second leg

$$\sin 8° = \frac{Py''}{P} \Rightarrow Py'' = P \sin 8° = 8600N = Fy''$$

$$\cos 8° = \frac{Px''}{P} \Rightarrow Px'' = P \cos 8° = 61193N = Fx''$$

Now the free body diagram for the one of the leg can be drawn as on Figure 9.13.

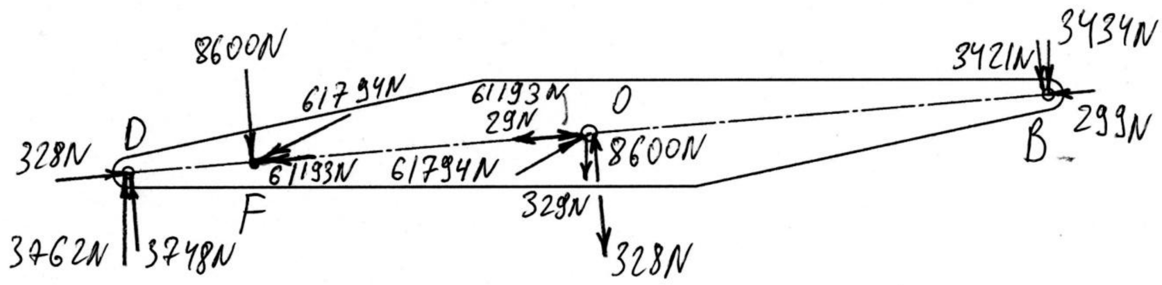


Figure 9.13 Free body diagram for the second leg in initial position.

9.2.2 Diagrams

Now it is possible to draw a shear force diagram, a normal force diagram, and a moment diagram. Then corresponding stresses can be calculated. The normal force diagram, shear force diagram and bending moment diagram for both legs are shown below on Figures 9.14 and 9.15.

”+” is for tension; ”-” is for compression:

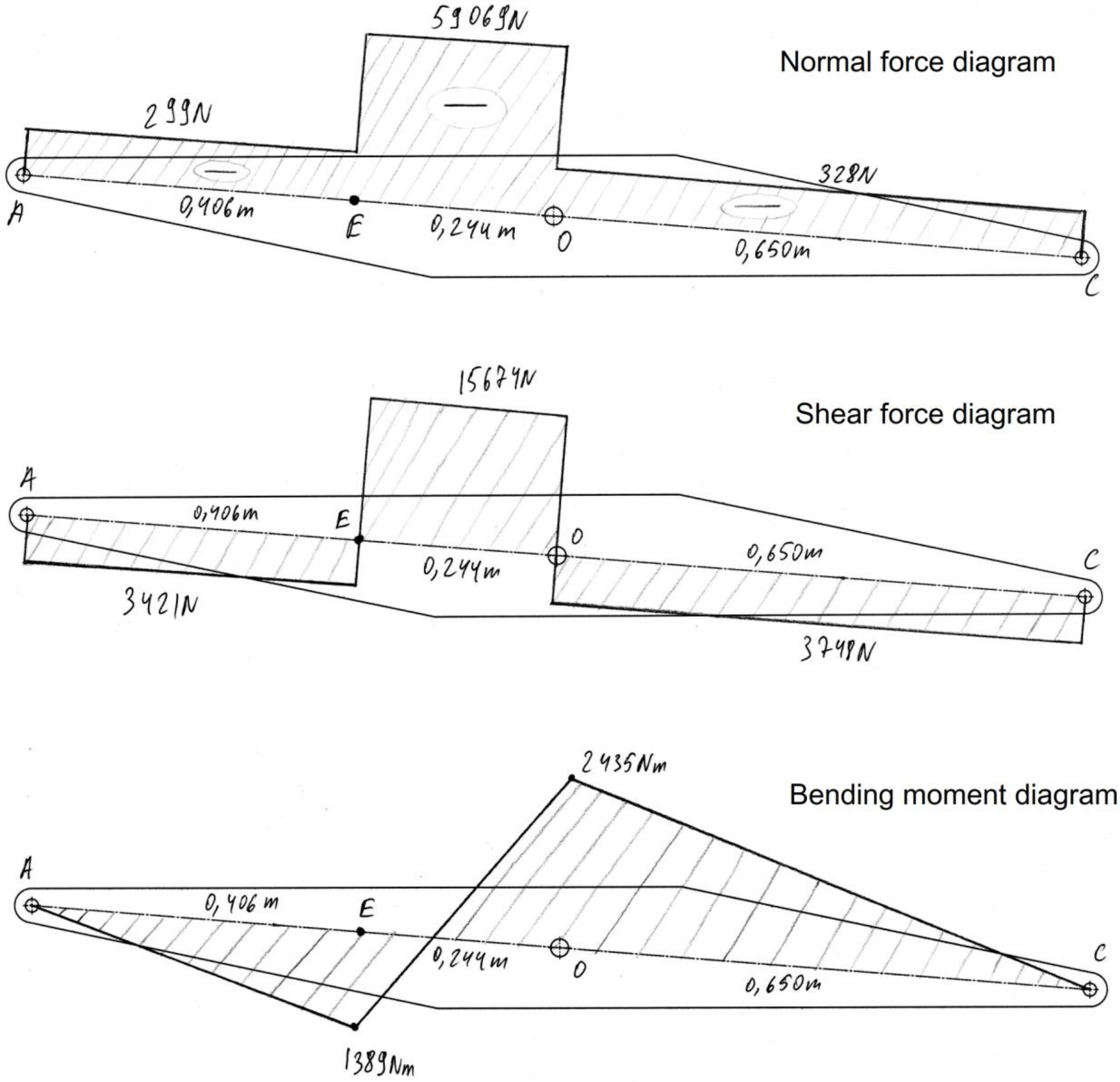


Figure 9.14 Diagrams for the first leg in initial position

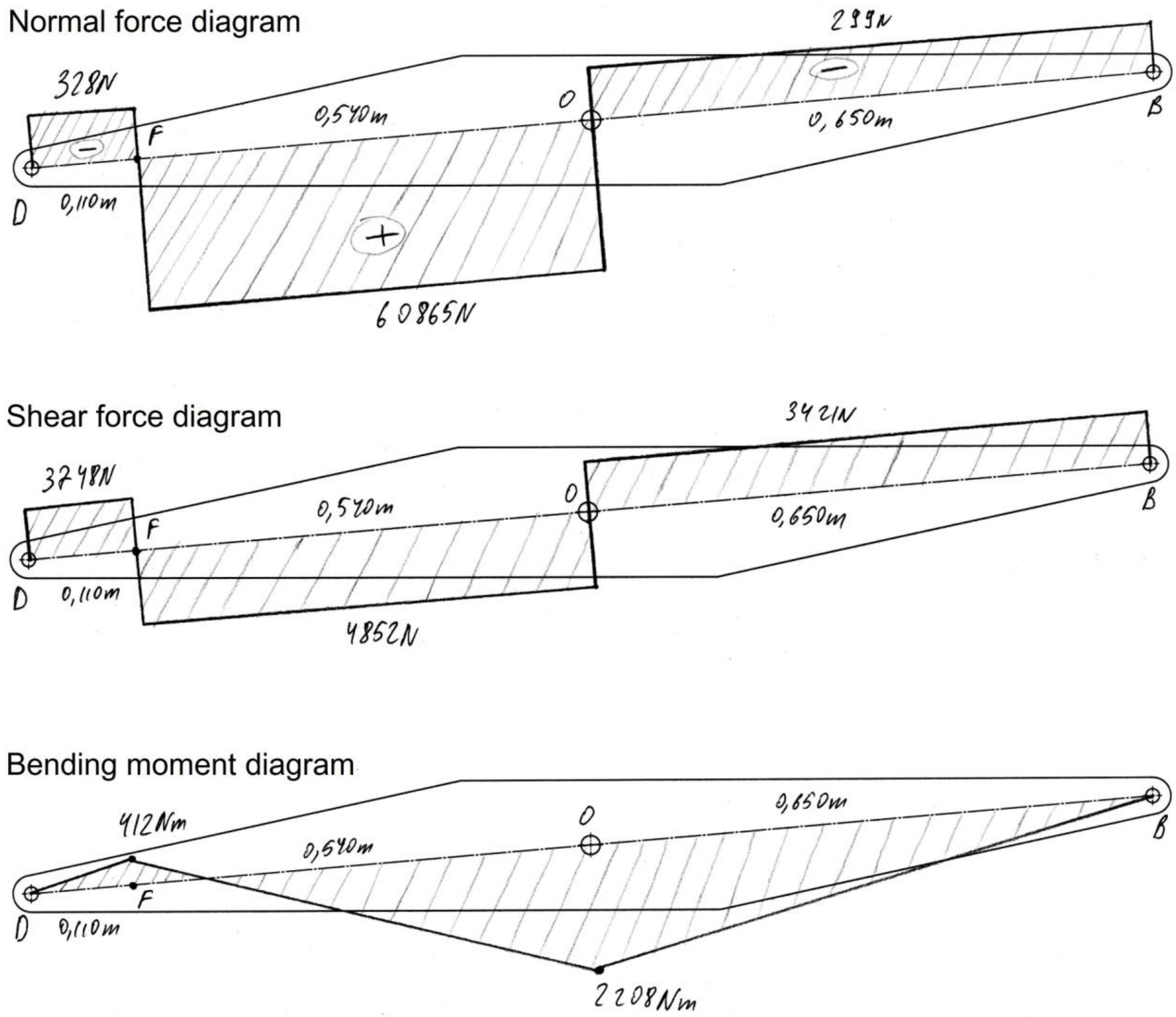


Figure 9.15 Diagrams for the second leg in initial position

9.2.3 Stresses calculations

Allowable normal stress for S355 steel:

Factor of safety is taken as 3 according to the safety standard ANSI MH29.1 (Ecoalifts.com 2016)

$$\sigma_{all} = \frac{R_e}{n} \text{ (Tammertekniikka 2012, p. 139).} \quad (4)$$

$$\sigma_{all} = \frac{355}{3} = 118.3 N/mm^2$$

Allowable shear stress:

$$\tau_{all} = 0{,}58 \cdot \sigma_{all} \text{(Tammertekniikka 2012, p. 140).} \quad (5)$$

$\tau_{all} = 68.6\, N/mm^2$

Actual stresses:

The highest normal stresses are between EO and FO, but the areas in the points E and F are the smallest, so as it is not obvious where the stress is higher, it is needed to check them both. Multiplier “2” comes from the fact that there are 2 symmetric legs supporting the table.

The width of the leg is 15 mm.

Point E:

$$\sigma_n = \frac{F}{A} = \frac{59069}{129 \cdot 15 \cdot 2} = 15.3 N/mm^2 \text{(Tammertekniikka 2012, p. 139).}$$

$$\tau = \frac{F}{A} = \frac{15674}{129 \cdot 15 \cdot 2} = 4.1 N/mm^2 \text{(Tammertekniikka 2012, p. 140).}$$

$$\sigma_{eq} = \sqrt{{\sigma_n}^2 + 3\tau^2} \text{ (Tammertekniikka 2012, p. 143).} \quad (6)$$

$$\sigma_{eq} = 16.87\ \ N/mm^2$$

Point F:

$$\sigma_n = \frac{F}{A} = \frac{60865}{66 \cdot 15 \cdot 2} = 30.7 N/mm^2$$

$$\tau = \frac{F}{A} = \frac{4852}{66 \cdot 15 \cdot 2} = 2.45 N/mm^2$$

$$\sigma_{eq} = 31 N/mm^2$$

Bending stress $\sigma_M = \frac{My}{I}$ where $I = \frac{1}{12} BH^3$(Tammertekniikka 2012, p. 144, p. 139).

M – maximum moment
y – dimension from the center to the top (half of the H)
B – width
H – height
The diameter of the hole at point O – 22 mm.

Point O:

$$\sigma_M = \frac{2435 \cdot 1000 \cdot 75}{\frac{1}{12} \cdot (15 \cdot 150^3 - 15 \cdot 22^3) \cdot 2} = 21.71\ N/mm^2$$

Point E:

$$\sigma_M = \frac{1389 \cdot 1000 \cdot 64.5}{\frac{1}{12} \cdot 15 \cdot 129^3 \cdot 2} = 16.7\ N/mm^2$$

Point F:

$$\sigma_M = \frac{376 \cdot 1000 \cdot 33}{\frac{1}{12} \cdot 15 \cdot 66^3 \cdot 2} = 17.26\ N/mm^2$$

As it can be seen all the actual stresses are lower than allowable stresses, that means that the current design is satisfactory and the structure is safe.

9.2.4 Highest position

In the other positions the formula for the force of the cylinder is different, and reaction forces and internal forces are different and stresses are needed to be revised. The second position is the highest possible point for the lift. But because of the geometry of the structure, the behavior of the forces is changed, internal forces are not the same as in the first position, its nature (compression and tension) is other.

Figure 9.16 shows the free body diagram of the first leg in the highest position.

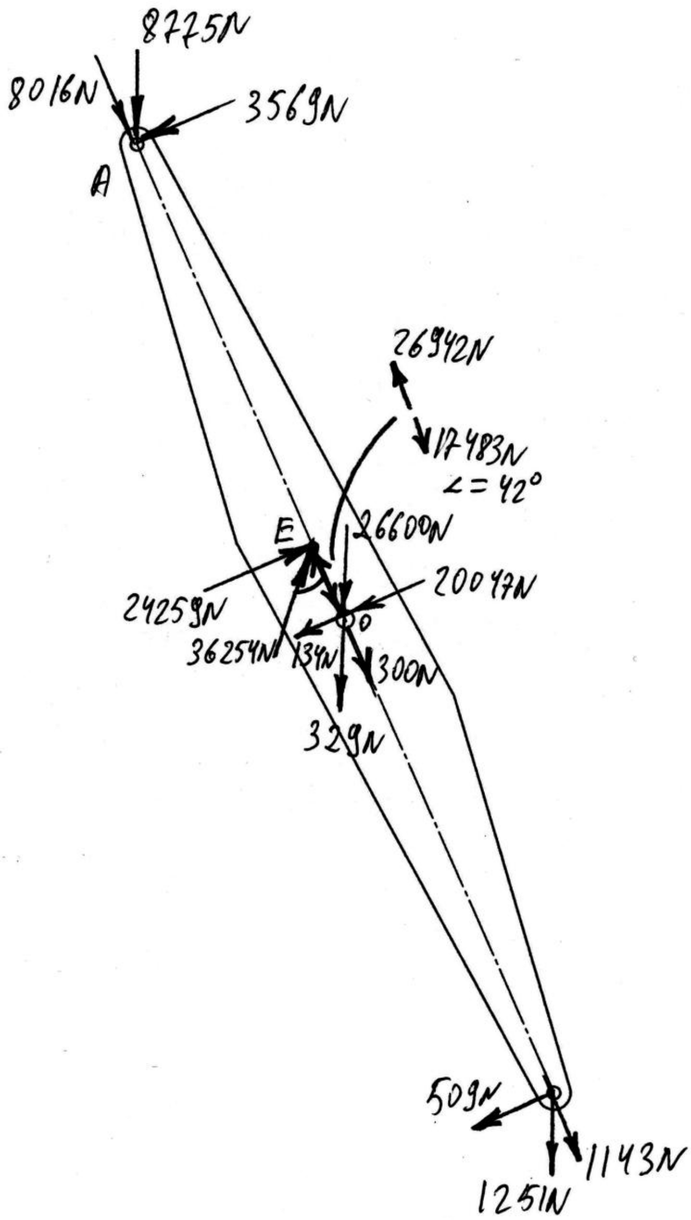


Figure 9.16 Free body diagram for the first leg in the highest position

$Cyx = \cos 24 \cdot 1251 = 1143N$

$Cyy = 1251 \cdot \sin 24 = 509N$

$\text{Ayx} = \text{Dyx} = \cos 24 \cdot 8775 = 8016N$

$\text{Ayy} = \text{Dyy} = 8775 \cdot \sin 24 = 3569N$

$\sin 42 = \frac{Py'}{P} \Rightarrow Py' = P \sin 42 = 24259N$

$$\cos 42 = \frac{Px'}{P} \Rightarrow Px' = P\cos 42 = 26942N$$

$$\sin 24° = \frac{\frac{w_{legs}}{2}y}{\frac{w_{legs}}{2}} \Rightarrow \frac{w_{legs}}{2}y = \frac{w_{legs}}{2}\sin 24° = 134N$$

$$\cos 24° = \frac{\frac{w_{legs}}{2}x}{\frac{w_{legs}}{2}} \Rightarrow \frac{w_{legs}}{2}x = \frac{w_{legs}}{2}\cos 24° = 300N$$

The force of the pin is no longer a counter force for the cylinder, its direction and magnitude is different now.

$$\mathrm{Fy}' = -3569 + 24259 - 134 - 509 = 20047\ \mathrm{N}$$

$$Fx' = -8016 + 26942 - 300 - 1143 = 17483N$$

$$F' = \sqrt{F_y'^2 + F_x'^2} = 26600N$$

The same is done for the second leg as shown on Figure 9.17.

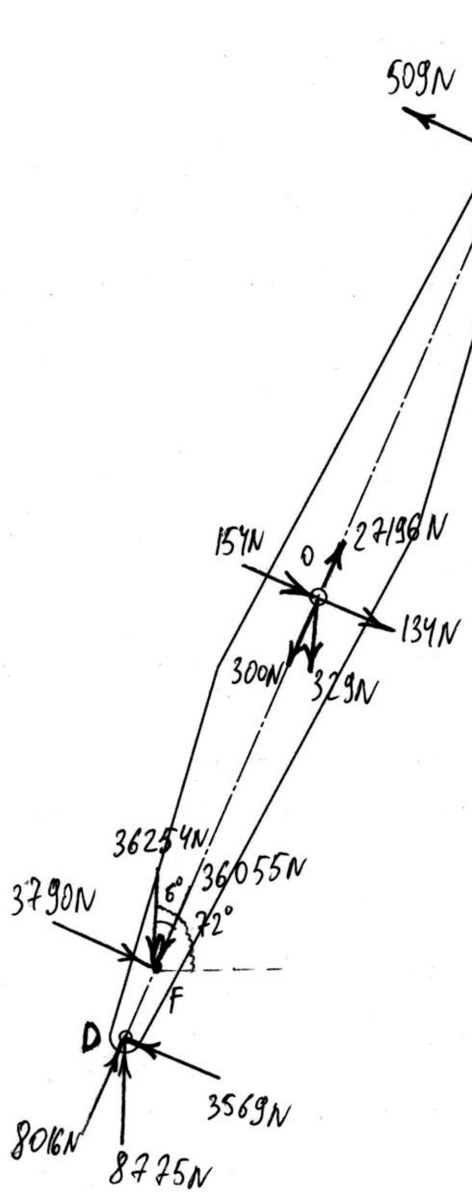


Figure 9.17 Free body diagram for the second leg in the highest position

$\text{Byx} = \text{Cyx} = \cos 24 \cdot 1251 = 1143N$; $\text{Byy} = \text{Cyy} = 1251 \cdot \sin 24 = 509N$

$\sin 6 = \frac{Py''}{P} \Rightarrow Py'' = P \sin 6 = 3790N$; $\cos 6 = \frac{Px''}{P} \Rightarrow Px'' = P \cos 6 = 36055N$

$\text{Fy}'' = 154\text{N}$ same direction as Py''; $Fx'' = 27196 = N$ opposite direction to Px''

$$F'' = \sqrt{F_y''^2 + F_x''^2} = 27197N$$

9.2.5 Diagrams

The normal force diagram, shear force diagram and bending moment diagram for both legs are shown below on Figures 9.18 and 9.19.

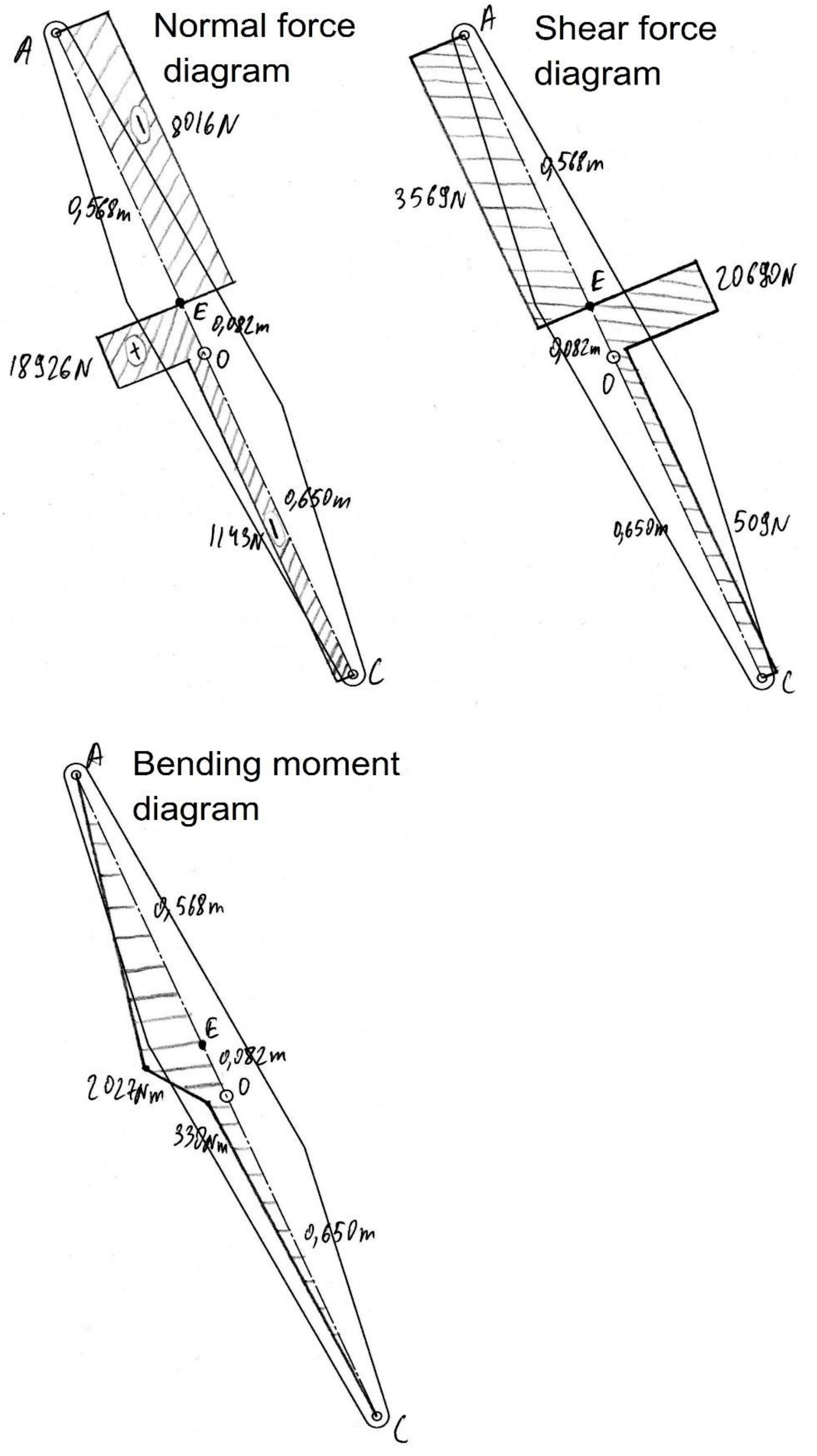


Figure 9.18 Diagrams for the first leg in the highest position

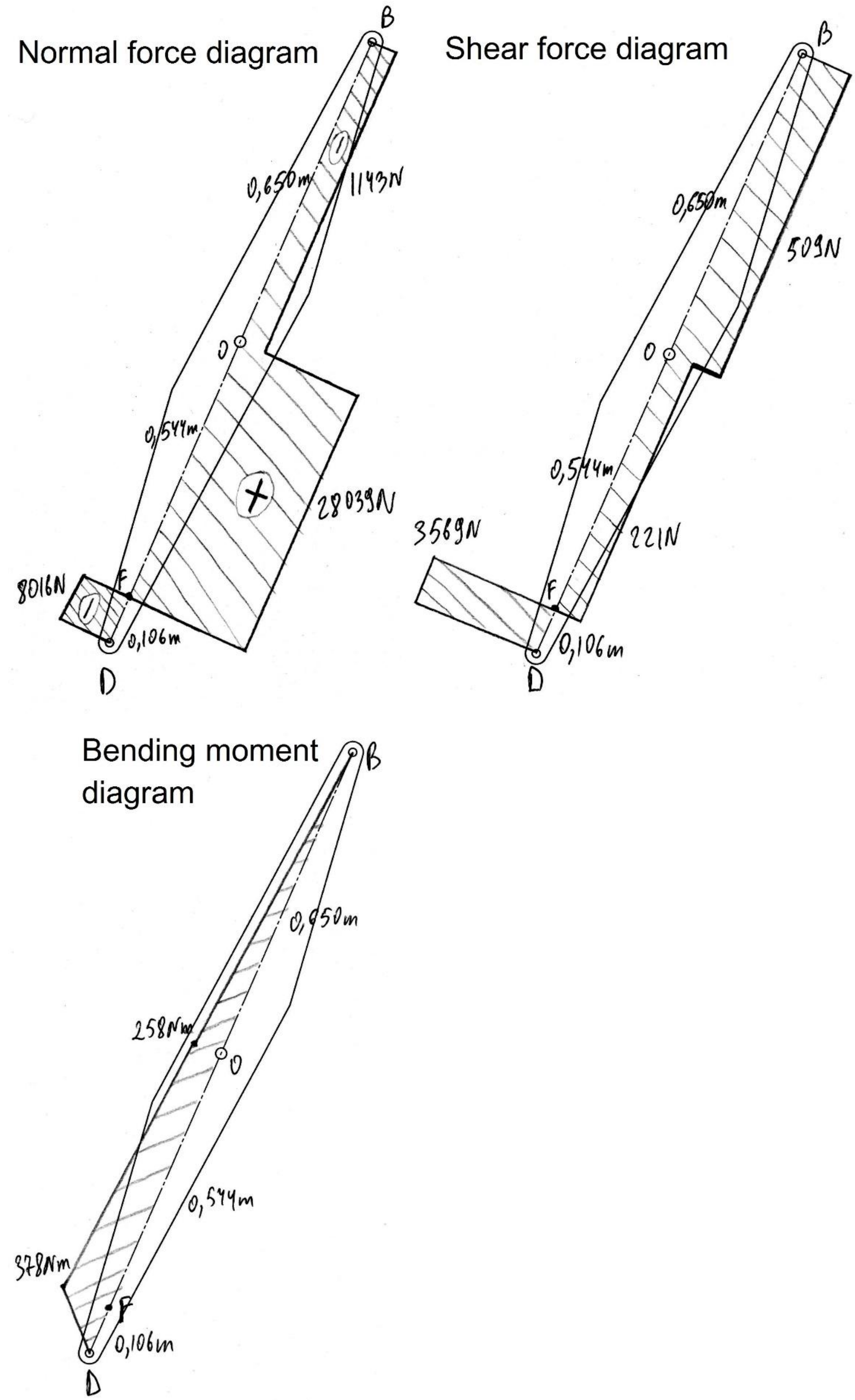


Figure 9.19 Diagrams for the second leg in the highest position

9.2.6 Stresses calculations

$$\sigma_{all} = \frac{R_e}{n} = \frac{355}{3} = 118.3 N/mm^2$$

$$\tau_{all} = 0{,}58 \cdot \sigma_{all} = 68.6\, N/mm^2$$

Actual stresses:

Point E:

$$\sigma_n = \frac{F}{A} = \frac{18926}{150 \cdot 15 \cdot 2} = 4.2 N/mm^2$$

$$\tau = \frac{F}{A} = \frac{20690}{150 \cdot 15 \cdot 2} = 4.6 N/mm^2$$

$$\sigma_{eq} = 9 N/mm^2$$

Point F:

$$\sigma_n = \frac{F}{A} = \frac{28039}{66 \cdot 15 \cdot 2} = 14.16 N/mm^2$$

$$\tau = \frac{F}{A} = \frac{3569}{66 \cdot 15 \cdot 2} = 1.8 N/mm^2$$

$$\sigma_{eq} = 14.9 N/mm^2$$

Point E:

$$\sigma_M = \frac{2027 \cdot 1000 \cdot 75}{\frac{1}{12} \cdot 15 \cdot 150^3 \cdot 2} = 18\, N/mm^2$$

As it can be seen all the actual stresses are lower than the allowable stresses, that means that the current design is satisfactory and the structure is safe. Bending stresses in point F and others are obviously too small, there is no need for calculations.

10 Conclusion

The project was carried out successfully according to the project plan. The outcome of the hydraulic scissors lift design meets the objective of the project. As a result, the project designed the electro-hydraulic parallelogram lift. The general section described the classification, purpose and technical characteristics of the lift, and the mechanism and operation principle of the designed lift.

In the design section, the lift calculation is done, where the forces acting in the cylinder and emerging stresses in the system were calculated. A 3D model was created.

After completed this project, I have gained some skills and knowledge in this field. I have learnt many things in terms of utilizing engineering mechanisms in a proper manner. Finally, the experience I have obtained throughout this project will certainly help me to be a creative engineer in the future.

11 A list of figures

12 A list of graphs

13 A list of tables

14 References

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