

# Mechanical Parking System

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*in cooperation with*





# Abstract

With the development of the transport, the traffic is more and more crowded. And another reason which is the price of the vehicle is cheaper. So much more people can buy the cars, thus, the road is more crowd, people should park their cars which need a lot of area, so we can see lots of parking lots in the city, but the classical parking system cannot reach the requirements nowadays. So, we should a new parking system.

So, in this report, we will introduce a new parking lot and system, which includes the modelling, programming, material stress analysis and motors.

At first, we reference the classical parking lots and some new parking lots. We find some problem about them which have not enough area and non-automated. Thus, we design a dimensional parking lot with programming. Which can realize automatic.

Secondly, we use the inventor 2017 to build the model and analysis about stress concentration. We also use inventor to simulation the action about our parking lot. In the model, we use the hydraulic system to drive the lift, which can up and down to park the cars, and we create a new system to fix the wheels to make sure the cars cannot move in the movement procedure.

Finally, our parking lot is an automatic and dimensional project. We will show you much more detail about our project, we hope our project will improve the parking lots to make people's life better and convenient.

## **Keywords:**

Automatic, PLC programming, lift, hydraulic system, dimensional, fixed system.



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FengYuan Wang  
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# List of symbols

Symbol	Quantity	Unit
$\alpha$	Angle	degree
$\theta$	Angle	degree
$M_{max}$	Maximum bending	N · mm
$W$	Force	N
$F$	Force	N
$m$	Mass	kg
$L$	Beam length	mm
$F_N$	Axial force	N
$F_{Ax}$	Force at point A x axis	N
$F_{Ay}$	Force at point A y axis	N
$F_{RA}$	Force at point A	N
$F_{RB}$	Force at point B	N
$F_{RC}$	Force at point C	N
$F_{RD}$	Force at point D	N
$b$	Beam cross section width	mm
$h$	Beam cross section height	mm
$z$	Distance neutral surface to extreme fiber	mm
$I$	Moment of inertia	
$Z$	Section modulus	
$E$	Elastic modulus	GPa
$\sigma_{max}$	Maximum stress	MPa
$\delta$	Deflection	mm
$D$	Cross section external side length	m
$d$	Cross section internal side length	m
$H$	External surface width and height	m
$h$	Internal surface width and height	m
$z_1$	Number of pinion teeth	
$z_2$	Number of wheel teeth	
$d_{1t}$	Reference diameter	mm
$P$	Input power	KW
$n_1$	Pinion speed	r/min
$u$	Gear ratio	
$K_t$	Load factor	
$T_1$	Torque of the pinion	N · mm

$\phi_d$	Tooth width coefficient	
$Z_E$	Material influence coefficient	$MPa^{\frac{1}{2}}$
$\sigma_{Hlim1}$	Fatigue strength limit of the pinion	MPa
$\sigma_{Hlim2}$	Fatigue strength limit of the wheel	MPa
$K_H$	Load coefficient	
$K_A$	Using coefficient	
$K_V$	Dynamic load coefficient	

# List of acronyms

<b>Acronym</b>	<b>Unfolding</b>
PLC	Programmable logic controller
FEM	Finite elements method
Gppw	Mitsubishi edit program
I/O	Input or output
CPU	Central processing unit
GB	China national standard



# 1 Chapter: Introduction

Nowadays, more and more vehicle is created over the world, especially cars. They play a vital role in our daily life, but there is something wrong with the cars, we do not have enough place to park the cars. So, we build a lot of parking lots, but we still cannot put all cars in it, we just park our cars on the road which is a terrible feeling for everyone. We do not have an own parking space. We should spend much time to find the parking space, so we want to design a totally new parking system to be instead of the classical parking system.[1]



*Figure 1-1. Parking Lot.*

On the control of the parking lots, we should park our cars by ourselves, we cannot use some machine to help us, and we do not know whether the parking lots are full, so we need a system to control the parking lots, and the system can help you to park your cars, even totally automatic.

Classical parking lots need much area to park more cars. When you want to go shopping, you enter a parking lots and you just see much more cars, you cannot park your cars. Some classical parking lots have not the second floor or third floor, some parking lots have some floors, but you may feel it is a bad feeling, because you need drive your cars to upstairs, you will feel so tired.

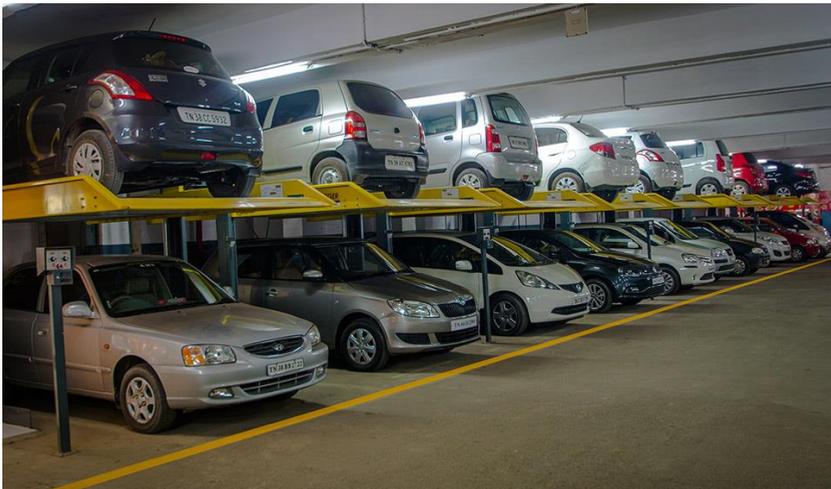
So, we need a totally new system to realize the people's requirements, for instance automatic, much more place, information about the number of the parking space, which are more important to everyone over the world.

## 2 Chapter: Survey of related work

Over the world, especially in the big cities, it's really hard for drivers to find a parking place, thus the parking lots cannot give enough space to everyone's cars. So, we design an automatic and dimensional parking system, to help people to park their cars and improve people's daily life.

About our project, we investigate varieties of parking lots which include a lot of problem, for instance, there are not enough space to park cars, the parking lots without programming, thus, people do not know if the parking space is empty or full, and people still drive by themselves to park. The three problems influence the city traffic and people's daily life. We always see these parking lots.

### 2.1 Step Stacker Type Parking System



*Figure 2-1. Step stacker type parking system.*

From the above picture, we can see this type of system features a pallet that is lifted after the car is loaded. Cars can be parked on the upper layer through the lift, but there is also a problem with it, which is that the bottom car must be moved to access the top car.

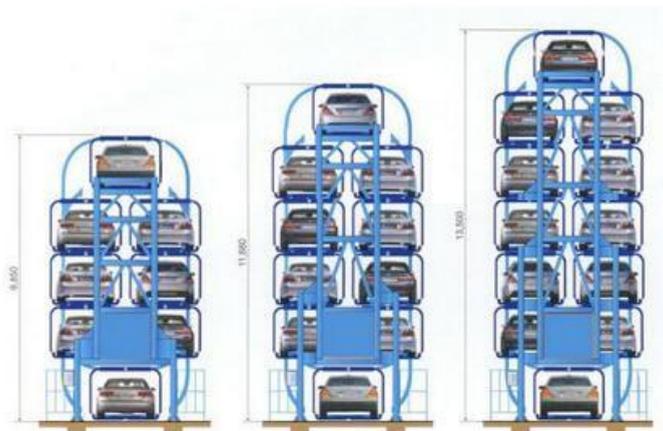
## 2.1.1 Features and Scope of application

- (1) Both indoor and outdoor installation is possible, installation can be done on simply flat area without additional architectural work.
- (2) Lift parking lot can reduce the lane area and increase the parking area utilize rate.
- (3) Mainly for the large area. Especially for both the request to solve the parking spaces and the ground can be made green, this device has been widely used.

However, this type of parking system also has the following environment conditions

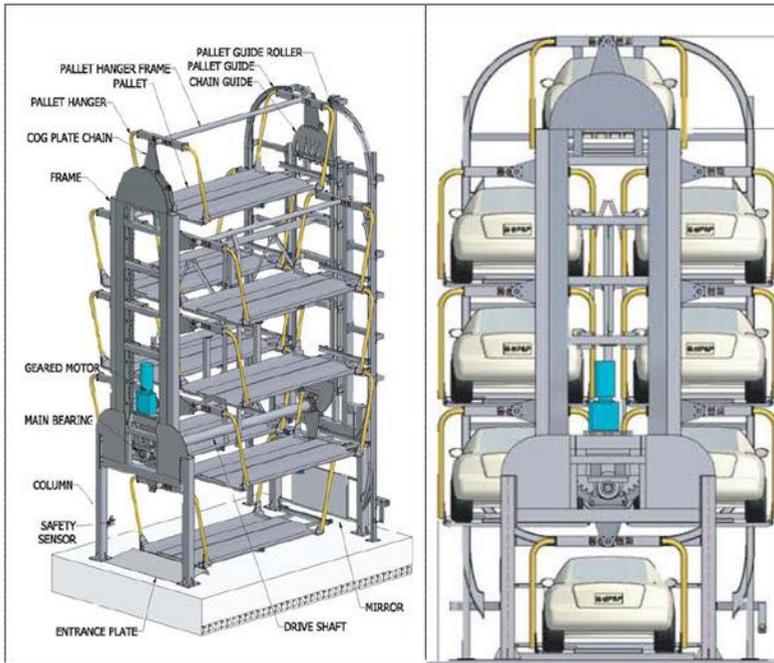
1. Environment temperature:  $-5^{\circ}\text{C} \sim +40^{\circ}\text{C}$ .
2. Relative humidity for the wettest month relative humidity should be less than the 95 percent.
3. Altitude should not exceed 2000m, the corresponding atmospheric pressure is 86~110KPa.
4. The environment should be no explosion, corrosion, electrical insulation and conductive media, and should avoid strong magnetic field interference.

## 2.2 Tower-Rotary Type Parking System



*Figure 2-2. Tower-rotary type parking system.*

This system features a rotary mechanism that allows the system and all the cars travel in the rotary motion. With this motion the load, unload cycle is possible. This system is preferable for 8 to 12 cars.



*Figure 2-3. Vertical circulation parking lot.*

Tower-rotary type of mechanical parking equipment with a single power, and control, footprint, which is easy to operate, park the car fast and economical[2].

It is simple to operate with the driver parking and leaving the vehicle in the system at the ground level. Once the driver leaves the incorporated safety zone the vehicle is automatically parked by the system rotating to lift the parked car away from the bottom central position.

Parking equipment through the programmable controller to control the operation of the equipment, the car can be parked on the platform with the chain for lifting movements, which can make any layer of the car on the rapid lift to the ground.

## 2.2.1 Dimension of the vertical circulation parking lot

*Table 2-1. Dimension of Tower-rotary type parking lot*

Type of parking lot	PCX
Location of the entrance and exit	bottom
Size of the cars (mm)	$\leq 5000 \times 1850 \times 1550$
Weight of the cars (kg)	$\leq 1700$
Number of the cars	8
Size of the entrance and exit (mm)	$2400 \times 2000$

## 2.2.2 Features and Scope of Application

This type of parking system has the following advantages

- (1) Quick Automated Parking and retrieval of vehicles.
- (2) Up to 12 cars or 10 SUV's can be easily and safely parked.
- (3) Surface space required equivalent to just 2 surface car parking spaces.
- (4) Easily constructed in a small area, just requiring a simple concrete base and 3 phase electricity.

## 2.2.3 Environment conditions

1. Environment temperature:  $-5^{\circ}\text{C} \sim +40^{\circ}\text{C}$ .
2. Relative humidity for the wettest month relative humidity should be less than the 95 percent.
3. Altitude should not exceed 2000m, the corresponding atmospheric pressure is 86~110KPa.
4. The environment should be no explosion, corrosion, electrical insulation and conductive media, and should avoid strong magnetic field interference.

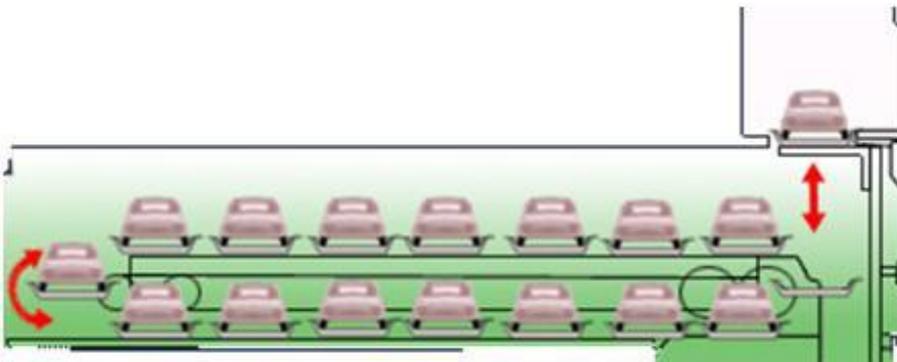
## 2.3 Horizontal circulation parking equipment

We also find another new parking lot, which is a horizontal Circulation parking equipment.

Horizontal Circulation is a system meant for parking cars in tight spaces that lack driveways, thus using the space most effectively in small and middle sized buildings. The system operates in a manner similar to that of a conveyor type chain drive arrangement. Horizontal Circulation system can be installed in underground basements as well as podium levels.[3]



*Figure 2-4. Horizontal Circulation parking system.*



*Figure 2-5. Principle of horizontal Circulation parking system.*

The operating principle of the horizontal circulation parking system follows the above figure, from the red arrow, which is use the lift to up and down the cars, and lift can be utilized to put the cars to cycle, which is rotation.

The horizontal circulation parking system is also the most concentrated way to park vehicles. There is almost no wasted space and is usually used below ground with elevator access.

### 2.3.1 Feature and scope of the application

Feature: it can save the original parking exit road, improve and increase the rate of the lane utilization. The use of this equipment in the basement reduces both the entry and exit lanes, increase land, reduce emissions, reduce pollution, and reduce ventilation costs

### 2.3.2 Dimension of the horizontal cycle parking lot

*Table 2-2. Dimension of horizontal cycle parking lot.*

Type of the cars	Range of the size	
	Length (mm)	Width (mm)
Small car	$(5000\sim5300) \times 2$	$(2250\sim2300) \times N+2$
Medium cars	$(5300\sim5600) \times 2$	$(2310\sim2450) \times N+2$
Large cars	$(5600\sim6100) \times 2$	$(2400\sim2550) \times N+2$

(Note: N-Number of parking units)

### 2.3.3 Height Requirements

*Table 2-3. Height of horizontal cycle parking lot.*

Floor	Range of size
Ground floor	2000~2200
First floor(B)	2000~2200
Second floor(B)	3500~4400
Third floor(B)	5650~5900

## 2.4 Stacker type parking system

The parking lots with the platform to park the cars, which can also be used to up and down to realize multi-floor movement.

This system features a typical storage system. This system has unique mechanism called stacker, it moves centrally and it has parking slot on its either sides. It has inbuilt robotic mechanism that pull and push the car to and from the parking bay. Preferably, this system can be used in longitudinal parking area.[4]



*Figure 2-6. Stacker type parking system.*

Storage and claim of vehicles is realized by aisle stacker and storage column. Constructed with concrete or steel structure in full closure. Besides, it is characterized with automatic control, intelligent management, high security and flexible system plan, arranged on or underneath the ground.

Mainly to reduce the lane area, increase the parking density, improve area utilization, but the actual application is still very little.

Multi-level horizontal movement parking equipment can be built on the ground, can also be built in the ground, which is safety, reliability, high degree of automation, access to high efficiency, high space utilization.



*Figure 2-7. Plane lifting parking lots.*

Mainly for large garage, especially for both the request to solve the parking spaces and the ground can be used for greening, sculpture and other landscaping facilities.

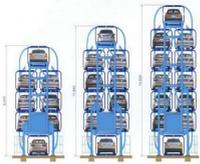
#### 2.4.1 Feature and scope of the application

1. Environment temperature:  $-5^{\circ}\text{C} \sim +40^{\circ}\text{C}$ .
2. Relative humidity for the wettest month relative humidity should be less than the 95 percent.
3. Altitude should not exceed 2000m, the corresponding atmospheric pressure is 86~110KPa.
4. The environment should be no explosion, corrosion, electrical insulation and conductive media, and should avoid strong magnetic field interference.

## 2.5 Comparison with the parking system

We investigate four kinds of parking lots including simple lift parking lots, Vertical circulation parking lot, horizontal cycle parking lots and plane lifting parking lots.

*Table 2-4. Comparison with varieties parking system.*

Pictures	Type	Feature
	Step Stacker Type	Parking with the simple lift, without enough space
	Tower-Rotary Type	Much time to park and take your cars.
	Horizontal cycle	Cycling to park and take your cars
	Stacker type	Parking with plane and it can be much more floors, which can be used in large garage

## 2.6 Conclusion

From the table and introduction of the parking systems, we are more interested in the last one. Stacker type is more convenient for people to parking their cars and more safety to load the cars. And plane lifting is more satisfied with this type of garage in the big cities' residential place.

### **3 Chapter: Method and Goals**

Through the survey of the related work, there are so many problems about the classical parking lots and other special parking lots, which include there are not automatic, enough space, parking by hand, enough information about the parking space. Thus, we should change it.

Through the inventor 2017, we build three floors with a movement platform, which can be controlled by PLC and motors, and we add hydraulic system to run the lift to up and down the cars, which can realize the automatic with our parking system.

Initial, we build three floors, the first floor is still same with the classical parking lots. But the rest floors are new parking lots, which have 12 parking space.

Then, we create a platform with hydraulic system, which is controlled by PLC programming. The design can realize automatic for everyone, you just drive your car to the platform and press the button, the platform will run per the programming to put your car on the fixed parking space, which is convenient to drivers.

About the lift, we utilize the hydraulic system to control. We choose the hydraulic system including piston, piston rod and others. PLC programming control the platform and hydraulic system. We choose a kind of PLC machine.

Above of all, we design a new parking lot including platform, parking lot model, hydraulic system, programming, motor, and rest small component.

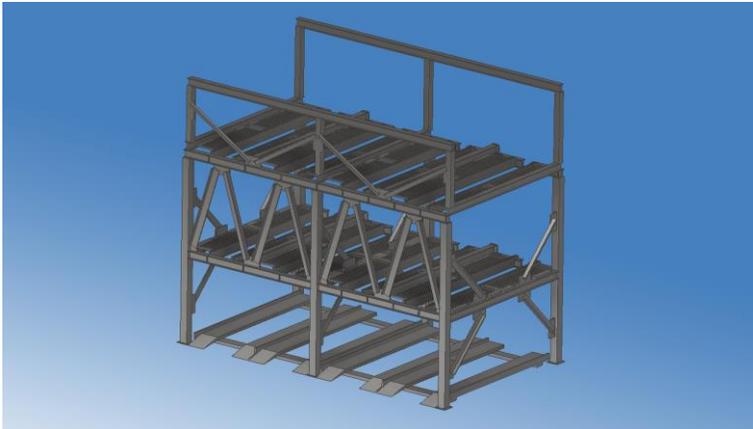
We hope to improve the classical parking lots and help people to park their cars.

# 4 Chapter: Modelling

Inventor 2017 is the main software for the modelling and dynamic simulation. The modelling includes the garage, scissor hydraulic lift, car transporter.

## 4.1 Garage Truss

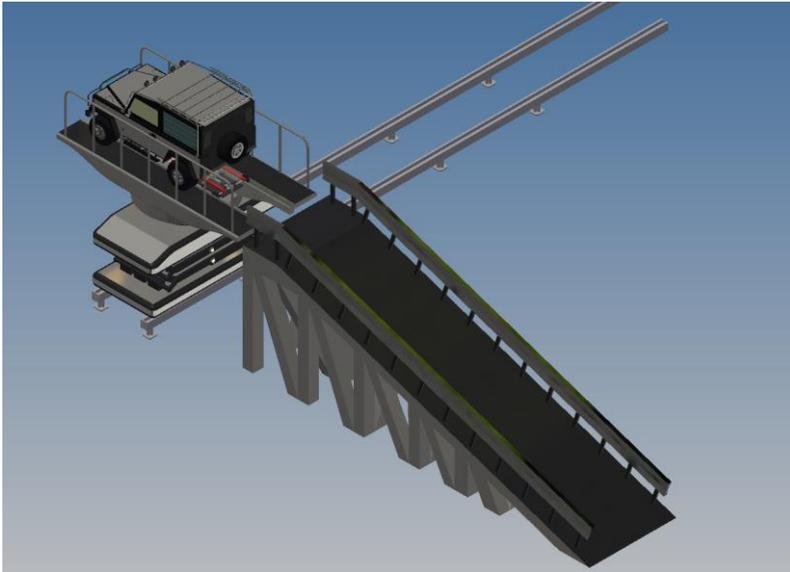
In our case, the garage especially designed for the residential place, which means one vehicle owner has the corresponding parking place. To simplify the garage as well as shows our design principle, the final assembly have 24 parking places. The following picture shows how it looks like.[5]



*Figure 4-1. Garage Truss.*

For the first layer, the vehicle owner can just drive in and park, however, for the second and third layer, the vehicle need to be park on the elevator platform, waiting for the transport to park the vehicle to its specific place.

## 4.2 Parking Bridge

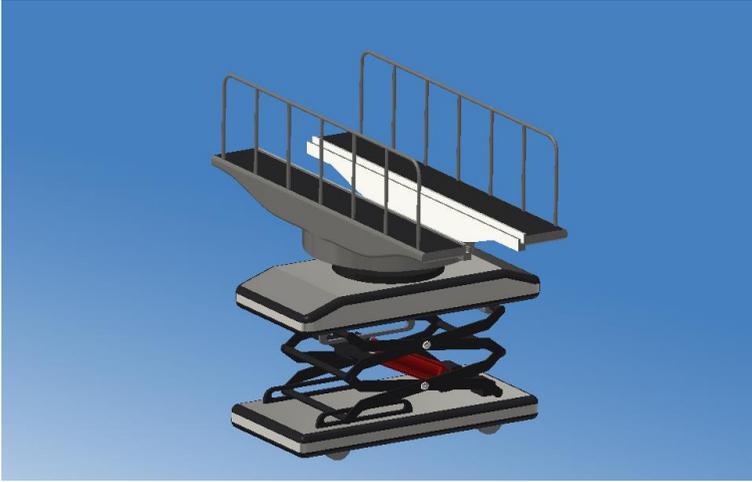


*Figure 4-2. Parking Bridge.*

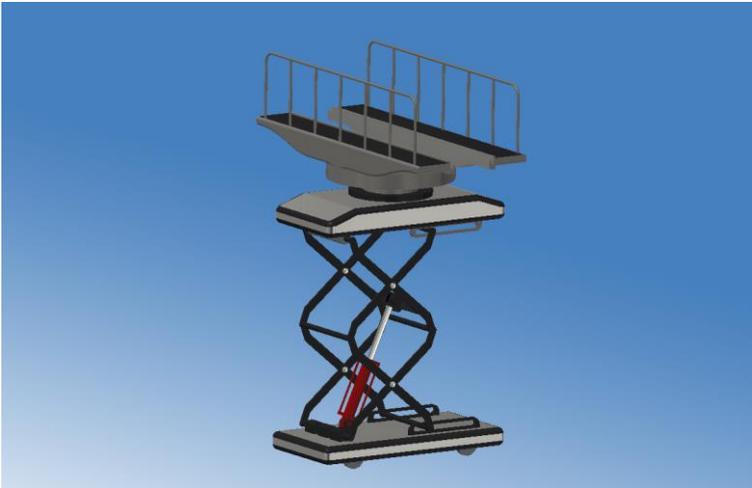
As mentioned before, the first layer vehicle owner can just drive in and out, do not need to use the lift. However, for the second and third layer vehicle owner, they need to park their car on the lift platform, so the parking bridge connect the ground with the lift platform. The design of the parking bridge use the truss structure, makes it more reliable and save material.

## 4.3 Parking Elevator Platform System

This system includes two movement, firstly, the elevator transport move along the transverse direction, then the hydraulic elevator starts to lift the vehicle to its corresponding layer.



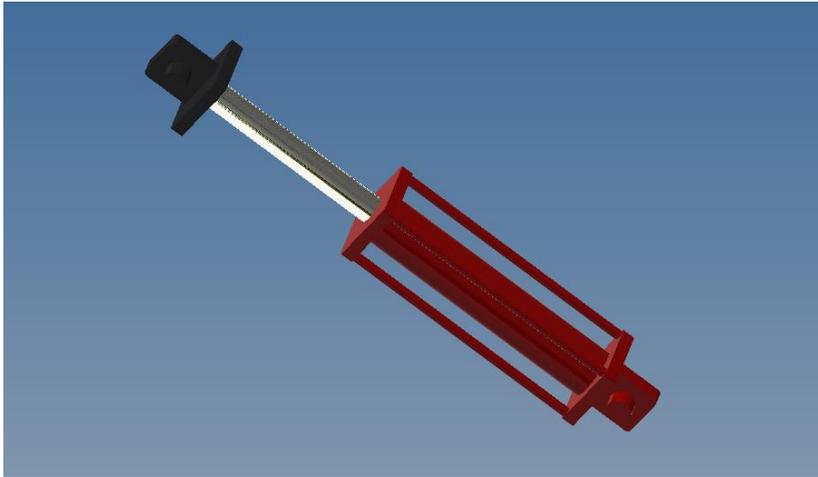
*Figure 4-3. Hydraulic elevator at the lowest position.*



*Figure 4-4. Hydraulic elevator at the highest position.*

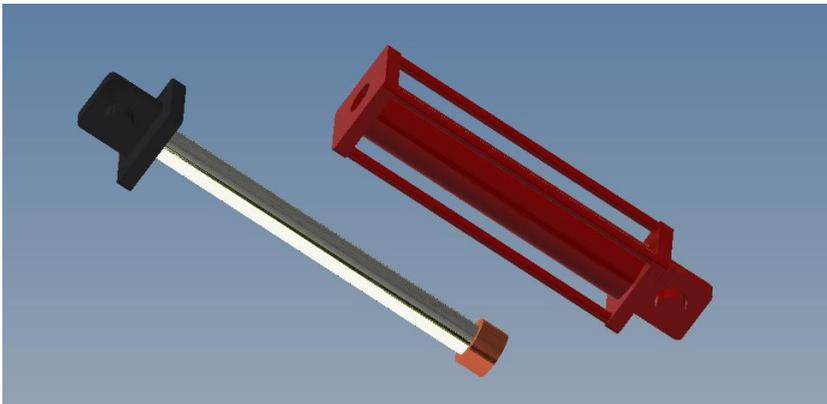
When the platform at the lowest position, the angle between the beam and ground  $\alpha = 5^\circ$ , and the height of the platform is 3.06m; when the platform at the highest position, the angle between the beam and ground  $\alpha = 45^\circ$ , and the height of the platform is 6.40m. The height range satisfied the height requirement of the garage.[6]

### 4.3.1 Hydraulic Cylinder and piston



*Figure 4-5. Hydraulic System.*

Hydraulic system is the main support mechanism of the lift, the detailed design calculation of the hydraulic cylinder and piston will be introduced in the following chapter. The hydraulic cylinder (red part) end will be connected on the bottom platform, meanwhile, the hydraulic rod end will be connected on the support plate, which is welded on the support beam.[7]



*Figure 4-6. Hydraulic Cylinder and Rod.*

### 4.3.2 Scissors Lift support beam

There are two type of support are used in the lift system, you can see the following picture, the support beam type A will be connected with support beam type B, connected by pin. As for the support beam type B, there will be connected with platform, so we designed the both end have round rod for connection.

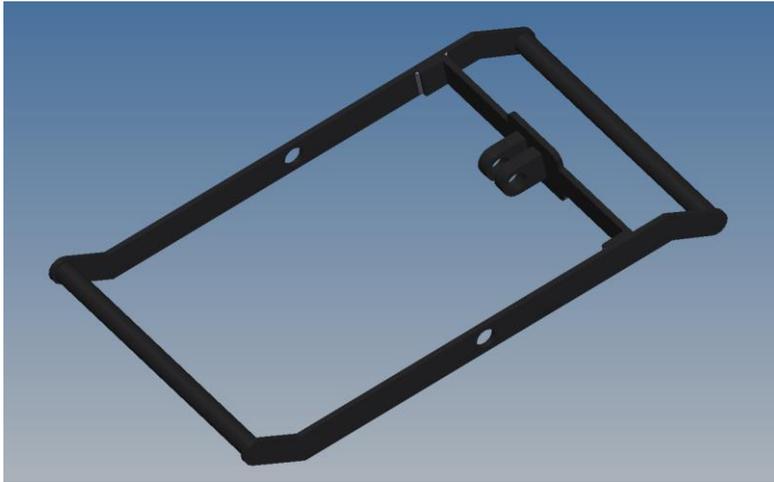


*Figure 4-7. Lift support beam type A.*

The support beams are the main part of the scissors lift system, so the force and strength need to be analysed, it will all be introduced in the following chapter, the model will be simplified and the result will be got from analysis software, and verified by philosophy method calculation.



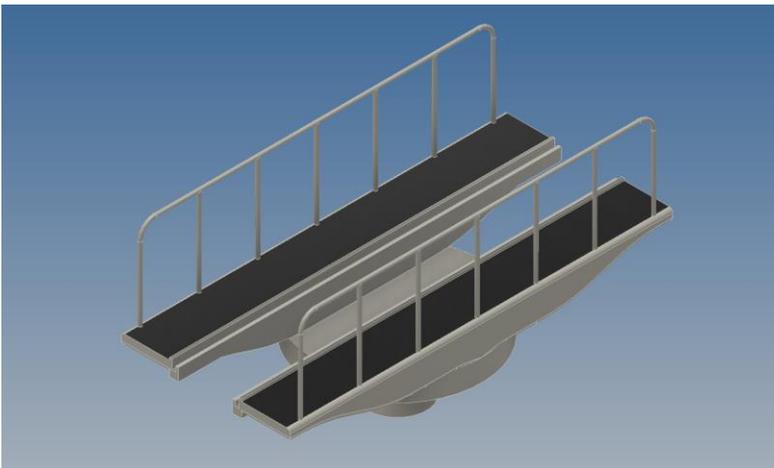
*Figure 4-8. Lift support beam type B.*



*Figure 4-9. Lift support beam with plate.*

The above figure has a little bit different with the beam type B, because the beam is welded with a support plate, which will connected with the hydraulic rod.

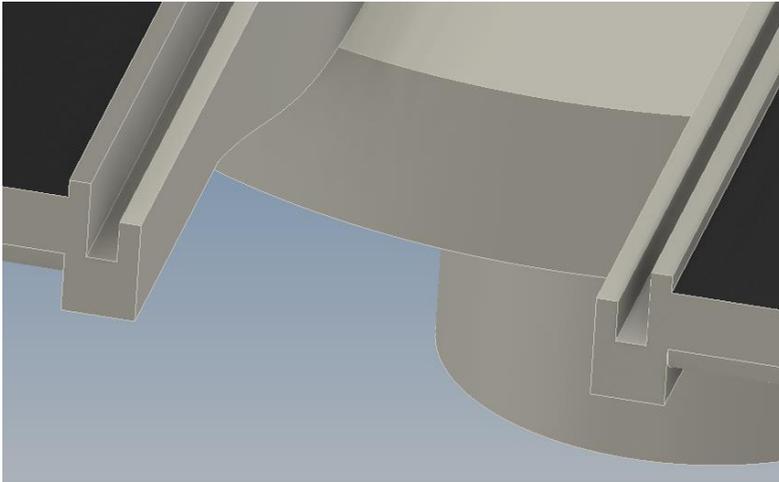
#### 4.3.3 Rotatable Platform and Moving Track



*Figure 4-10. Rotatable platform.*

This part will connected with the lift upper platform, it's rotatable, so it can meet more requirement by the residential place situation, and meanwhile the parking bridge's place will also be adjusted according to this platform's

position. The driver need to park the car at the specific place wait for the transport system hold the vehicle's tire and move the vehicle's place.



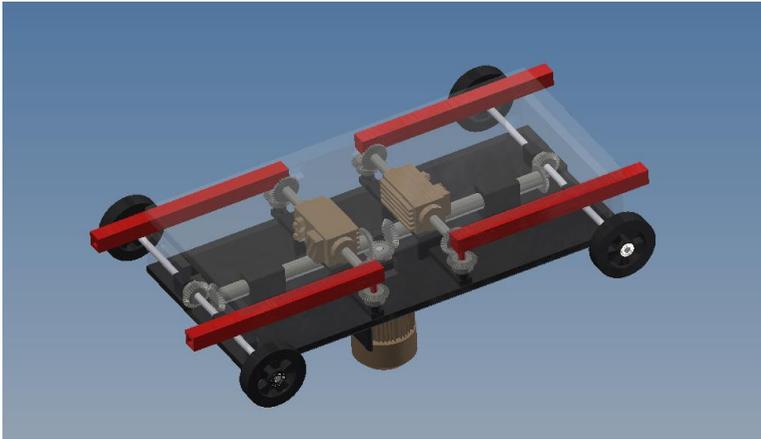
*Figure 4-11. Hydraulic Cylinder and Rod.*

From the above figure, there is track on the platform, because the transport system need to move along the track, we design to use track as the transport solution just for the stable reason, before the vehicle park on the platform, the transport system will be in position, once the car parked and the driver left, the transport system will start to work.

#### **4.4 Vehicle Carrying and transport System**

The transport system is main responsible for the moving vehicle to the corresponding place. The transport in the final assembly is consist of two vehicle transporter and carrying units, they are connected by a length adjustable beam, because of the different has the different wheel base. To meet more vehicles size requirement, the connector beam is designed adjustable.

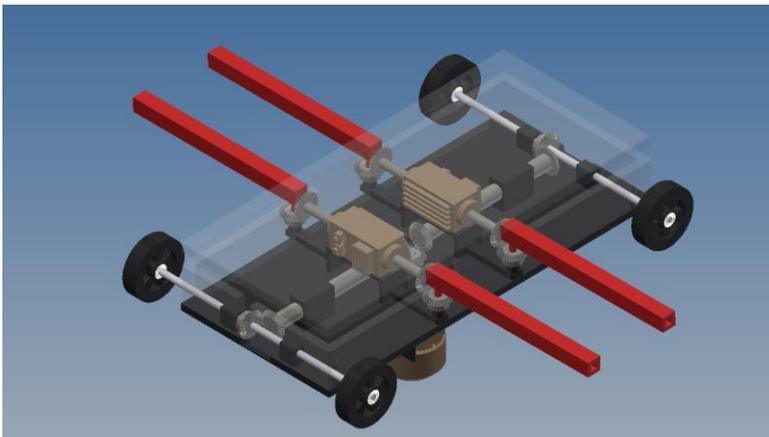
#### 4.4.1 Bevel Gears



*Figure 4-12. Vehicle transport and carrying unit-beam at initial position.*

Before the vehicle parked on the platform, the rotate beam will in the initial position, once the vehicle parked, two small motor start to work, with the bevel gear transmission mechanism.

#### 4.4.2 Rotate carrying beam

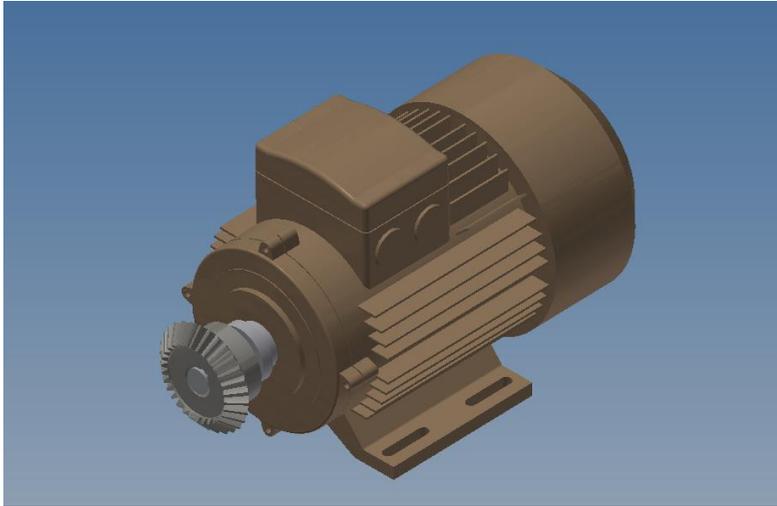


*Figure 4-13. Vehicle transport and carrying unit-beam at operating position.*

In the above figures, you can see four red beams, which are used for holding the tire, from the initial position to the operating position, the beam

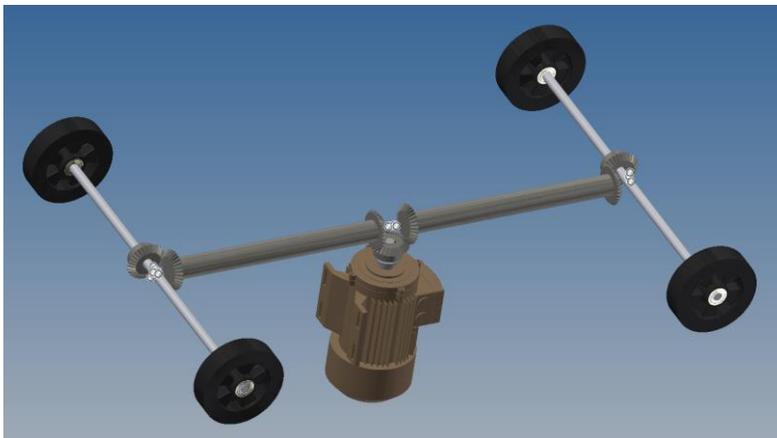
need to rotate  $90^\circ$ , so the beams are drove by the single motor with bevel gear transmission.

#### 4.4.3 Motors and bevel gears



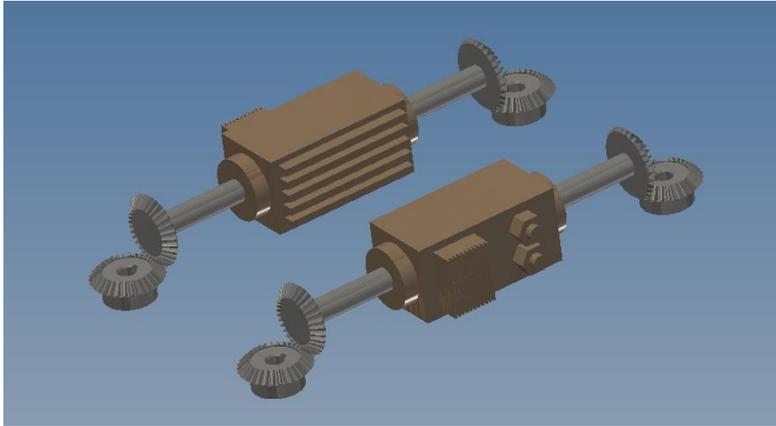
*Figure 4-14. AC Motor.*

This motor is use for the drive power of the transport, in order not to intervene the transport system's move, the motor is installed at the bottom of the transporter plate.



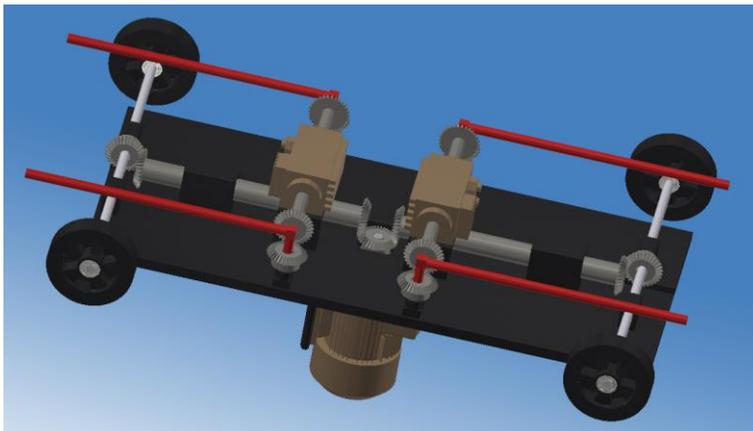
*Figure 4-15. AC Motor and bevel gears transmission system.*

To decrease the weight as much as we can, we only use one motor as our drive power, so we use the tribble bevel gears transmission, make the transport system four-wheel drive.



*Figure 4-16. Small motor with bevel gears.*

The rotate beam transmission is quite same as the drive power transmission part, use the isolate motors as the drive power, controlled by the plc modules, the motor will rotate the specific angle.



*Figure 4-17. Vehicle transport and carrying unit.*

As for the wheel drive of the transporter, three pairs of bevel gears transmission by one motor are used, make the transport four wheel drive, and the transmission ratio is 1:1, so the motor's rotation speed decide the speed of the transport.

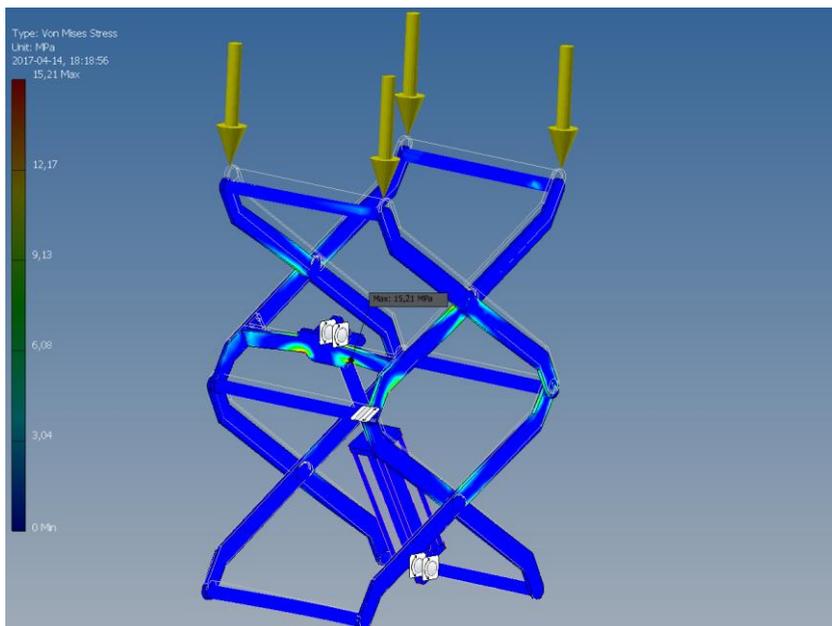
# 5 Chapter: Stress Analysis FEM and Hand Calculation

## 5.1 Support beam of the hydraulic lift

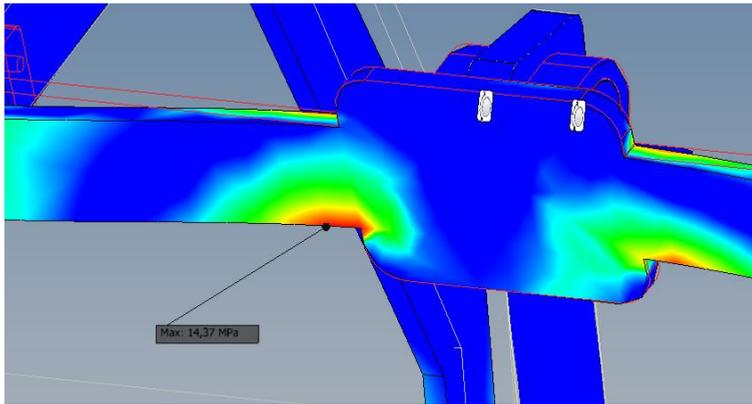
The Support beam of the hydraulic lift is the most important part in our design, so in this section we will analyse each beam and find its maximum stress. And the result will be compared with Abaqus result.

### 5.1.1 Overall Stress Analysis

The force analysis has been discussed in chapter 7, the beam has two different force situations. Firstly, the overall stress will be analysed by inventor, find the maximum stress point in this system; secondly, each beam will be analysed by Abaqus, and verified by hand calculation. All members are rectangle steel rod, 30mm thickness, 150mm width. Inventor result can be found in the following figures.[8]



*Figure 5-1. Maximum stress of the scissors lift system.*



*Figure 5-2. Maximum stress point.*

According to the result, the maximum stress point occurs at the corner of the hydraulic cylinder connector, and the value is 15.21MPa. Obviously, the connector doesn't have smooth fillet, so it has the stress concentration at this point.

### 5.1.2 Force analysis of support beam

Support beam is the most important lifting component, also the main loading structure. Select Steel No.45 and hot-rolled, because of the higher quality, its excellent strength, plasticity, toughness than carbon structural steel comprehensive mechanical properties are better, main use of the manufacture of more important mechanical parts. The following figure shows the sketch.

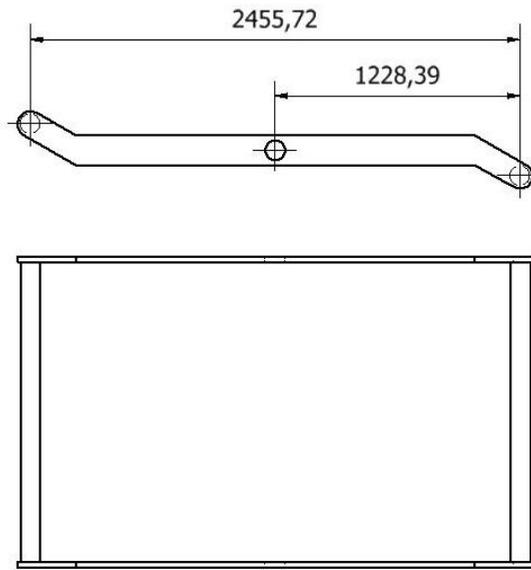


Figure 5-3. Sketch of the support beam.

### 5.1.2.1 Determination of the support beam construction

Conduct the stress analysis for the beam

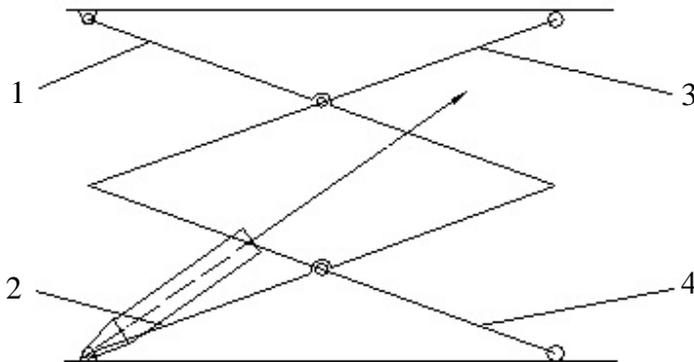


Figure 5-4. Support beam number.

(1) Analyse the load condition of beam No.3

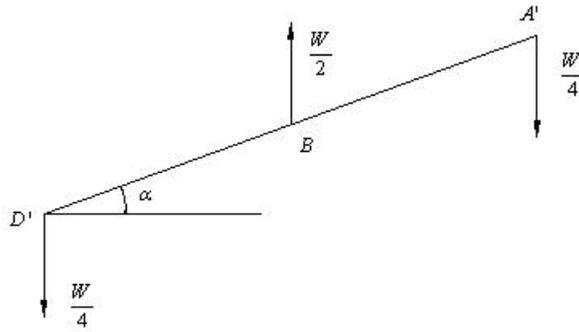


Figure 5-5. Force diagram of beam No.3.

Respectively, drawing the bending moment and axial force diagram

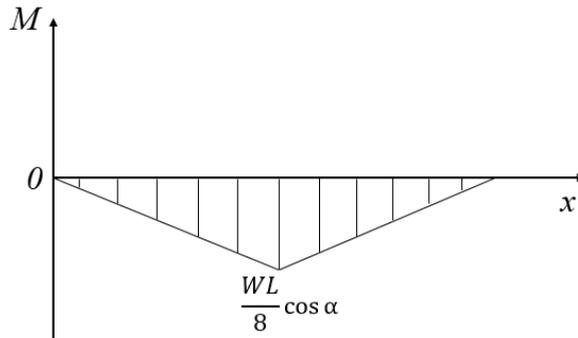


Figure 5-6. Bending diagram of beam No.3

When the platform at the minimum position,  $\alpha = 5^\circ$ , the beam has the maximum bending.

From the above figure, the maximum bending occurs in point B.

$$M_{max} = \frac{WL}{8} \cos \alpha = \frac{24500 \times 2.36}{8} \times \cos 5^\circ \text{ N} \cdot \text{m} = 7200 \text{ N} \cdot \text{m}$$

When the platform at the highest position  $\alpha = 45^\circ$ . The support beam has the maximum axial force.

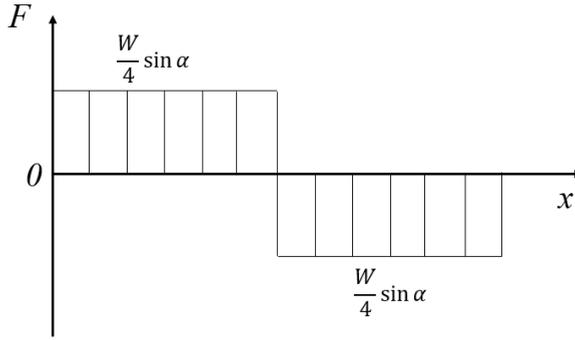


Figure 5-7. Axial force diagram of beam No.3

$$F_N = \frac{W}{4} \sin \alpha = \frac{24500}{4} \times \sin 45^\circ = 4331 \text{ N}$$

Beam No.2 and beam No.4 have the same load situation like beam No.3.

(2) Then analysis the load condition of beam No.1.

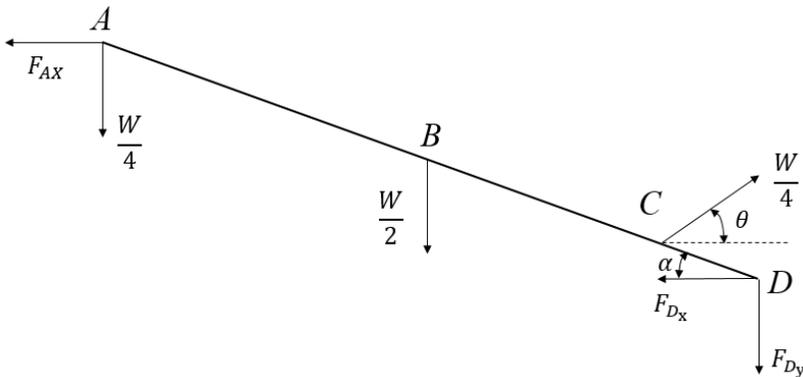


Figure 5-8. Force diagram of beam No.1

Analysis the bending of point D.

$$F_{Ax} L \sin \alpha + \frac{W}{4} L \cos \alpha + \frac{W}{2} \frac{L}{2} \cos \alpha = \frac{P}{2} \frac{L}{6} \sin(\theta + \alpha)$$

Obtain  $F_{Ax} = -94467.2 \text{ N}$ .

Figure 6-10 can be transferred to the following figure.

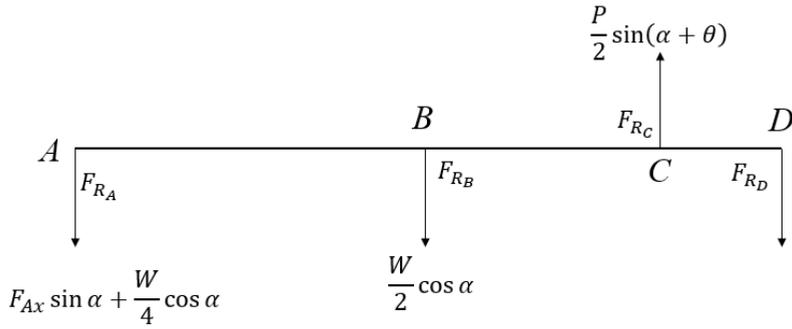


Figure 5-9. Force diagram of beam No.1.

Based on the above figure, the bending diagram can be drawn

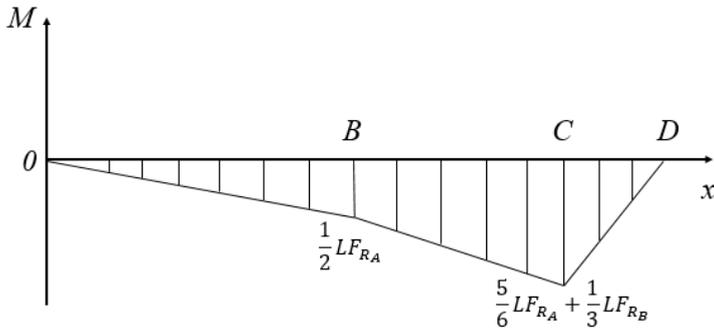


Figure 5-10. Bending force diagram of beam No.1.

From the above figure, the maximum bending moment occurs in point C.

When the platform at the lowest position  $\alpha = 5^\circ$ . The support beam has the maximum axial force.

Take  $W=25000\text{N}$ ,  $P=9.36W$ .

$$M_{max} = -\left(\frac{5}{6}F_{RA} + \frac{1}{3}F_{RB}\right)L = -2476.817\text{N} \cdot \text{m}$$

The result of the force analysis will be used in the strength analysis in the following chapter.

When the platform at the highest position  $\alpha = 45^\circ$ . The support beam has the maximum bending moment.

Take  $W=25000\text{N}$ ,  $P=9.36W$ .

$$M_{max} = -\left(\frac{5}{6}F_{R_A} + \frac{1}{3}F_{R_B}\right)L = -17272.46\text{N} \cdot \text{m}$$

### 5.1.3 Single beam stress analysis

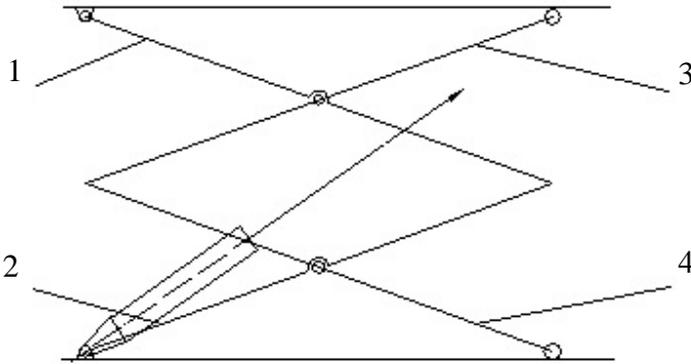


Figure 5-11. Support beam number.

Assume the load  $W = 25000\text{N}$ , consider the maximum weight of normal family car is approximately  $2000\text{kg}$ , the force analysis as follows figure.

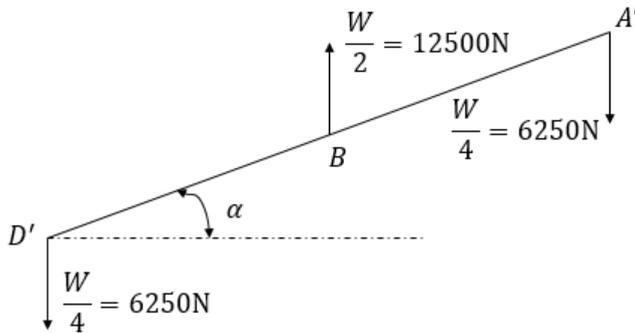


Figure 5-12. Force analysis of beam No.3.

The material of the beam is Stainless Steel, because of its good Comprehensive performance, like Corrosion resistance and formability

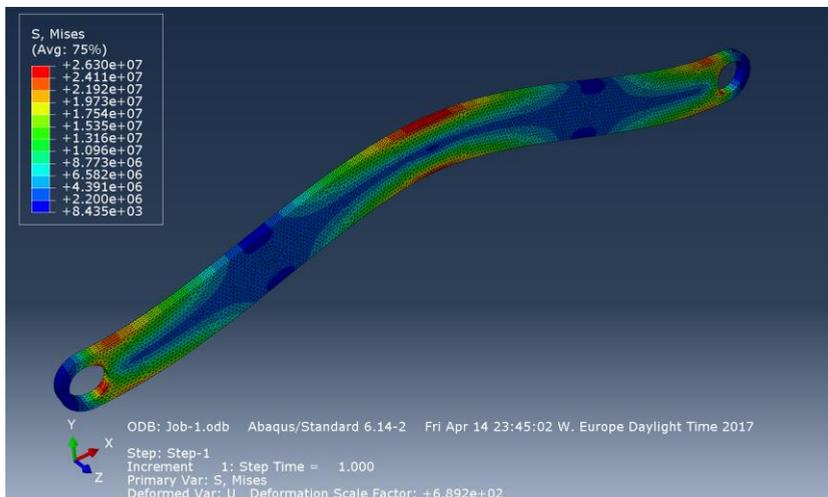
corresponding Material's physical property can be found in the following table.

*Table 5-1. Material's physical property*

<b>Mechanical</b>	
Young's Modulus	193.000 GPa
Poisson's Ratio	0.30
Shear Modulus	86000.00 MPa
Density	8.000 g/cm <sup>2</sup>
<b>Strength</b>	
Yield Strength	250.000 MPa
Tensile Strength	540.00 MPa

Based on the load direction in the real life, the middle position of the beam should bear 12500 N. And both endpoint ought to bear 6250N.

When the platform at the lowest position, which means when  $\alpha = 5^\circ$ , see the result in the following figure.



*Figure 5-13. Maximum stress of the support beam No.3.*

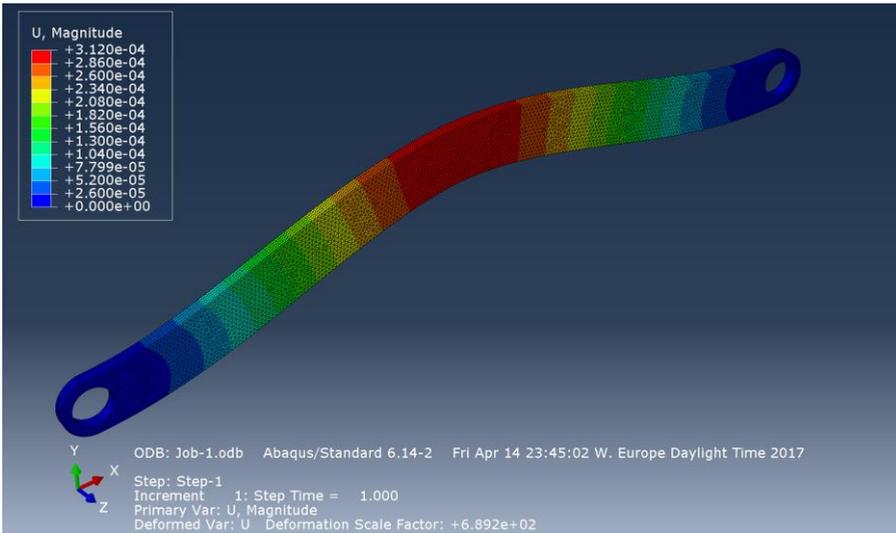


Figure 5-14. Maximum deflection of the support beam No.3.

When the platform at the highest position, which means when  $\alpha = 45^\circ$ , see the result in the following figure.

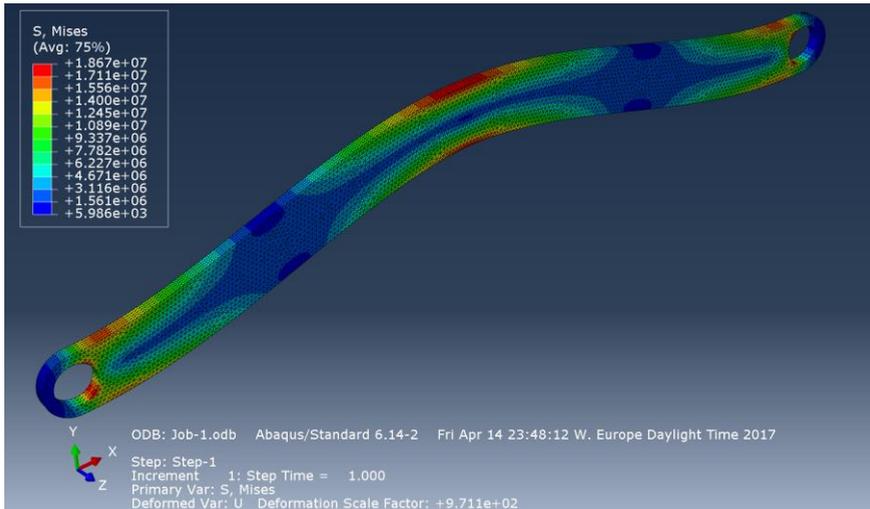


Figure 5-15. Maximum stress of the support beam No.3.

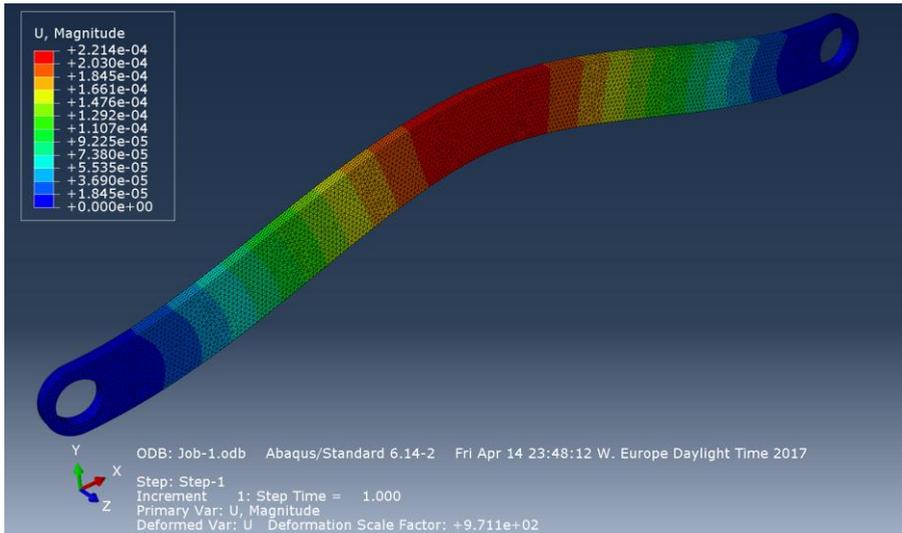


Figure 5-16. Maximum deflection of the support beam No.3.

According to the result get from Abaqus, the maximum stress and deflection at its corresponding position value can be concluded in the following table.

Table 5-2. FEM-Maximum stress and deflection of beam No.3

Angle	Maximum stress(MPa)	Maximum deflection(mm)
$\alpha = 5^\circ$	26.3	0.3120
$\alpha = 45^\circ$	18.67	0.2214

Because the beam No.2 and beam No.4 have the same load situation like beam No.3. Then analyse the stress of beam No.1. The force analysis as follows figure.

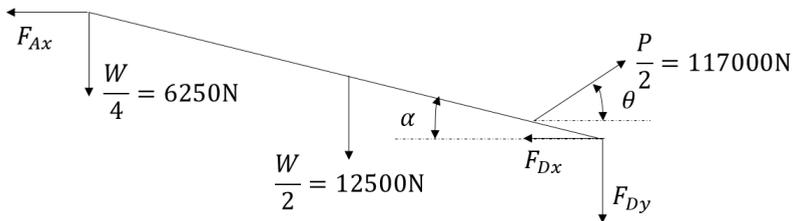


Figure 5-17. Force analysis of beam No.1.

Based on the load direction in the real life, the middle position of the beam should to bear 12500 N. And the hydraulic cylinder support at 1/6 length of length from right endpoint ought to bear N.

When the platform at the lowest position, which means when  $\alpha = 5^\circ$  and  $\theta = 6.98^\circ$ , see the result in the following figure.

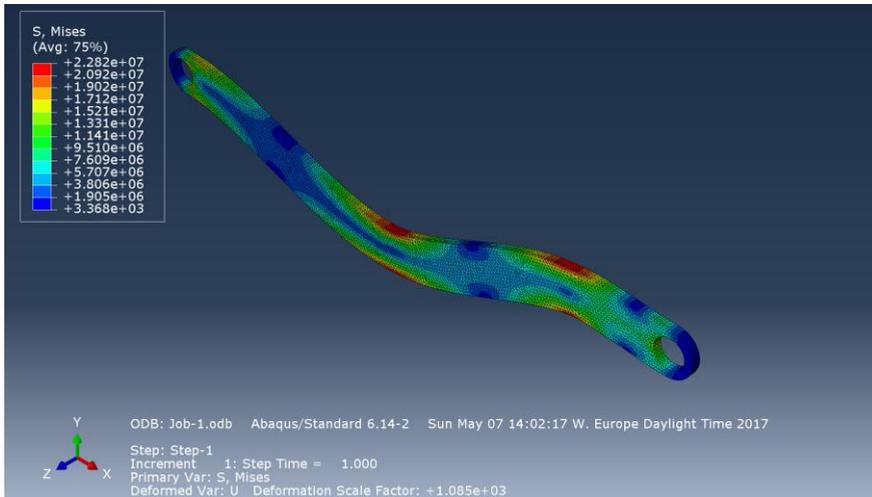


Figure 5-18. Maximum stress of the support beam No.1.

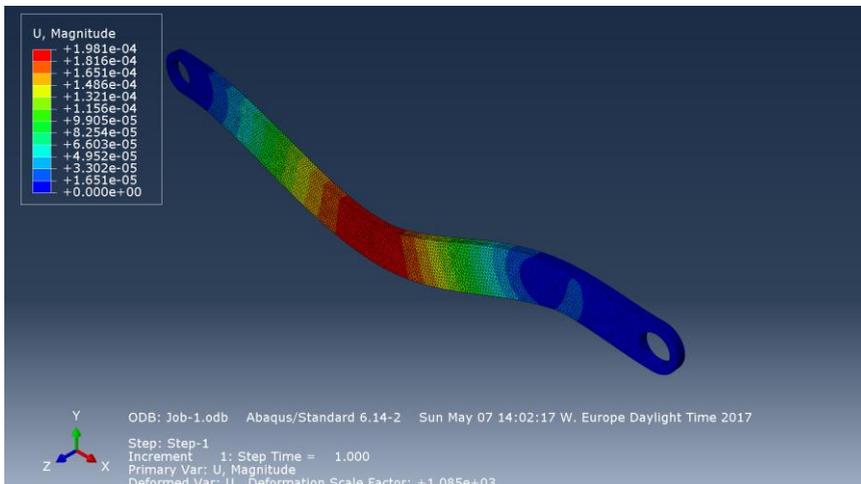


Figure 5-19. Maximum deflection of the support beam No.1.

When the platform at the lowest position, which means when  $\alpha = 45^\circ$  and  $\theta = 54.46^\circ$ , see the result in the following figure.

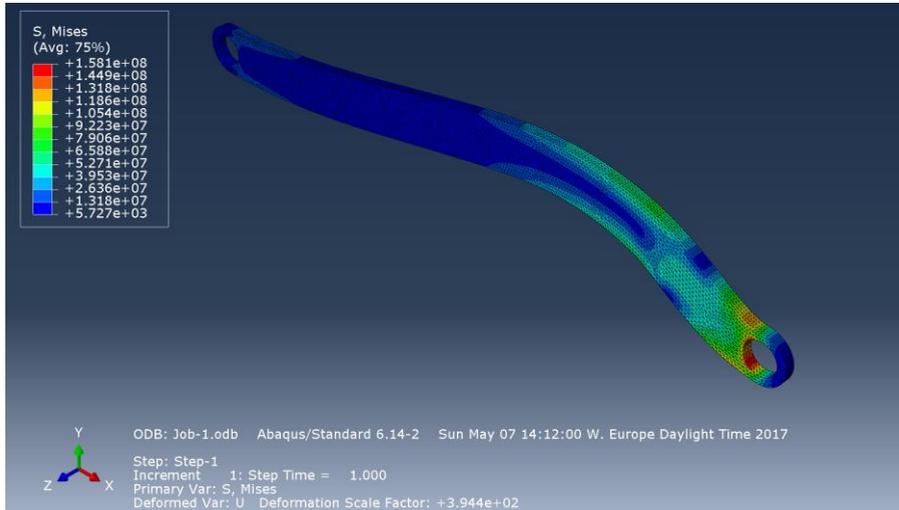


Figure 5-20. Maximum stress of the support beam No.1.

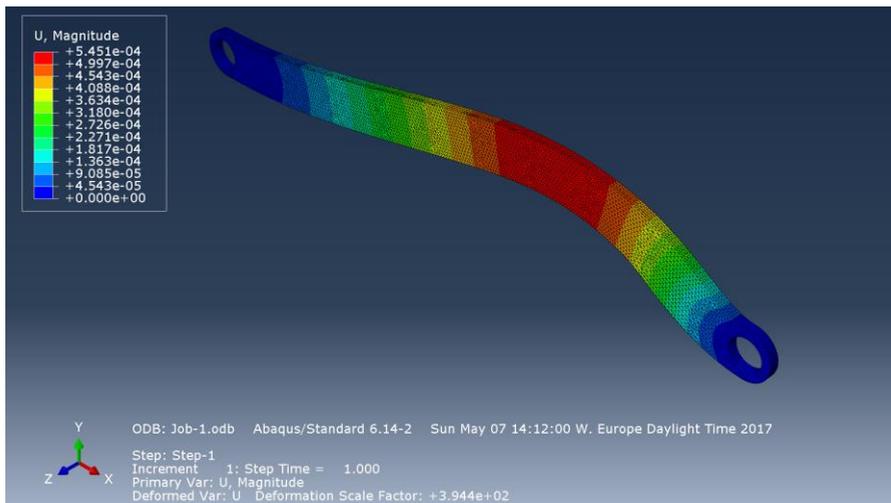


Figure 5-21. Maximum deflection of the support beam No.1.

According to the result get from Abaqus, the maximum stress and deflection at its corresponding position value can be concluded in the following table.

Table 5-3. FEM-Maximum stress and deflection of beam No.1

Angle	Angle	Maximum Stress(MPa)	Maximum Deflection(mm)
$\alpha = 5^\circ$	$\theta = 6.98^\circ$	22.82	0.1981
$\alpha = 45^\circ$	$\theta = 54.46^\circ$	158.1	0.5451

#### 5.1.4 Hand Calculation verification

The cross-section shape and its dimension can be found in the following figure.

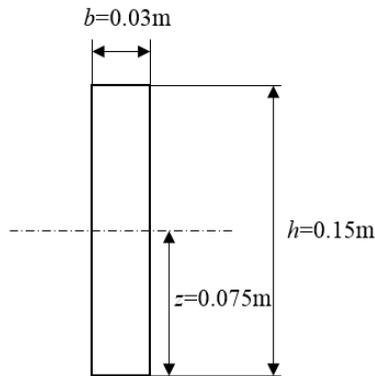


Figure 5-22. Scissors lift support beam cross section.

Where

- Thickness  $b$  30 mm
- Height  $h$  150 mm
- Distance neutral surface to extreme fiber  $z$  75 mm

According to the data, the moment of inertia  $I$  and section modulus  $Z$  can be calculated.

$$I = \frac{bh^3}{12}$$

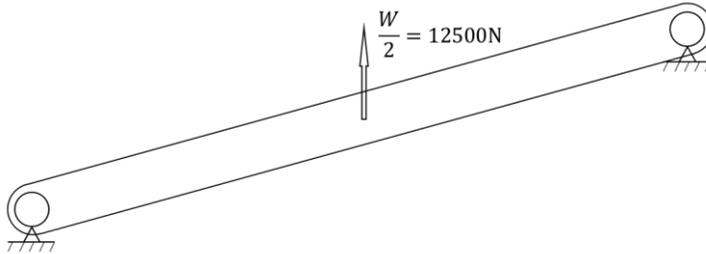
$$Z = \frac{I}{z}$$

The result can be seen in the table.

*Table 5-4. Result of moment of inertia and section modulus.*

$I$	$8.4375 \times 10^{-6}$
$Z$	$1.125 \times 10^{-4}$

As for the beam No.3 the simplified sketch can be found in the following figure.



*Figure 5-23. Support beam No.3 sketch.*

The stress at the central section

$$\sigma_{max} = \frac{FL}{8Z}$$

The maximum deflection at load

$$y_{max} = \frac{FL^3}{192EI}$$

*Table 5-5. Hand calculation maximum stress and deflection of beam No.3.*

Angle	Maximum stress(MPa)	Maximum deflection(mm)
$\alpha = 5^\circ$	27.67	0.3075
$\alpha = 45^\circ$	19.64	0.2182

As for the beam No.1 the simplified sketch can be found in the following figure.

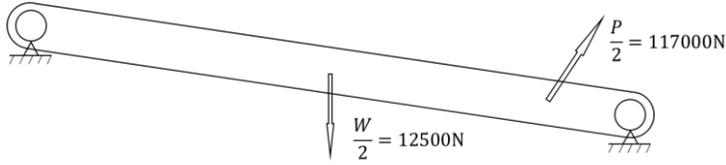


Figure 5-24. Support beam No.1 sketch.

The beam will be simplified as the both ends pinned beam with two different point load.

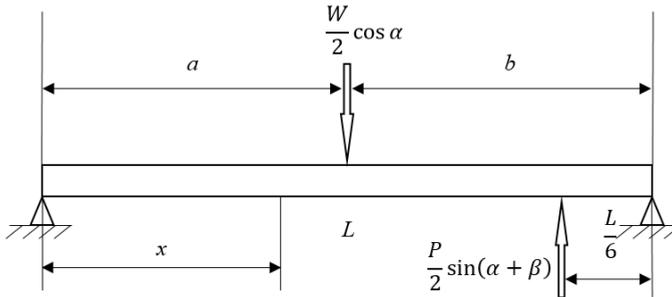


Figure 5-25. Simplified support beam No.1.

The general relation between moment and stress is

$$\sigma_{max} = \frac{M_{max} \cdot y}{I}$$

Where

$M_{max}$ -the maximum moment about the neutral axis;

$y$ - the perpendicular distance to the neutral axis;

$I$ - the second moment of area about the neutral axis.

$$\sigma_{max} = \frac{\frac{5}{6}LF_{RA} + \frac{1}{3}LF_{RB}}{Z}$$

Where

$Z$ -section modulus

Use the superposition theory to find the maximum deflection, the formula of deflection at load is

$$\delta = \frac{Fx^2b^2}{6EIL^3} [2a(L-x) + L(a-x)]$$

Where

$\delta$ -deflection

$E$ -elastic modulus

$I$ -moment of inertia

*Table 5-6. Hand calculation result of maximum stress and deflection.*

Angle $\alpha$	Angle $\theta$	Maximum Stress(MPa)	Maximum Deflection(mm)
$\alpha = 5^\circ$	$\theta = 6.98^\circ$	22.02	0.229
$\alpha = 45^\circ$	$\theta = 54.46^\circ$	153.53	0.604

### 5.1.5 Result comparison

*Table 5-7. Comparison with maximum stress and deflection of beam No.3.*

Angle	FEM maximum result		Hand calculation maximum result	
	Stress	Deflection	Stress	Deflection
$\alpha = 5^\circ$	26.3	0.3120	27.67	0.3075
$\alpha = 45^\circ$	18.67	0.2214	19.64	0.2182

*Table 5-8. Comparison with maximum stress and deflection of beam No.1.*

Angle $\alpha$	Angle $\theta$	FEM maximum result		Hand calculation maximum result	
		Stress	Deflection	Stress	Deflection
$\alpha = 5^\circ$	$\theta = 6.98^\circ$	22.82	0.1981	22.02	0.229
$\alpha = 45^\circ$	$\theta = 54.46^\circ$	158.1	0.5451	153.53	0.604

## 5.2 Welding

As mentioned in the above chapter, this part called connector plate for the support of the hydraulic rod. Since this part is welded on the lift support beam, the stress analysis of the welding need to be analysed.

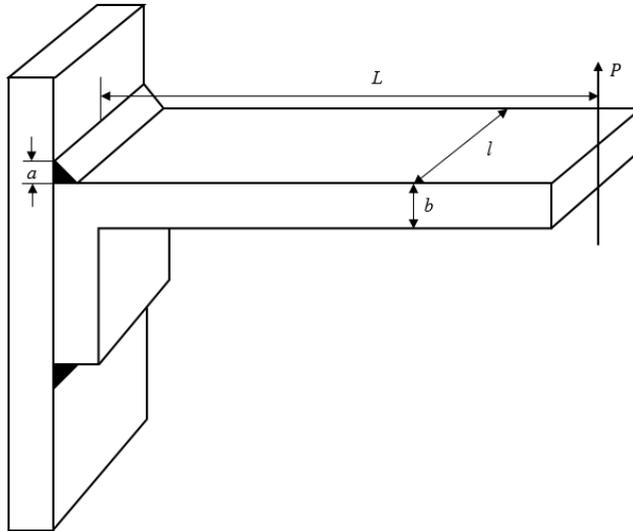


Figure 5-26. Simplified welding part sketch  $\alpha = 5^\circ$ .

From the above figure, the load is at the middle of the plate, but when we analysis, it's only need to analysis, because the other side is symmetry.

In this case, the load is depending on the angle of the beam, which means the height of the platform, in our project, we do two angles, when  $\alpha = 5^\circ$  and when  $\alpha = 45^\circ$ . The FEM result can be found in the following figures.

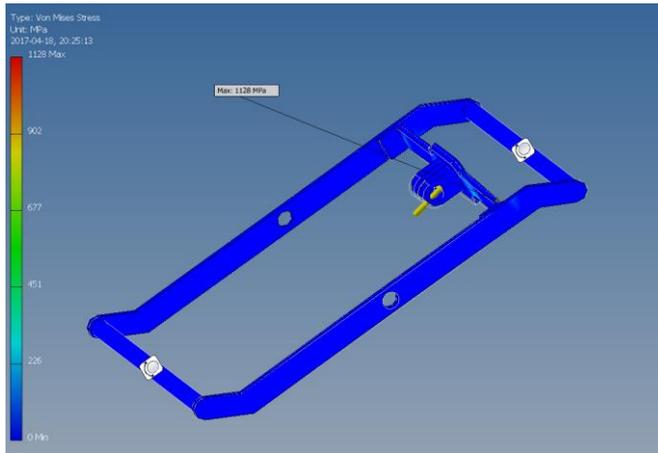


Figure 5-27. Maximum stress of the welding part  $\alpha = 5^\circ$ .

Zoom in the maximum stress point.

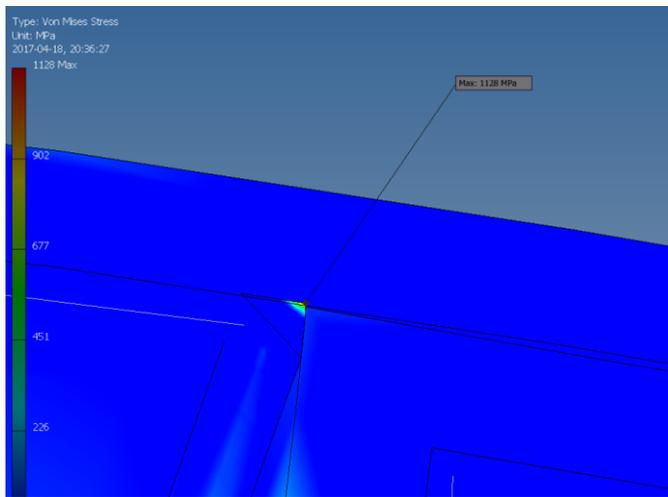


Figure 5-28. Maximum stress of the welding part  $\alpha = 5^\circ$ .

According to the formula, the maximum stress of the welding part is

$$\sigma_{max} = \frac{P}{al(a+b)} \sqrt{2L^2 + \frac{(a+b)^2}{2}}$$

Where

$P$ -External applied load, N

$l$ -Width of the plate, m

$b$ -Thickness of the plate, m

$a$ -Size of weld, m

$L$ -Distance beam to the load point

But when the platform at the highest position, the load is almost vertical to the beam direction, so the simplified model can be found in the following figure.

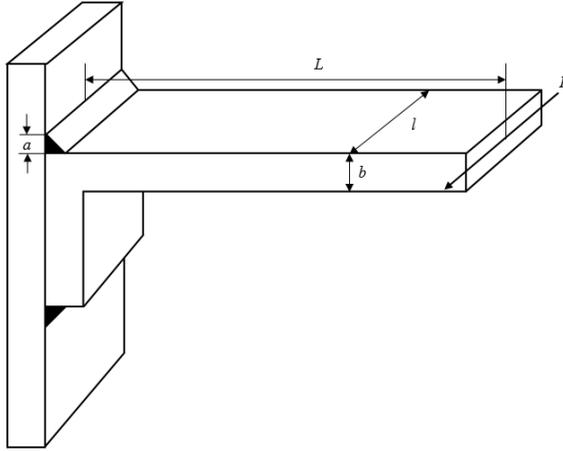


Figure 5-29. Simplified welding part sketch  $\alpha = 45^\circ$ .

The FEM result can be found in the following figures.

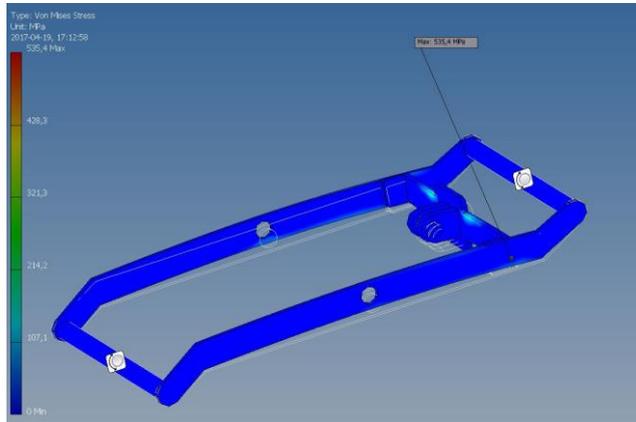


Figure 5-30. Maximum stress of the welding part  $\alpha = 45^\circ$

Zoom in the maximum stress point.

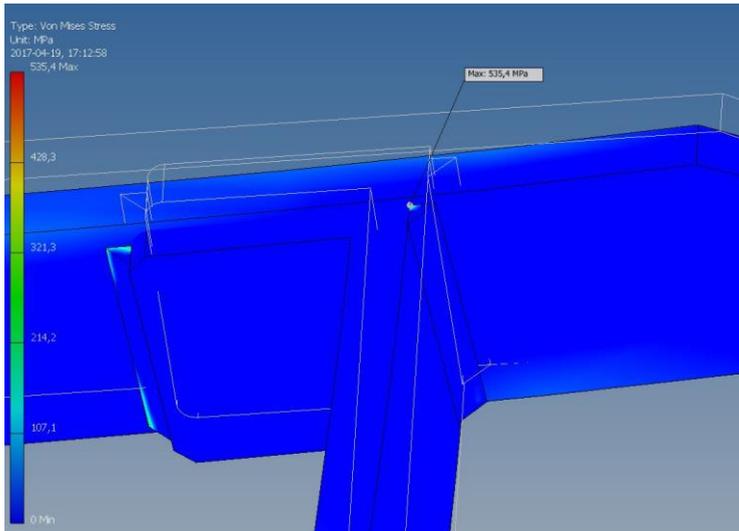


Figure 5-31. Maximum stress of the welding part  $\alpha = 45^\circ$

According to the formula, the maximum stress of the welding part is

$$\sigma_{max} = \frac{4.24PL}{al^2}$$

Where

$P$ -External applied load, N

$l$ -Width of the plate, m

$a$ -Size of weld, m

$L$ -Distance beam to the load point

The result of the maximum stress of the welding part at the corresponding angle can be found in the following table.

Table 5-9. Maximum stress of the welding part

Angle $\alpha$	Angle $\theta$	FEM (MPa)	Hand calculation (MPa)
$\alpha = 5^\circ$	$\theta = 6.98^\circ$	1128	1120.9
$\alpha = 45^\circ$	$\theta = 54.46^\circ$	535.4	528.3

## 5.3 Transporter Rotate Beam

In this section, the rotate beam of the transporter need to be analysed, the material of the beam is defined as Steel Carbon, one vehicle is held by eight beams, and choose the load from average vehicle weight, which means each rotate beam bear 1/8 weight of vehicle, the average weight of the vehicle has been set as 2ton, so each beam hold approximately 2500N force on the upper surface of the rotate beam.

### 5.3.1 FEM result

Since the material of the beam is Steel carbon, so the corresponding Material's physical property can be found in the following table.

*Table 5-10. Material's physical property*

<b>Mechanical</b>	
Young's Modulus	200.000 GPa
Poisson's Ratio	0.29
Shear Modulus	79700.00 MPa
Density	7.850 g/cm <sup>2</sup>
<b>Strength</b>	
Yield Strength	350.000 MPa
Tensile Strength	420.00 MPa

Based on the load direction in the real life, the top surface of the beam should to bear bending under 2500 N. We fixed one endpoint and then add 2500N, the result see figures.

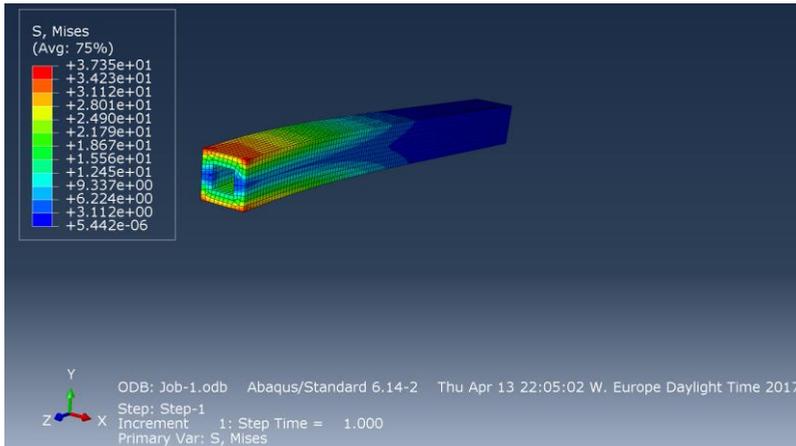


Figure 5-32. Maximum stress at critical section of the rotate beam.

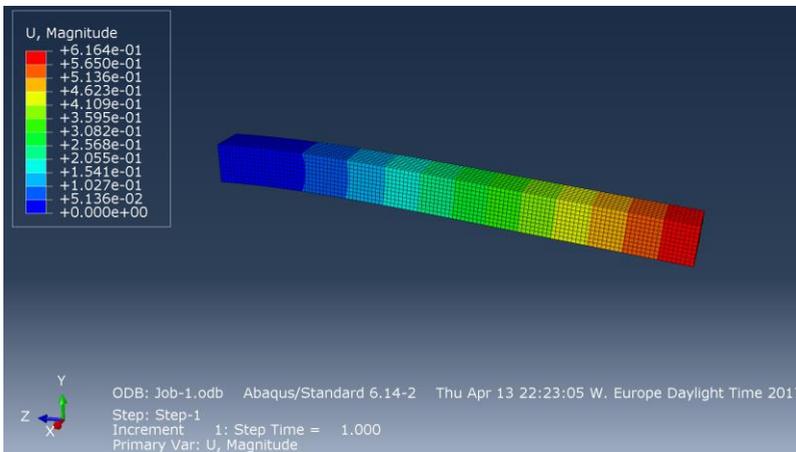


Figure 5-33. Maximum deflection at free end of the rotate beam.

From the picture, the maximum stress at critical section is 37.35MPa, the maximum deflection at free end is 0.6164mm.

### 5.3.2 Hand calculation verification

The simplified sketch can be found in the following figure.

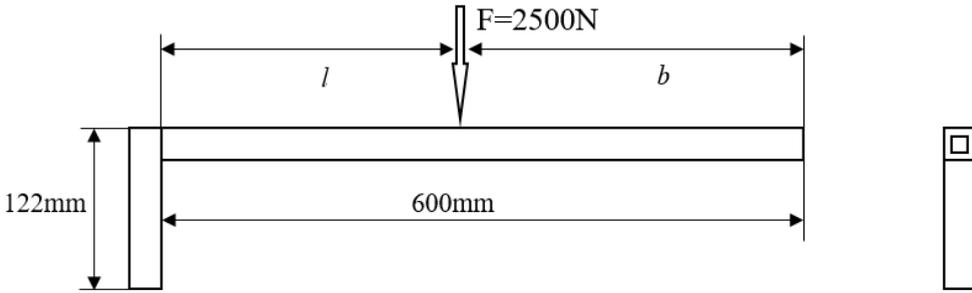


Figure 5-34. Rotate beam sketch.

Where

The sketch data and shape:

- Distance critical section to force point  $l$  300 mm
- Distance force point to the free end  $b$  300 mm

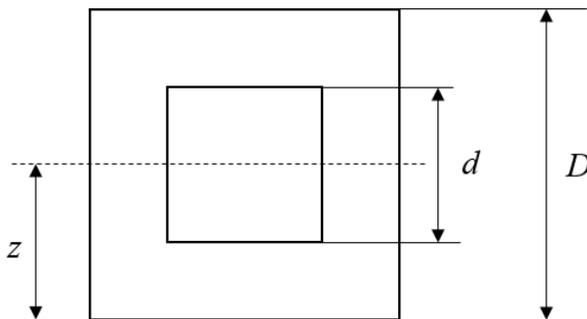


Figure 5-35. Rotate beam cross section sketch.

Where

- External surface width and height  $D$  50 mm
- Internal surface width and height  $d$  25 mm
- Distance neutral surface to extreme fiber  $z$  25 mm

According to the data, the moment of inertia  $I$  and section modulus  $Z$  can be calculated.

$$I = \frac{D^4 - d^4}{12}$$

$$Z = \frac{I}{z}$$

The result can be seen in the table.

*Table 5-11. Result of moment of inertia and section modulus.*

$I$	$4.883 \times 10^{-7}$
$Z$	$1.953 \times 10^{-5}$

Stress at critical location can be denoted.

$$\sigma_{max} = \frac{Wl}{Z}$$

Maximum deflection at end is

$$y_{max} = \frac{Wl^2}{6EI} (2l + 3b)$$

*Table 5-12. Result of maximum stress and deflection.*

$\sigma_{max}$	38.40MPa
$y_{max}$	0.623 mm

*Table 5-13. Comparison with Result of maximum stress and deflection.*

	Abaqus Result	Hand calculation
$\sigma_{max}$	37.35MPa	38.40MPa
$y_{max}$	0.6164 mm	0.623 mm

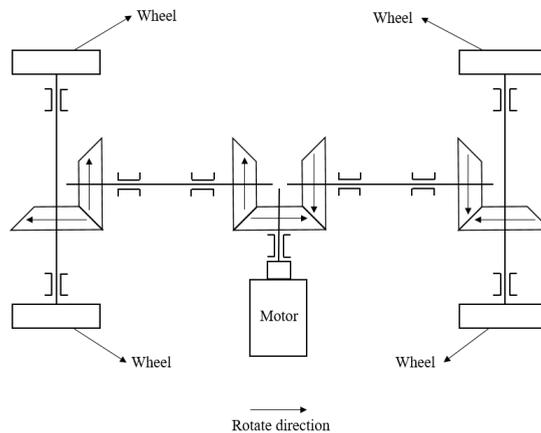
Compared with hand calculation, Abaqus result, the maximum stress value and maximum deflection of the one end cantilevered beam with partial distributed load can be verified.

# 6 Chapter: Vital Components Design Method

This chapter will introduce some important components design method. Specifically, the design principle and detailed calculation step of bevel gear transmission system and Scissor hydraulic lift system will be introduced.

## 6.1 Bevel gear transmission system

The bevel gears are used in the vehicle transporter, in order to realize the four-wheel drive transporter under one motor drive, the triple bevel gear transmission is used in this system. The following figure shows the transmission sketch, because the bevel gears are all the same type, so the only one pair of gear calculations will be done in this section.



*Figure 6-1. Bevel gear transmission system sketch.*

### 6.1.1 Determination of gear type accuracy, material, number of teeth

- (1) According to above figure's transmission Scheme, choose spur bevel gear
- (2) As general working machine, low speed, so choose 7 Accuracy (GB10095-88)

- (3) Material choice, according to table 10-1(P191), the material of Pinion is quenched and tempered steel No.45, hardness 250HB; the material of Wheel is normalizing steel No.45, hardness 210HB.
- (4) Number of teeth  
 Pinion:  $Z_1 = 30$ .  
 Wheel:  $Z_2 = 30$ .
- (5)  $20^\circ$  Pressure Angle.

### 6.1.1.1 Design by tooth contact strength

- (1) Calculation of the reference diameter  $d_{1t}$

$$d_{1t} \geq \sqrt[3]{\frac{4K_{Ht}T_1}{\Phi_R(1-0.5\Phi_R)^2u} \cdot \left(\frac{Z_H Z_E}{[\sigma_H]}\right)^2}$$

- 1) Determination of parameters in the formula

① Choose  $K_{Ht} = 1.3$ .

② Calculation of the gear torque

$$T_1 = 9.55 \times 10^6 \frac{P}{n_1} = 9.55 \times 10^6 \times 10 / 960 \text{ N} \cdot \text{mm} = 9.948 \times 10^4 \text{ N} \cdot \text{mm}$$

③ Choose tooth width coefficient  $\Phi_R = 0.3$ .

④ According to the table 10-20, find the zone material influence coefficient  $Z_H = 2.5$ .

⑤ According to the table 10-5, find the material elastic influence coefficient  $Z_E = 189.8 \text{ MPa}^{1/2}$ .

⑥ Calculate the contact fatigue allowable stress  $[\sigma_H]$ .

Contact fatigue strength limit of the pinion is  $\sigma_{Hlim1} = 600 \text{ MPa}$ .

Contact fatigue strength limit of the wheel is  $\sigma_{Hlim2} = 600 \text{ MPa}$ .

Calculate the stress cycles:

$$N = 60n_1jL_h = 60 \times 960 \times 1(2 \times 8 \times 300 \times 15) = 4.147 \times 10^9.$$

According to the fig 10-23 choose the Contact fatigue life factor:

$$K_{HN1} = K_{HN2} = 0.9$$

Choose the failure probability 1%, safety factor  $S=1$ , according to the formula 10-14

$$[\sigma_H]_1 = \frac{K_{HN1}\sigma_{Hlim1}}{S} = \frac{0.90 \times 600}{1} \text{ MPa} = 540 \text{ MPa}$$

$$[\sigma_H]_2 = \frac{K_{HN2}\sigma_{Hlim2}}{S} = \frac{0.90 \times 600}{1} \text{ MPa} = 540 \text{ MPa}$$

The contact fatigue allowance stress is

$$[\sigma_H] = 540 \text{ MPa}$$

2) Calculate the pinion reference diameter

$$d_{1t} \geq \sqrt[3]{\frac{4K_{Ht}T_1}{\Phi_R(1-0.5\Phi_R)^2u} \cdot \left(\frac{Z_H Z_E}{[\sigma_H]}\right)^2}$$

$$= \sqrt[3]{\frac{4 \times 1.3 \times 9.948 \times 10^4}{0.3 \times (1 - 0.5 \times 0.3)^2 \times 1} \times \left(\frac{2.5 \times 189.8}{540}\right)^2} \text{ mm} = 122.599 \text{ mm}$$

(2) Adjust the diameter of reference

1) Preparation of the data

① Calculate the Circumferential speed  $v_0$

$$d_{m1} = d_{1t}(1 - 0.5\Phi_R) = 122.599 \times (1 - 0.5 \times 0.3) \text{ mm} = 104.209 \text{ mm}$$

$$v_m = \frac{\pi d_{m1} n_1}{60 \times 1000} = \frac{3.14 \times 104.209 \times 960}{60 \times 1000} = 5.235 \text{ m/s}$$

② The tooth width coefficient of virtual gear  $\Phi_d$

$$b = \Phi_R d_{1t} \sqrt{u^2 + 1} / 2 = 0.3 \times 122.599 \times \sqrt{2} / 2 = 26.007 \text{ mm}$$

$$\Phi_d = b / d_{m1} = 26.007 / 104.209 = 0.249$$

2) Calculate the load coefficient  $K_H$

① Find the using coefficient  $K_A = 1$  in table 10-2.

② Choose the dynamic load factor as  $K_V = 1.15$  based on  $v_m = 5.235 \text{ m/s}$ , 7 accuracy.

③ The spur bevel gear has low accuracy, choose  $K_{H\alpha} = 1$ .

④ Get  $K_{H\beta} = 1.345$  based on asymmetrically support and 7 accuracy from table 10-4.

Then, the load coefficient can be calculated

$$K_H = K_A K_V K_{H\alpha} K_{H\beta} = 1 \times 1.15 \times 1 \times 1.345 = 1.547$$

- 3) The reference diameter can be calculated according to the load coefficient

$$d_1 = d_{1t} \sqrt[3]{\frac{K_H}{K_{Ht}}} = 122.599 \times \sqrt[3]{\frac{1.547}{1.3}} = 129.917 \text{ mm}$$

And the corresponding modulus

$$m = d_1 / z_1 = \frac{129.917}{30} = 4.331$$

Choose  $m = 4.5$  according to the standard value.

### 6.1.1.2 Checked by root bending strength

$$\sigma_F = \frac{K_F T_1 Y_{Fa} Y_{Sa}}{\Phi_R (1 - 0.5 \Phi_R)^2 m^3 z_1^2 \sqrt{u^2 + 1}} \leq [\sigma_F]$$

Determination of the parameters

- 1) Choose loading coefficient  $K_F = 1.3$ .
- 2)  $T_1 = 9.948 \times 10^4 \text{ N} \cdot \text{mm}$ .
- 3) Tooth form factor  $Y_{Fa} = 2.55$  can be obtained from figure 10-17.
- 4) Stress correction coefficient  $Y_{Sa} = 1.625$  can be obtained from figure 10-18.

Then, calculate the tooth root bending fatigue strength

$$\begin{aligned} \sigma_F &= \frac{K_F T_1 Y_{Fa} Y_{Sa}}{\Phi_R (1 - 0.5 \Phi_R)^2 m^3 z_1^2 \sqrt{u^2 + 1}} \\ &= \frac{1.3 \times 9.948 \times 10^4 \times 2.55 \times 1.625}{0.3 \times (1 - 0.15)^2 \times 4.5^2 \times 30^2 \times \sqrt{2}} = 95.925 \text{ MPa} \end{aligned}$$

Contact fatigue strength limit of the pinion is  $\sigma_{Hlim1} = 600 \text{ MPa}$ .

Contact fatigue strength limit of the wheel is  $\sigma_{Hlim1} = 600 \text{ MPa}$ .

Choose bending fatigue coefficient from figure 10-22

$$K_{FN1} = K_{FN2} = 0.88$$

Choose bending fatigue life coefficient  $S = 1.7$ .

$$[\sigma_F] = \frac{K_{FN1} \cdot \sigma_{Hlim1}}{S_F} = \frac{0.88 \times 600}{1.7} = 310.588 \text{Mpa}$$

$$\sigma_F < [\sigma_F]$$

### 6.1.1.3 Bevel gear geometry

Table 6-1. Geometry of the bevel gear

	Component	Value (mm)
$n$	Number of Teeth	30
$P.D.$	Reference Diameter	130
$d$	Bore	22
$S$	Face Width	18.6
$L$	Length	44.65
$D_1$	Hub diameter	66
$l_1$	Hub	23.64
$A$	Mounting Distance	75
$l_2$	Backing Pitch line	40

## 6.2 Scissor hydraulic lift system

In order to meet more cars weight and size requirement, the largest model of household vehicle and its corresponding size need to be selected as reference parameters. For example, the Sport Utility Vehicle, model Volvo XC90 is selected as the reference size.

The relevant parameters of Volvo XC90 T8 Twin Engine AWD (407hp) Auto 7 seat can be found in the following table. [9]

*Table 6-2. Description of the table placed above the table*

<b>Parameter</b>	<b>Value</b>
Weight	2319 kg
Width	2008 mm
Length	4950 mm
Overall Height	1776 mm
Wheel Base	2984 mm

In order to meet the height requirement of the parking garage. We choose to use double lift work at the same time, meanwhile, the lift share the same platform. This arrangement requires one hydraulic cylinder. To enhance its safety and reliability, it can be assumed that the total carrying capacity is  $W=2.5 \times 1000 \times 9.8=24500\text{N}$ . The load that hydraulic cylinder need to bear is 24500 N.[10]

### 6.2.1 Determine the main parameters of the hydraulic system.

Pressure and flow are the main parameters of the hydraulic system, they are the major basis of hydraulic system design. The pressure determined by external load, the flow decided by hydraulic actuators' velocity and structure size.

### 6.2.1.1 The calculation of the load

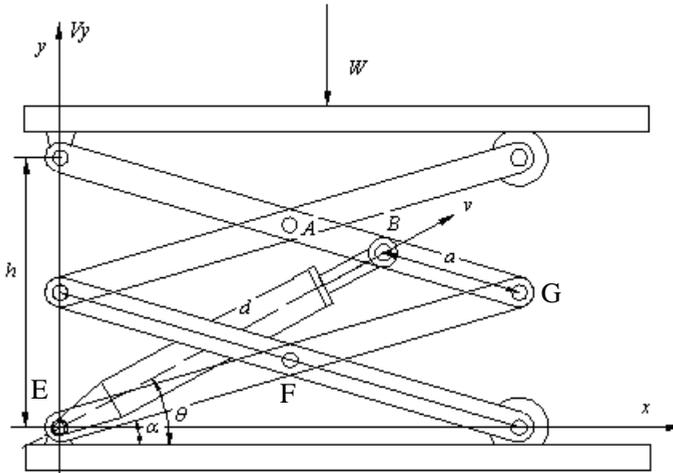


Figure 6-2. Dimension of the hydraulic lift.

Firstly, find the position when the hydraulic cylinder under the maximum load, when the angle between hydraulic cylinder and ground has the minimum value, the angle between support beam and ground has the minimum value as well, the hydraulic cylinder is under the maximum operating load. According to the wheel base 3m, define the length of support beam as 2.46 m. When hydraulic cylinder at the minimum height  $\alpha_0 = 5^\circ$ , according to the formula

$$\theta = \tan^{-1} \left[ \frac{l+a}{l-a} \tan \alpha \right]$$

Obtain  $\theta_0 = 11.71^\circ$ , where

$l$ -The distance between hinged joint A to hinged joint G.

$a$ - The distance between hinged joint G to hinged joint B.

Now,  $a$  is still an unknown, consider that the cylinder and support's hinged joint A cannot be too close to the hinged joint B, otherwise the significant stress concentration will occur in these two hinged joints, decrease the fatigue strength.

So, it will be property to choose  $= \frac{l}{3}$ , put the  $a = \frac{l}{3}$  to the equation between piston rod force and the load on the platform.

$$P = \frac{6 \cos \alpha}{\sin(\theta + \alpha) + 3 \sin(\theta - \alpha)} W$$

$$\tan \theta = \frac{l + a}{l - a} \tan \alpha = 2 \tan \alpha$$

Obtain  $P = 9.36 * W$ , when the platform at the lowest position  $\alpha_0 = 5^\circ$ , the hydraulic cylinder has the maximum operating load  $P$ , where  $P = 9.36 \times 24500N = 229320N$ , then choose the property hydraulic cylinder by the load.

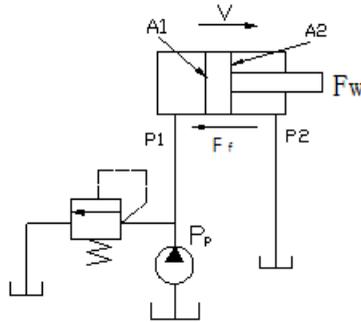


Figure 6-3. Hydraulic cylinder.

Figure 6-2 showed a hydraulic system calculation diagram, where  $F_w$  is the load acting on the piston rod,  $F_f$  is the sealing resistance between the piston and the cylinder wall and between the piston rod and the guide sleeve.

- (1) Operating load  $F_w$

$$F_w = P = 229320N$$

- (2) Friction load  $F_f$

$$F_f = f(G + W) = 0.1 \times (4500 + 24500) = 2900N$$

- (3) Inertial load  $F_a$

$$F_a = ma, \quad a = \frac{\Delta v}{\Delta t}$$

Where  $\Delta v$ —Velocity variation  $m/s$ .

$\Delta t$ —Starting or braking time, general mechanical = 0.01 ~ 0.5s, for mild load and low speed moving parts take a small value; for heavy load and high-speed components take a large value, walking machinery generally take = 0.5 ~ 1.5s.

$a$ —acceleration  $m/s^2$ .

Choose the velocity variation  $\Delta v = 0.2 \text{ m/s}$ ,  $\Delta t = 0.7 \text{ s}$

$$\text{Then } a = \frac{\Delta v}{\Delta t} = \frac{0.2}{0.7} = 0.285 \text{ m/s}^2.$$

$$F_a = ma = 1000 \times 0.285 = 285 \text{ N}$$

Add all the loads

$$F = F_w + F_f + F_a = 229320 + 2900 + 285 = 232505 \text{ N}$$

### 6.2.1.2 Hydraulic cylinder dimension

(1) Relative Parameters and structural dimension

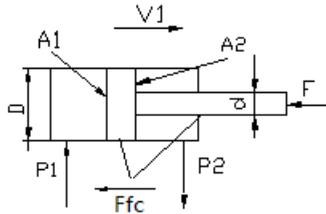


Figure 6-4. Hydraulic cylinder.

From the figure

$$\frac{\pi}{4} D^2 p_1 = F + \frac{\pi}{4} (D^2 - d^2) p_2 + F_{fc}$$

$$D^2 = \frac{4(F + F_{fc})}{\pi p_1} + (D^2 - d^2) \frac{p_2}{p_1}$$

Where

$A_1 = \frac{\pi}{4} D^2$ --Effective working area of rod less piston;

$A_2 = \frac{\pi}{4} (D^2 - d^2)$ --Effective working area of rod piston;

$P_1$ --Working pressure of the hydraulic cylinder;

$P_2$ -- Back pressure of the hydraulic cylinder;

$D$ --Diameter of the piston;

$d$ --Diameter of the rod;

$F$ --The maximum load at the working cycle;

$F_{fc}$ --Friction of hydraulic cylinder seal, it's very hard to get the accuracy value, usually use the mechanical efficiency of hydraulic cylinder  $\eta_{cm}$  estimate.

$$F + F_{fc} = \frac{F}{\eta_{cm}}$$

Where  $\eta_{cm}$ --Mechanical efficiency of hydraulic cylinder, usually  $\eta_{cm} = 0.9\sim 0.97$ .

So, the maximum external working load of the hydraulic cylinder

$$F = \frac{F_w}{\eta_{cm}} = \frac{229320}{0.95} N = 241389.5N$$

Table 6-3. Back pressure value of operating component

System Type		Back pressure $p_2$ (MPa)
Low-medium pressure system (0~8MPa)	Simple system	0.2~0.5
	The return loop with the compensated flow control valve	0.5~0.8
	The return loop with back pressure valve	0.5~1.5
	Hydraulic pump with the closed loop	0.8~1.5
Medium-high pressure system > 8~16 MPa	Same as above	50%~100% higher than low-medium pressure system
High pressure system > 16~32 MPa	Metal forming machinery	Can be cancelled

Choose back pressure  $p_2 = \text{MPa}$ .

Determine the relation between  $A_1$  and  $A_2$ , or the relation between piston diameter  $D$  and rod diameter  $d$ , let  $\psi = \frac{D}{d}$ , the value can be determined by the following table.

Table 6-4. Relation between piston diameter  $D$  and rod diameter  $d$

Working Pressure MPa	< 5.0	5.0~7.0	$\geq 7.0$
$\psi = d/D$	0.5~0.53	0.62~0.70	0.70

Choose  $\psi = \frac{D}{d} = 0.7$ .

Denote that

$$D^2 = \frac{4(F + F_{fc})}{\pi p_1} + (D^2 - d^2) \frac{p_2}{p_1}$$

$$D = \sqrt{\frac{4F}{\pi p_1 \eta_{cm} \left\{ 1 - \frac{p_2}{p_1} \left[ 1 - \left( \frac{d}{D} \right)^2 \right] \right\}}}$$

$$= \sqrt{\frac{4 \times}{3.14 \times 15 \times 10^6 \times 0.95 \times \left\{ 1 - \frac{3}{15} [1 - 0.7^2] \right\}}} = 155.01 \text{ mm}$$

Accordingly,  $d = 0.7D = 0.7 \times 155.1 \text{ mm} = 108.57 \text{ mm}$ .

The calculated value of the piston diameter  $D$  and the rod diameter  $d$  shall be modified according to the GB/T 2348-1993, choose piston diameter  $D = 160 \text{ mm}$ , rod diameter  $d = 110 \text{ mm}$ .

### 6.2.1.3 Determine the cylinder parameters

#### (1) Calculation of thickness and external diameter of Cylinder

If the ratio of the internal cylinder diameter  $D$  to its thickness  $\delta$  is greater than 10, it will be called a thin walled cylinder. Calculate the thickness by cylinder formula.

$$\delta \geq \frac{p_y D}{2[\sigma]}$$

Where

$\delta$ --Thickness of the cylinder;

$D$ —Internal diameter of the cylinder;

$p_y$ —Experimental pressure;

$[\sigma]$ —Cylinder material's allowed stress. The value: Forged steel:  $[\sigma] = 110\sim 120$  MPa; Cast Steel  $[\sigma] = 100\sim 110$  MPa; Seamless steel pipe  $[\sigma] = 100\sim 110$  MPa; High strength cast iron  $[\sigma] = 60$  MPa; Grey Cast iron  $[\sigma] = 25$  MPa.

According to the formula, obtain  $\delta \geq 16.8$  mm, choose  $\delta = 20$  mm.

Now, the external diameter of the cylinder  $D_1$  can be calculated,  $D_1 \geq D + 2\delta$ , choose  $D_1 = 200$  mm.

### (2) Determination of working stroke of cylinder

When the platform at the lowest position, the length of the cylinder has the minimum value  $d_{min}$ ,  $d_{min} = \sqrt{a^2 + L^2 - 2aL \cos 2\alpha} = 2058$  mm.

The height of the platform  $h = 2L \sin \alpha = 2 \times 2.36 \times \sin 5^\circ$  mm = 429 mm.

Then calculate the highest position of the platform, assume when the platform at the highest position,  $\alpha = 45^\circ$ , so the highest position can be calculated  $h_{max} = 3479$  mm. Meanwhile, the rod extends to  $d_{max} = \sqrt{a^2 + L^2 - 2aL \cos 2\alpha} = 2494$  mm.

Calculate the stroke:  $s = d_{max} - d_{min} = 2494 - 2058 = 436$  mm, choose the standard value 500 mm.

### (3) Determination of the minimum guide length

When the piston rod is fully extended, the distance  $H$  from the midpoint of the piston support surface to the midpoint of the cylinder head sliding bearing surface becomes the minimum guide length, as shown in the following figure. For the general hydraulic cylinder, the minimum guide length  $H$  should meet the requirements:

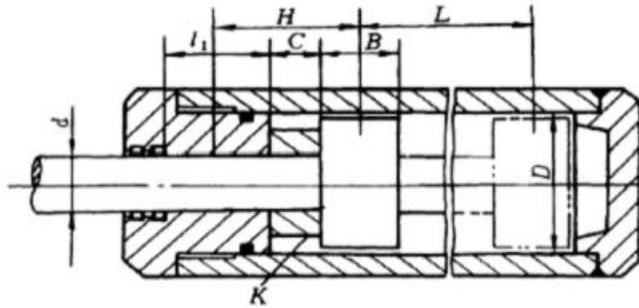


Figure 6-5. Guide length of hydraulic cylinder.

$$H \geq \frac{L}{20} + \frac{D}{2}$$

Where

L—The maximum working stroke of hydraulic cylinder;

D—Internal diameter of hydraulic cylinder.

Usually choose the width of the piston  $B$  as  $(0.6 \sim 1.0)D$ ; The length of the sliding surface of the cylinder head  $l_1$  is decided by Internal diameter of hydraulic cylinder;

When  $D < 80\text{mm}$ , choose  $l_1 = (0.6 \sim 1.0)D$ ;

When  $D > 80\text{mm}$ , choose  $l_1 = (0.6 \sim 1.0)d$ ;

Take the  $L=500\text{mm}$ ,  $D=110\text{mm}$  to the above equation, obtain  $H \geq 105\text{mm}$ ,  
 $B = 0.6 \times 110\text{mm} = 66\text{mm}$ .

(4) Material of the pump

Usually choose Steel No.45, hardening and tempering, hardness:  
 $241 \sim 285\text{HBW}$ .

# 7 Chapter: PLC programming

## 7.1 Abstract

### 7.1.1 Description

In our project, we use PLC programming to realize the automatic with parking lot, so we introduce the PLC machine.[11]

PLC is an electronic device designed specifically for digital operations designed for use in industrial environments. which uses a memory that can be programmed to store instructions that perform operations such as logical operations, sequential operations, timing, counting, and arithmetic operations, and can control various types of data through digital or input and output date.

### 7.1.2 Fundamental structure

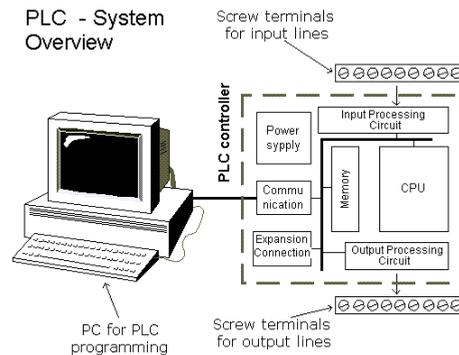


Figure 7-1. PLC overview.

PLC is a machine which has five parts including CPU, Memory, I/O interface unit, Extended interface and communication interface, and power.

CPU: Central processor single. The element is typically composed of a controller, an operator, and a register. CPU through the address bus, data bus, storage unit, input and output interfaces, communication interface, expansion interface. CPU is the core of PLC, it constantly collects the input signal, implements user programs, refreshes the system output.

Memory: PLC memory, including system memory and user memory. The system memory is used to store the system program of the PLC. The user memory is used to store the user program of the PLC. Now, PLC typically uses electrical erasable E2PROM memory, which as system memory and user memory.

I/O interface unit: PLC input interface through the button, the overtravel-limit switch or transducer, which submit the signal to the CPU; PLC output interface can convert the output signal into the external actuator to drive the signal to control the contactor coil and other electrical machine, which can control the power. PLC input and output interface generally use Photoelectric coupling isolation technology, which effectively protects the internal circuit.

Communication interface: expansion interface makes expansion unit and functional modules connected with the basic unit, to the configuration more flexible to meet the needs of varieties of control systems; communication interface's function through these communication interfaces and monitors, printers, and others to achieve the "man - machine" or "machine - machine" communication.

Power: PLC generally use 220V AC power or 24V DC power, the internal power supply 5V, 12V, 24V DC power for the PLC's central processing unit, memory and other circuits to which drive the PLC properly.[12]

## **7.2 Hardware design of PLC control system**

### **7.2.1 Control requirements of parking lots**

Our parking lot needs realize the automatic function, so we need a programming to control the park and help people. As we all know, the classical parking lots need people to park their cars by themselves. So, if we want to change it, we need a totally automatic machine, we choose PLC to complete the project. Our removable machine is a platform, which can load the cars and move the car to the fixed location and lift the car. So we have several electric engines to drive the platform, so the PLC programming can run the electric engines to achieve the automatic, people just press the button, it will take their cars to the parking lot.

## 7.2.2 Analysis of PLC on parking lots

Our parking lot has several actions, including lift up and down, go ahead, and clamp. so programming will control engines to get these actions through the hydraulic system or other components.

The hydraulic system through the engines to realize lift, which take the cars to the second floor with platform. And through the over-limit switches to control the platform to stop and run.

When you press the button, the clamp machine will fix the wheels of your cars, and press the second button, the platform will arrive the parking space and lift up then go ahead. The clamp machine will release the wheels, finally the car will be parked automatically, which is convenient for people to park the car, just press the buttons and PLC programming will complete the all actions.[12]

## 7.2.3 Selection of PLC

We choose FX2N plc machine. Because the FX2N is the most powerful and highest speed in the FX series, FX2N is made by Mitsubishi in the Japan.

*Table 7-1. FX series introduction.*

Type of the FX series			Number		
Relay output	Thyristor output	Transistor output	Inp ut	Outp ut	Block module
FX2N-16MR	FX2N -16MS	FX2N -16MT	8	8	24~32
FX2N -32MR	FX2N -32MS	FX2N -32MT	16	16	24~32
FX2N -48MR	FX2N -48MS	FX2N -48MT	24	24	48~64
FX2N -64MR	FX2N -64MS	FX2N -64MT	32	32	48~64
FX2N -80MR	FX2N -80MS	FX2N -80MT	40	40	48~64
FX2N -128MR		FX2N-128MT	64	64	48~64

At the end, we choose the FX-64MR, so there are 8 input points and output pints. The size is 130 x 90 x 87.



*Figure 7-2. FX-64MR.*

So, we choose the FX-64MR to realize the automatic about our project parking lot.

## 7.2.4 Introduction of FX2N-64MR

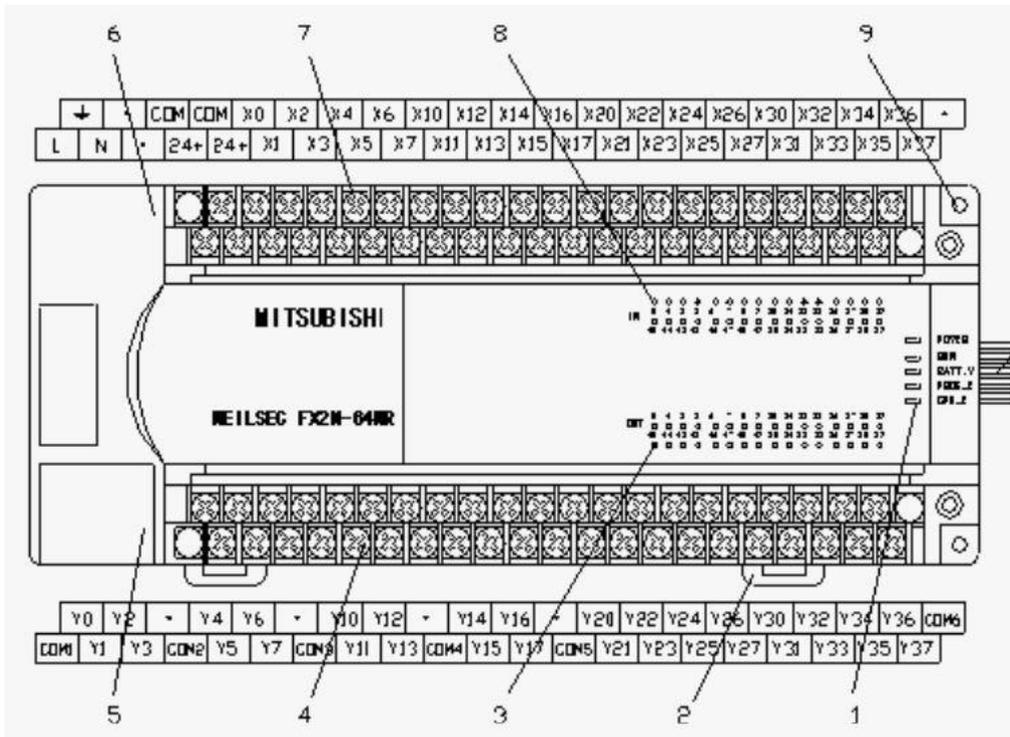


Figure 7-3. Structure of FX-64MR.

From the picture, we can see there are many ports, so I will introduce these ports.

- a) 1- action indicator
- b) 2-guide rail
- c) 3-output action indicator
- d) 4-output port
- e) 5-peripheral equipment power strip
- f) 6-panel cover
- g) 7-power and accessory power
- h) 8-Input indicator
- i) 9-mounting hole

## 7.3 Logic diagram of parking lot

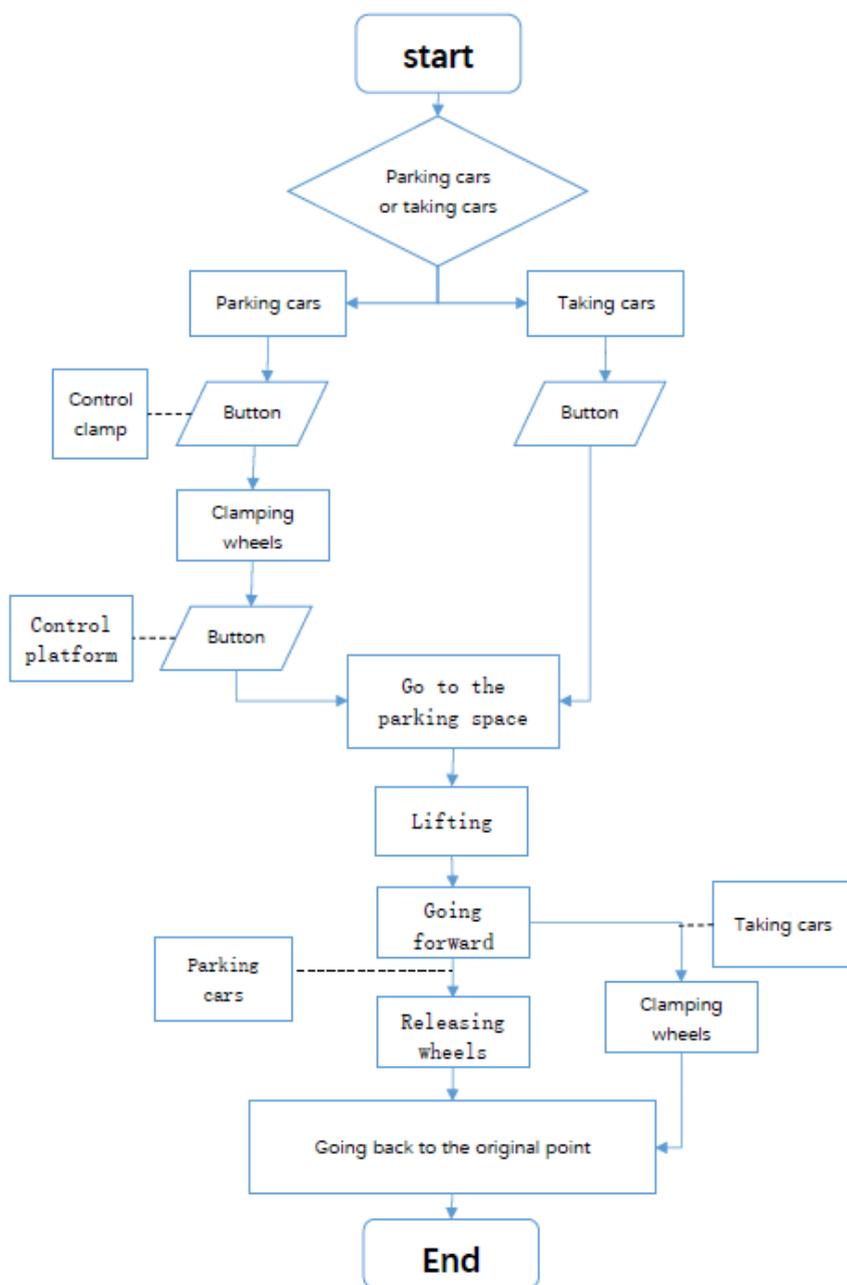


Figure 7-4. Logic diagram.

## 7.4 Parking Flow chart(the first PLC)

Our parking lots has 8 parking space on each side. So, we make a programming to realize the 8-parking space automatic parking. We use several motors to control the machine, which can lift, move and lift.

Then we introduce the flow chart. Through the software, which called Gppw



Figure 7-5. Gppw software.

We make a programming in the software, which is utilize to make FX series programming.

Because there are two logic diagrams in the project, one is people park their cars, and another one is people take out their cars.

So, at first, we introduce the first one: parking the cars. We through the button and limit switch to help programming more flexible to move the cars automatically.

### 7.4.1 Fixing cars flow chart

Our parking cars can be divided by two groups per the actions, which include fixing the wheel and move the cars.



Figure 7-6. Fix the wheels.

From this picture, we can see the X004, which is stand for the button, just press it, the fixing machine will fix the wheels, which protect your car safe in the procedure of moving.

M4 is stand for the motor, which control the fixing machine. When the X004 run, the M4 will follow the X004, then the fixing machine will run.

Then, M99 is utilized to lock the M4, which realize the self-lock in the programming, which is important to do it, because the X004(button) is just input one high-level electric potential when you press the button, thus we need M99 to achieve the self-lock function.

In the medium of the programming, the X100 is stand for the limit switch, which controls the distance about the fix machine's bar. It just be touched, which will input a high-level electric potential, but the electrical potential is to stop the M4(motor).

So, the programming is to realize the first step for the parking automatic, which is to fix the cars 'wheels.

#### 7.4.2 Moving cars flow chart

After fixing the wheels of the cars, we need to move the cars to the parking space. Through the platform, cars can be lifted up and down and go ahead. We utilize the motor to control the hydraulic system to lift. And in the programming, we also use the over-limit switch to control the distance of the machines, which make sure the location of the cars can be more precisely, so the programming as the pictures show:

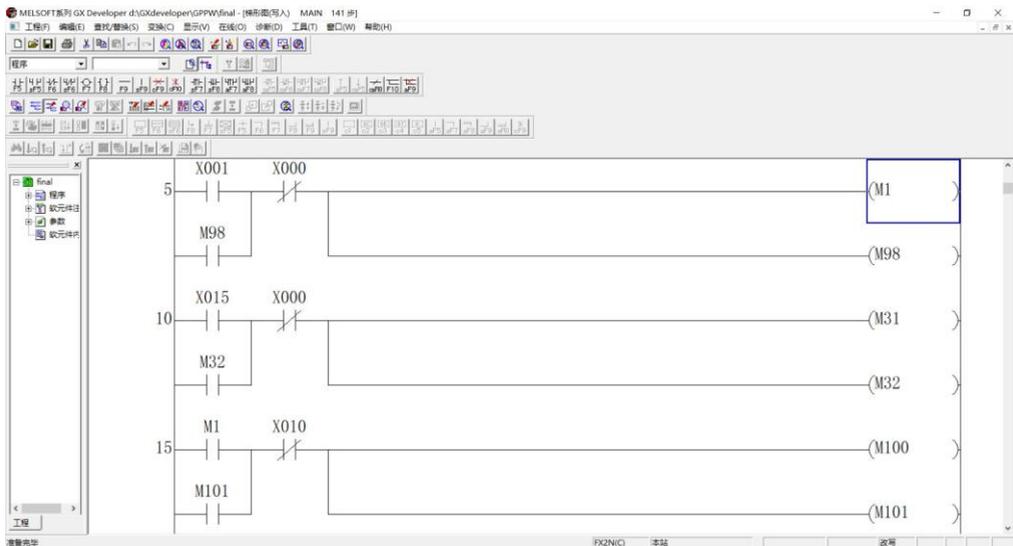


Figure 7-7. Moving the cars.

In the moving flow chart, there are two floor in our parking lot, each floor has 4 parking spaces, so we need control it by different codes.

At first, we introduce the X001, X015, they belong to the first row, X001 and X015 is stand for another button. It controls the movement about the cars. So, there are two kinds of buttons in the parking lot. The X001 and X015 control the motors, which drive the action of going forward and decide which parking spaces, for example, the X001 button control the NO 1 parking space.so, you just press the X001 button, your car will be parked to the location, the other parking spaces is like the NO 1 parking space. X015 is stand for the first parking space on the second floor.

M98 and M32 is also to realize the self-lock function, the reason is the same as the fixing cars flow chart.

In the programming, the X000 is stand for the over-limit switch, which also control the distance of going forward, when the movement machine touches the limit switch, the movement machine will stop. The motor will not run, then the machine will start the next step.

Because, there are 8 parking spaces on each side. So, the programming has 8 input points(button) to control. The other parking spaces as the pictures show:

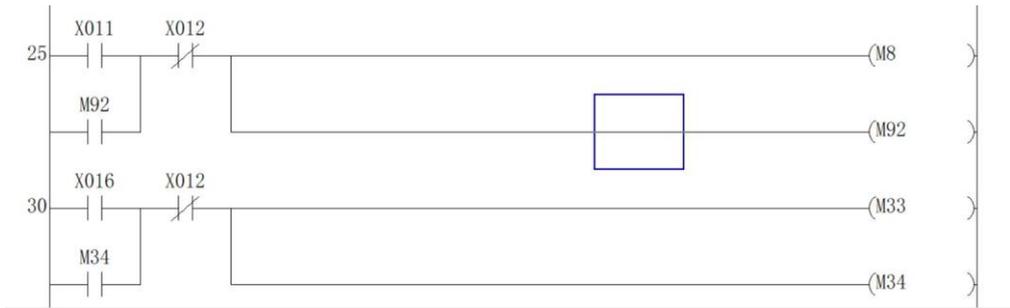


Figure 7-8. Other parking spaces.

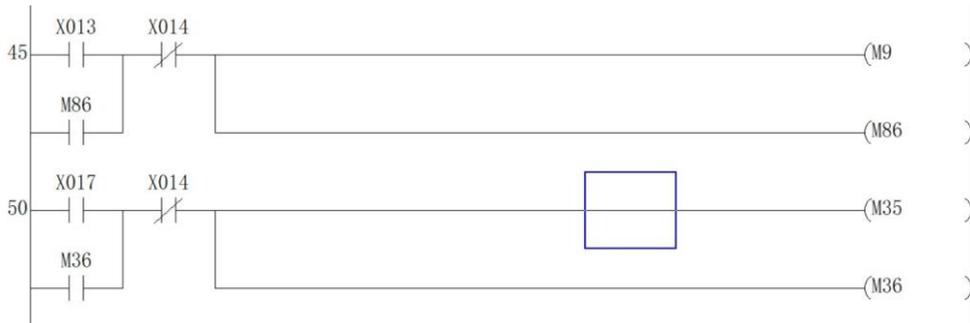


Figure 7-9. Other parking spaces.



Figure 7-10 Other parking spaces

### 7.4.3 Lifting the cars flow chart

After the movement. We need to lift the cars up. So, we use the hydraulic system to realize it. And we also utilize the PLC to control the motor, which drive the hydraulic system.

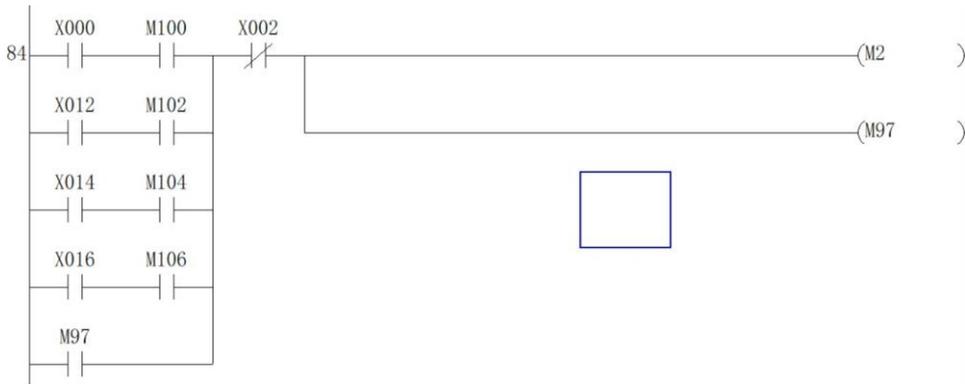


Figure 7-11. The first-floor lifting.



Figure 7-12. The second-floor lifting.

Because, there are two floors in our project. So, there are two flow charts to control, and we still use over-limit switches to control the platform's height.

Form the pictures, X002 and X021 are our project limit switches of the height.

X000, X012, X014, X016 are the limit switches, which to control the action of going forward and decide which parking space is belong to you, we will introduce the correlation chart at the end of flow chat.

We use the limit switches to control. So, when the platform go through the first space. The limit switches will run, if you want to park your car to the second space. Perhaps it is impossible. So, we add another programming to control it.



Figure 7-13 The first vertical row.

From this picture, M1 and M31 are the first vertical row. M1 is on the first floor, M31 is on the second floor.

So, when M1 run, the M100 will run too. And M100 will be self-local, from the picture the first-floor lifting, we need start M2, we need X000 and M100 to run meanwhile, so we through this programming to realize which spaces you can park your cars.

We also make the other programming to control other parking spaces.



Figure 7-14 The second vertical row.



Figure 7-15 The third vertical row.



Figure 7-16 The forth vertical row.

#### 7.4.4 The other programming

We also have other actions to run all parking system.

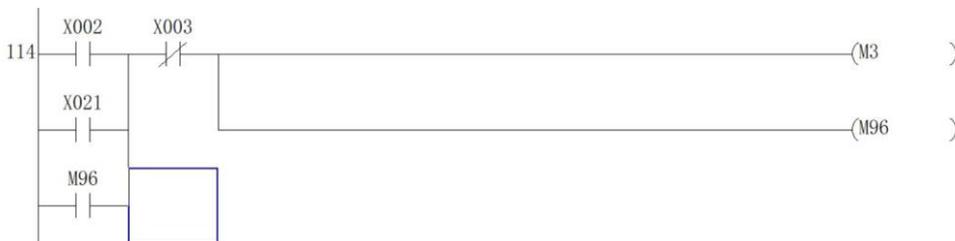


Figure 7-17 Short going forward

The picture show the after lifting, the platform will continue going forward, when the platform touch the X002 or X021, the M3 will run and be locked by M96.

So, when the programming runs to this step and touches the X003(limit switches).



Figure 7-18 Releasing the clamp.

The M5 will run in this programming. The wheels will not be fixed. So, your cars is free now, then the programming will continue next step.

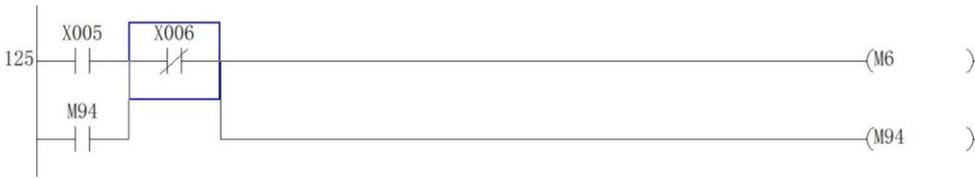


Figure 7-19 Short-backing.

The picture show after the clamp machine releases your cars, the platform will go back, it is also through X006(limit switches) to control the distance.

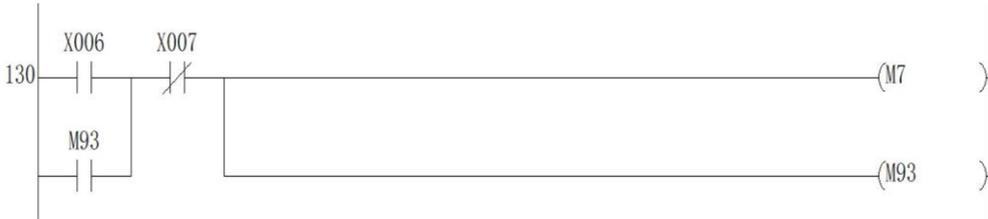


Figure 7-20 Lifting down.

When platform touches the X006(limit switches), the platform will lift down to the ground.

And then next step will start: go back to the original point

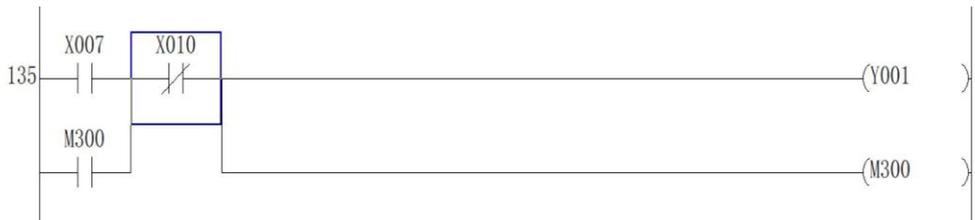


Figure 7-21 Back to the original location.

So, the whole flow chat completes the automatic to park cars.

#### 7.4.5 Corresponding relations table of PLC and parking lot

The table shows the corresponding relations between the machine and programming

Table 7-2. Corresponding relations.

I/O point (input or output)	objective
-----------------------------	-----------

X000	Limit switch
X002	Limit switch
X003	Limit switch
X004	Limit switch
X005	Limit switch
X006	Limit switch
X007	Limit switch
X010	Limit switch
X021	Limit switch
X100	Limit switch
X001	Button-1(parking space)
X011	Button-2(parking space)
X013	Button-3(parking space)
X030	Button-4(parking space)
X015	Button-5(parking space)
X016	Button-6(parking space)
X017	Button-7(parking space)
X020	Button-8(parking space)
X004	Button-9(control clamp)
M99	Relay coil(self-lock)
M98	Relay coil(self-lock)

M97	Relay coil(self-lock)
M32	Relay coil(self-lock)
M101	Relay coil(self-lock)
M201	Relay coil(self-lock)
M92	Relay coil(self-lock)
M34	Relay coil(self-lock)
M204	Relay coil(self-lock)
M103	Relay coil(self-lock)
M86	Relay coil(self-lock)
M26	Relay coil(self-lock)
M206	Relay coil(self-lock)
M105	Relay coil(self-lock)
M85	Relay coil(self-lock)
M38	Relay coil(self-lock)
M208	Relay coil(self-lock)
M107	Relay coil(self-lock)
M97	Relay coil(self-lock)
M84	Relay coil(self-lock)
M96	Relay coil(self-lock)
M95	Relay coil(self-lock)
M94	Relay coil(self-lock)

M93	Relay coil(self-lock)
M300	Relay coil(self-lock)
M1	Motor (go forward)
M31	Motor (go forward)
M8	Motor (go forward)
M33	Motor (go forward)
M9	Motor (go forward)
M35	Motor (go forward)
M10	Motor (go forward)
M37	Motor (go forward)
M2	Motor (lift up)
M11	Motor (lift up)
M3	Motor (short go forward)
M5	Motor (Release the clamp)
M6	Motor (short go back)
M7	Motor (lift down)
Y001	Motor (go back)

## 7.5 Flow chart of taking cars(the second PLC)

After parking the cars, we also need to make take the cars flow chart, people also want to take the cars automatically.

The take cars flow chart is like the parking flow chart. The difference of the two flow charts is about the clamp.

In the take cars flow chart, we do not need run the clamp machine at beginning.

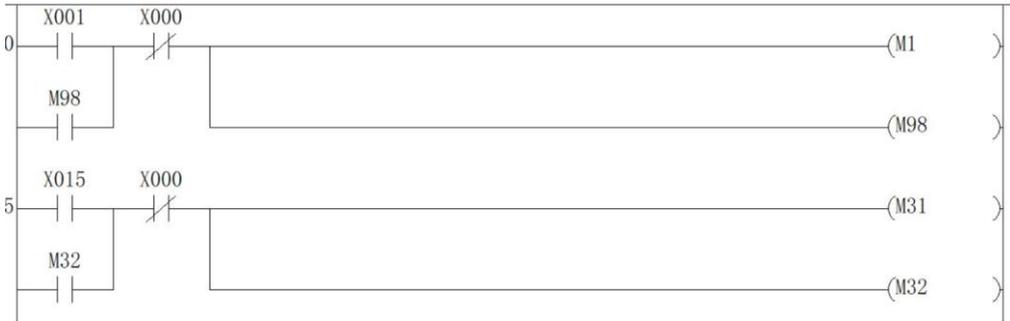


Figure 7-22. The beginning of the take cars

Compared with the parking flow chart. We just press the X001 at first, and then the following flow chart is the same.

Till the platform complete the action which is a short going forward. The clamp machine will fix the wheels of the car.

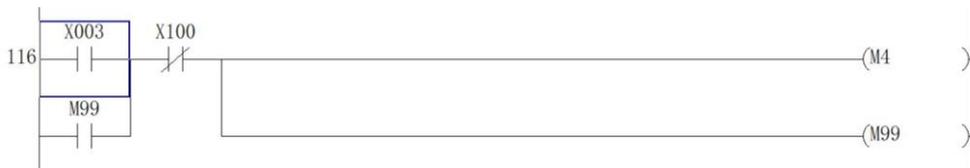


Figure 7-23. Clamp the wheels.

The clamp machine will fix the wheels through the X003(limit switch) to start the M4 (motor to control clamp).

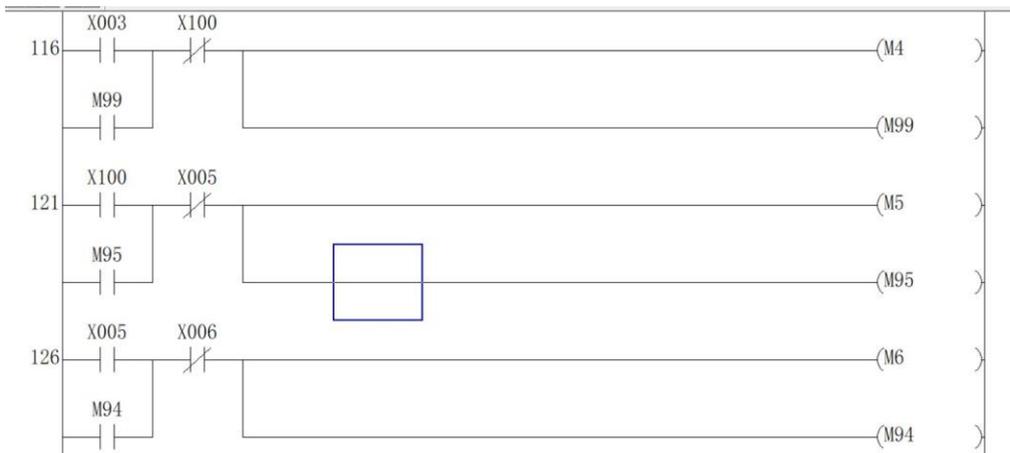


Figure 7-24. The following flow chart.

When, the clamp touches the X100(limit switch), M5 will be derived and back, thirdly, the X005(limit switch) will make the M6 start, the platform lift down.

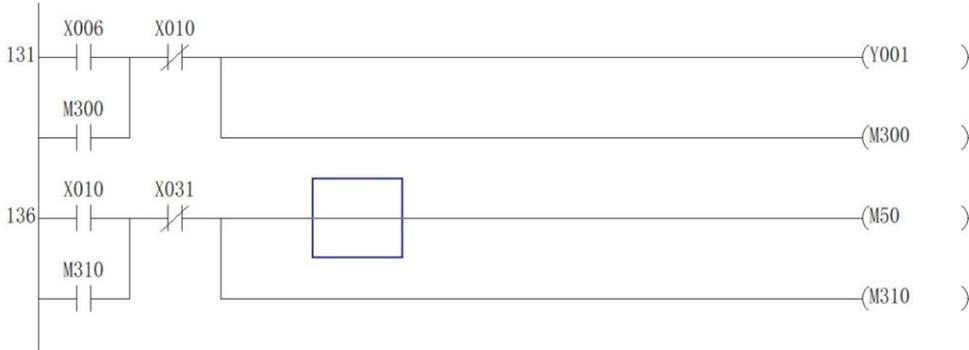


Figure 7-25. The last step.

The last step is going back the original point, and the clamp machine will release the wheels of the cars, people can drive their cars now.

### 7.5.1 Corresponding relations table of taking cars

Table 7-3. Corresponding relations table of taking cars.

I/O	objective
X005	Limit switch
X006	Limit switch
X003	Limit switch
X100	Limit switch
X031	Limit switch
M4	Motor(clamp)
M5	Motor (short back)
M6	Motor (lift down)

Y001	Motor (back to the original point)
M50	Motor (release the wheels)
M310	Relay coil(self-lock)
N: the other input or output is same as the corresponding relations table of parking	

## 7.6 Limit switch introduction

Because there are many limit switches in our parking lot, so we continue to introduce the limit switch.[13]

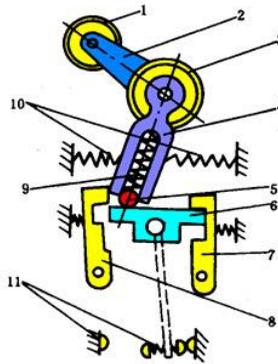


*Figure 7-26. Limit switch.*

Limit switch is a small electrical appliance. Which use mechanical moving parts to achieve the opening or breaking control circuit, to get a certain control purposes. Typically, such switches are used to limit the position or stroke of mechanical movement, so that the movement of machine per a certain position or stroke automatically stop, reverse movement, automatic round-trip movement.[14]

### 7.6.1 Roller limit switch

We decide to choose roller limit switches to be our limit switches.[15]



*Figure 7-27. Roller limit switch.*

1. Roller wheel
2. Bar
3. Pulley
4. Stock
5. Pulley
6. Board
7. Laminate
8. Laminate
9. Spring
10. Spring
11. Contactor

When a machine hits the bar with a roller wheel, and bar to the right, which can make the cam rolling press the top putter and micro switch contactor in action. the movement will return under the effect of spring parts, every part will reset.

## **8 Chapter: conclusion**

We use hydraulic system to realize the automatic parking and taking cars, and we also use PLC programming to realize the automatic controlling, which help people to park their cars more convenient and more relaxing.

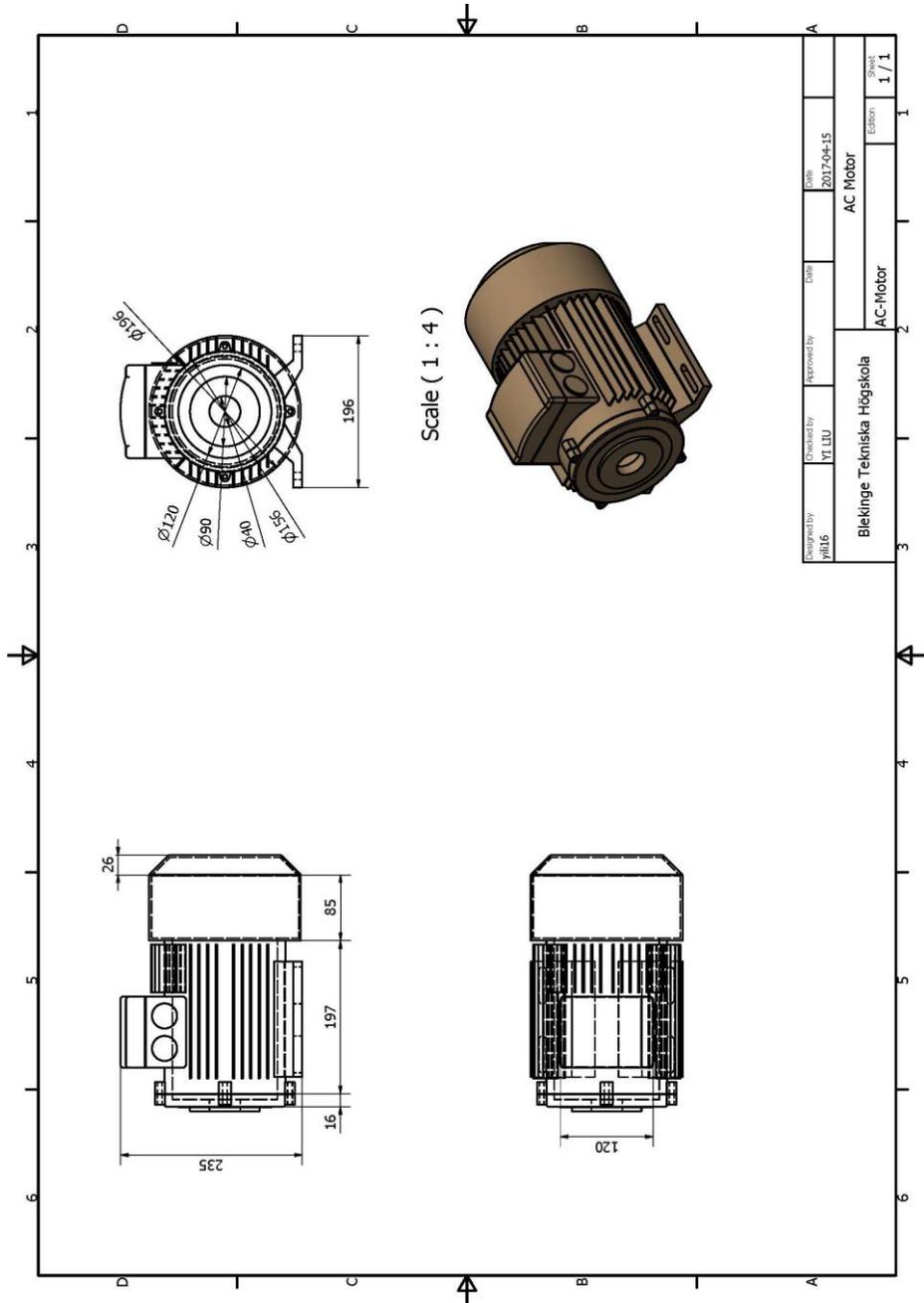
And about the parking space, we create the three floors, the ground one, the first one and the second one, perhaps, if someone need more parking space, our project may manufacture more floors to meet the requirements for people.

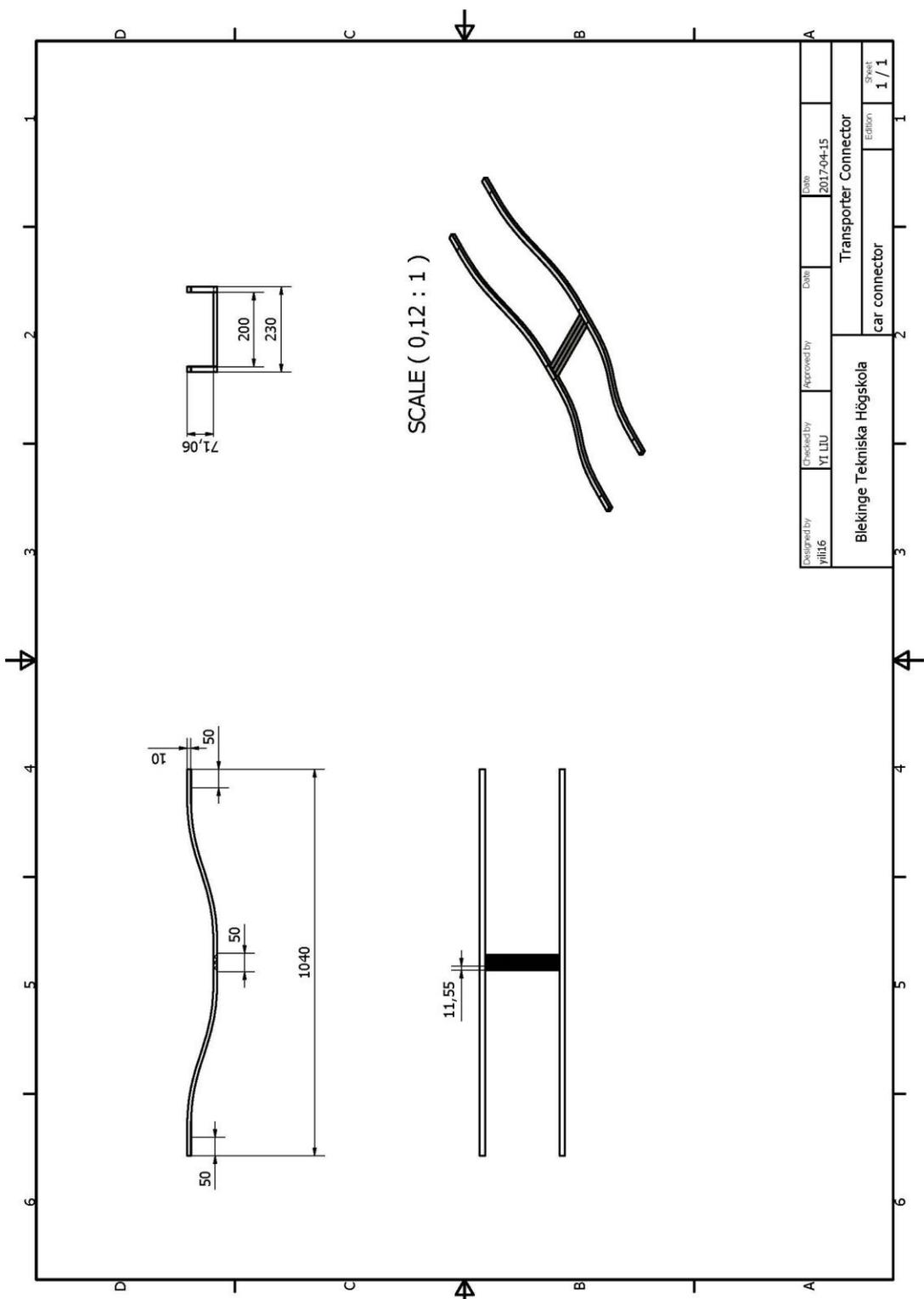
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- [19][https://www.alibaba.com/product-detail/5-layers-8-Cars-Vertical-Rotary\\_60415750987.html](https://www.alibaba.com/product-detail/5-layers-8-Cars-Vertical-Rotary_60415750987.html)
- [20]<http://www.lebaoshun.com/html/2015/0320/1772.html>
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- [22][http://www.inverter-plc.com/plc/FX\\_PLC/FX-64MR-UA1-UL.html](http://www.inverter-plc.com/plc/FX_PLC/FX-64MR-UA1-UL.html)
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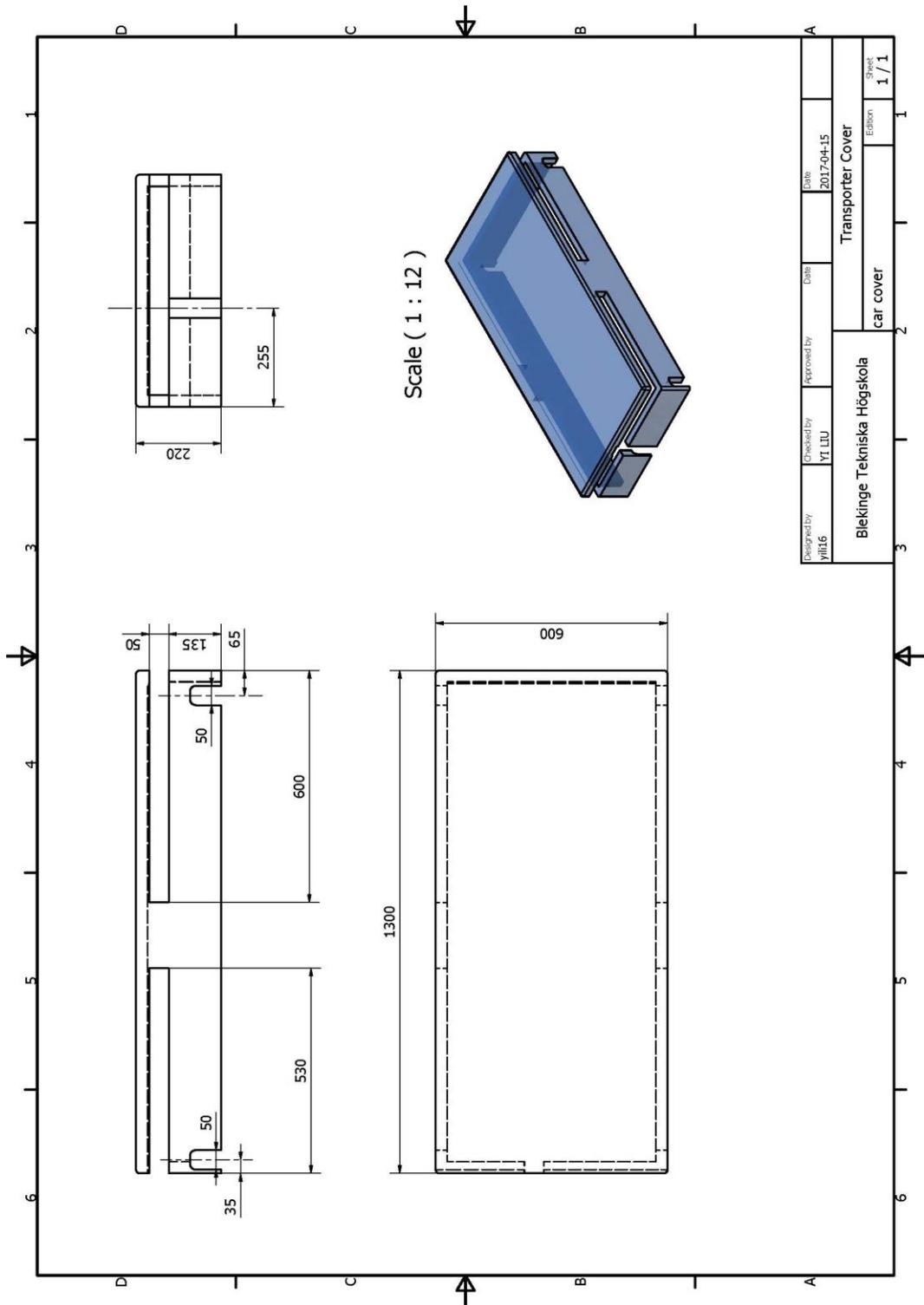
# Appendix 1: Drawing of Main Components



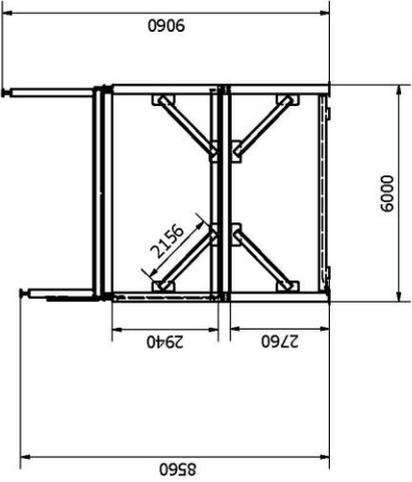
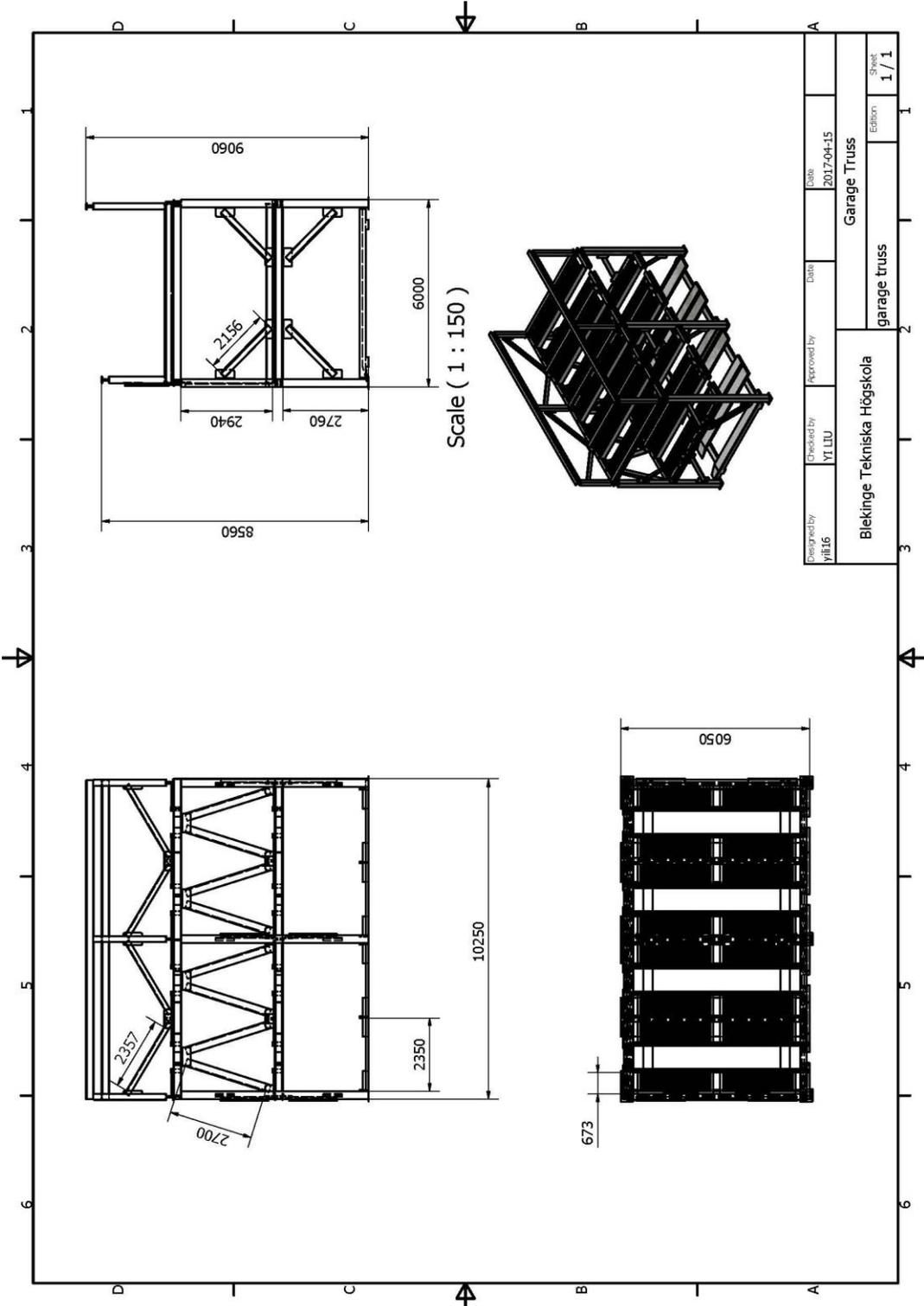


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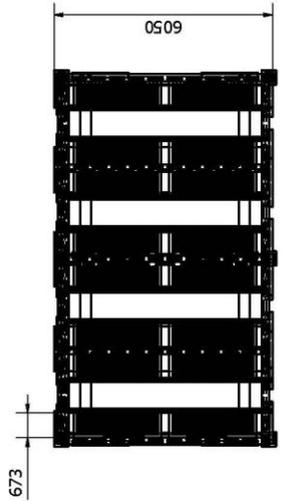
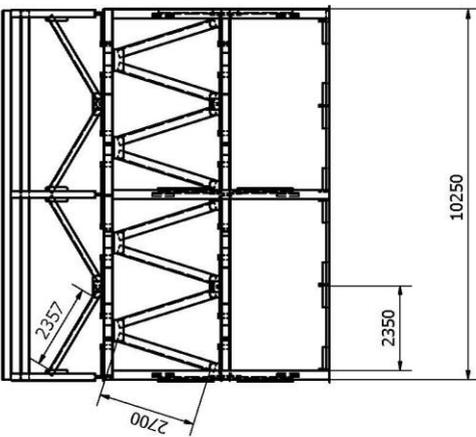
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car connector			Edison	



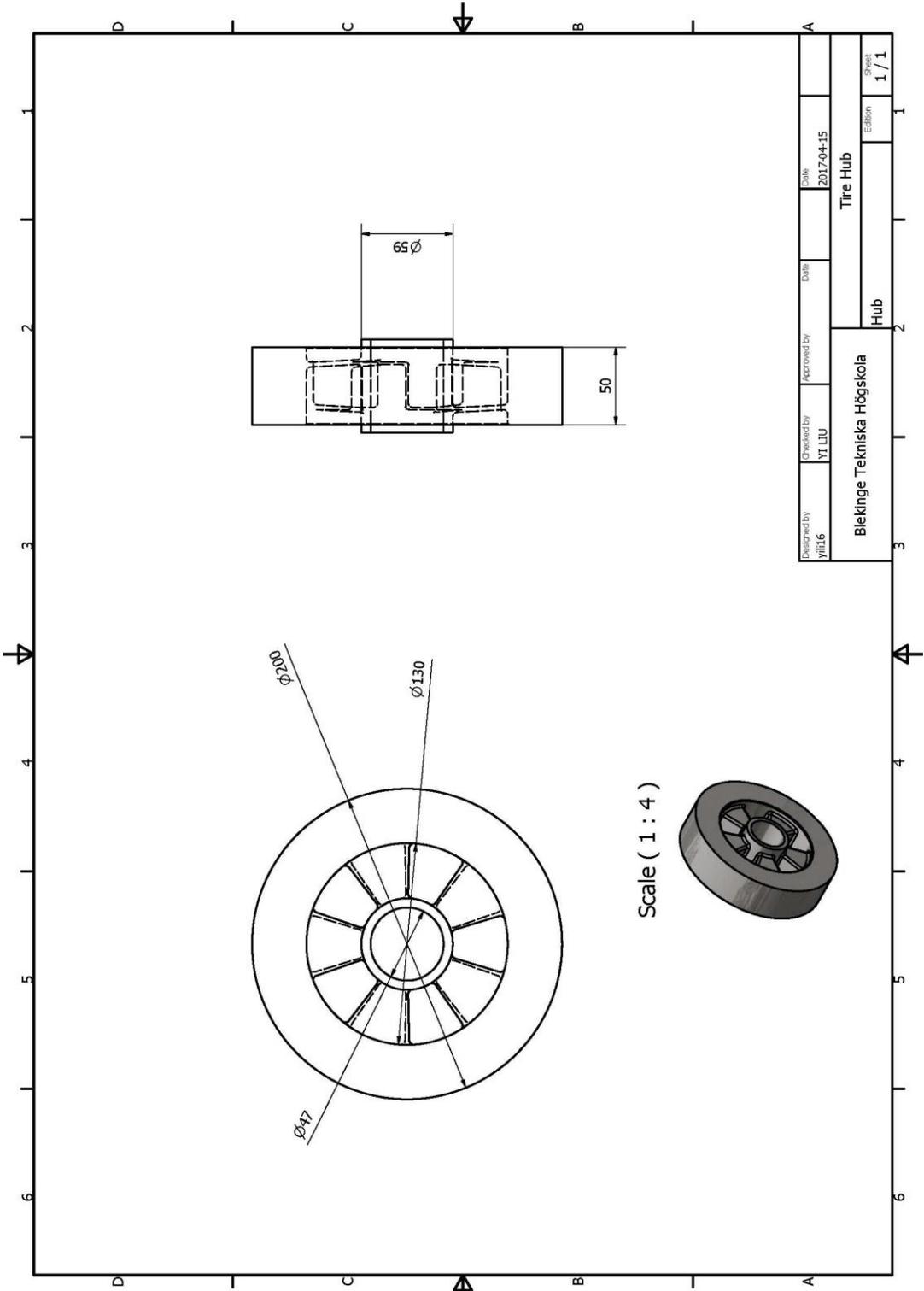
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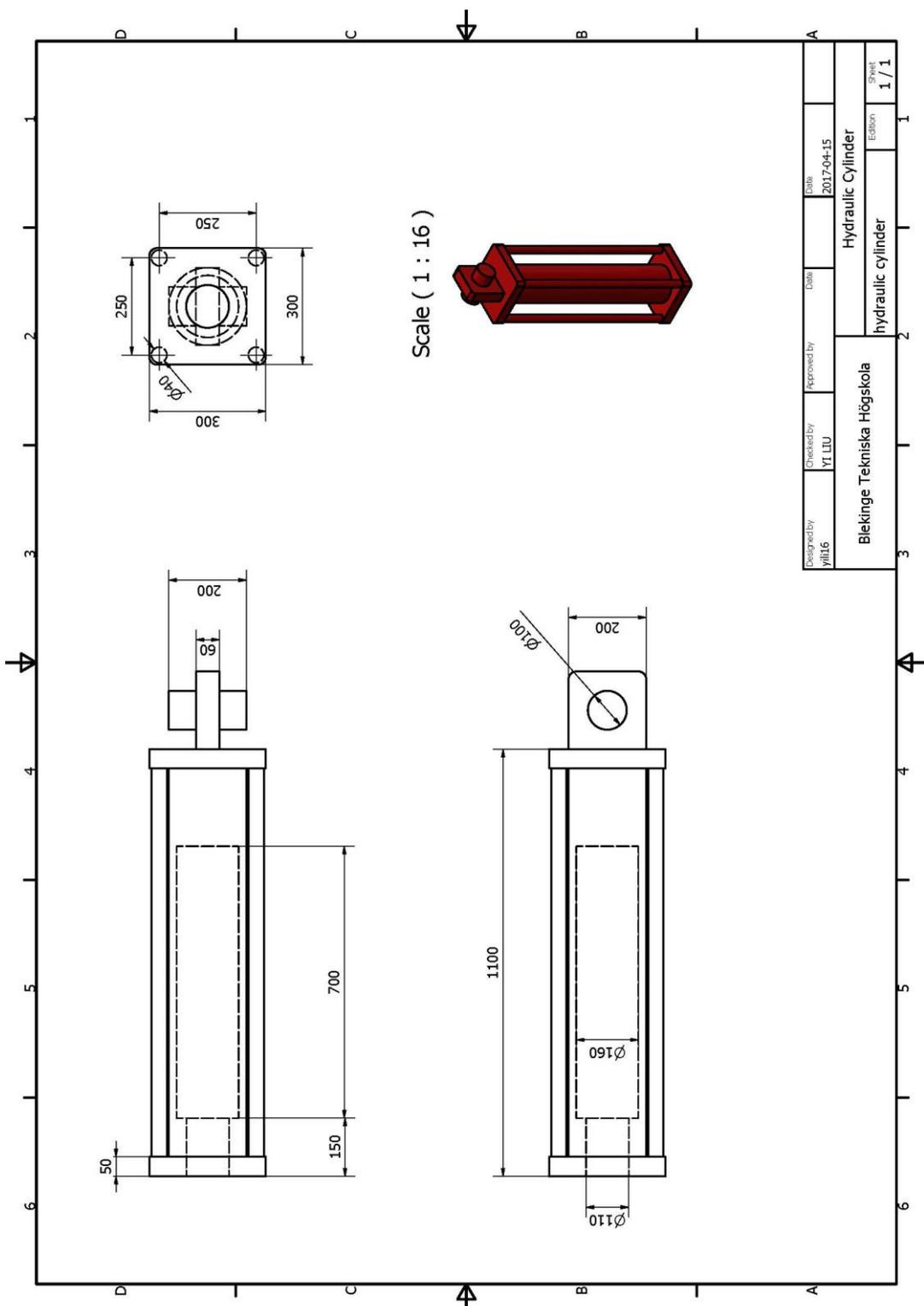
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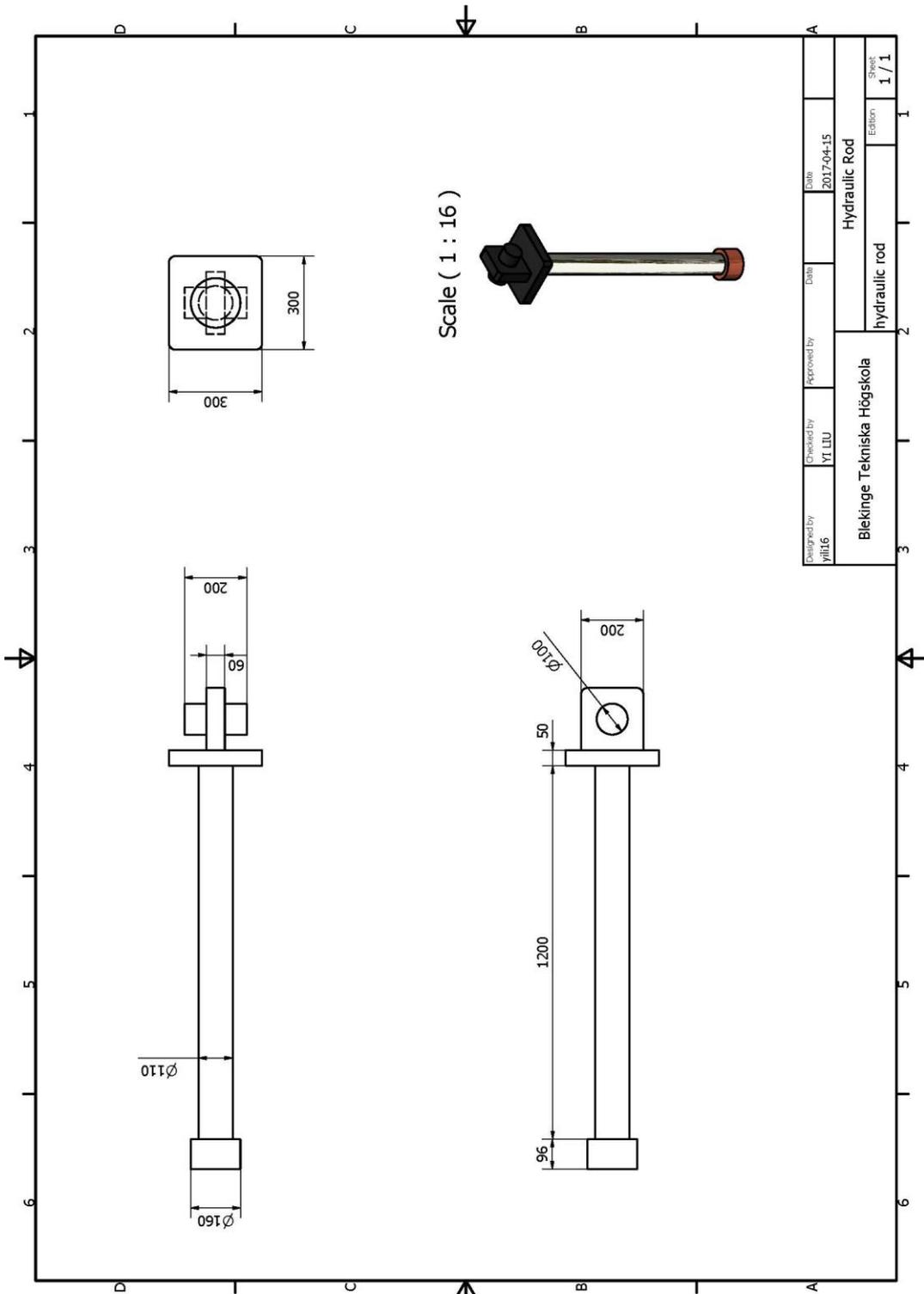
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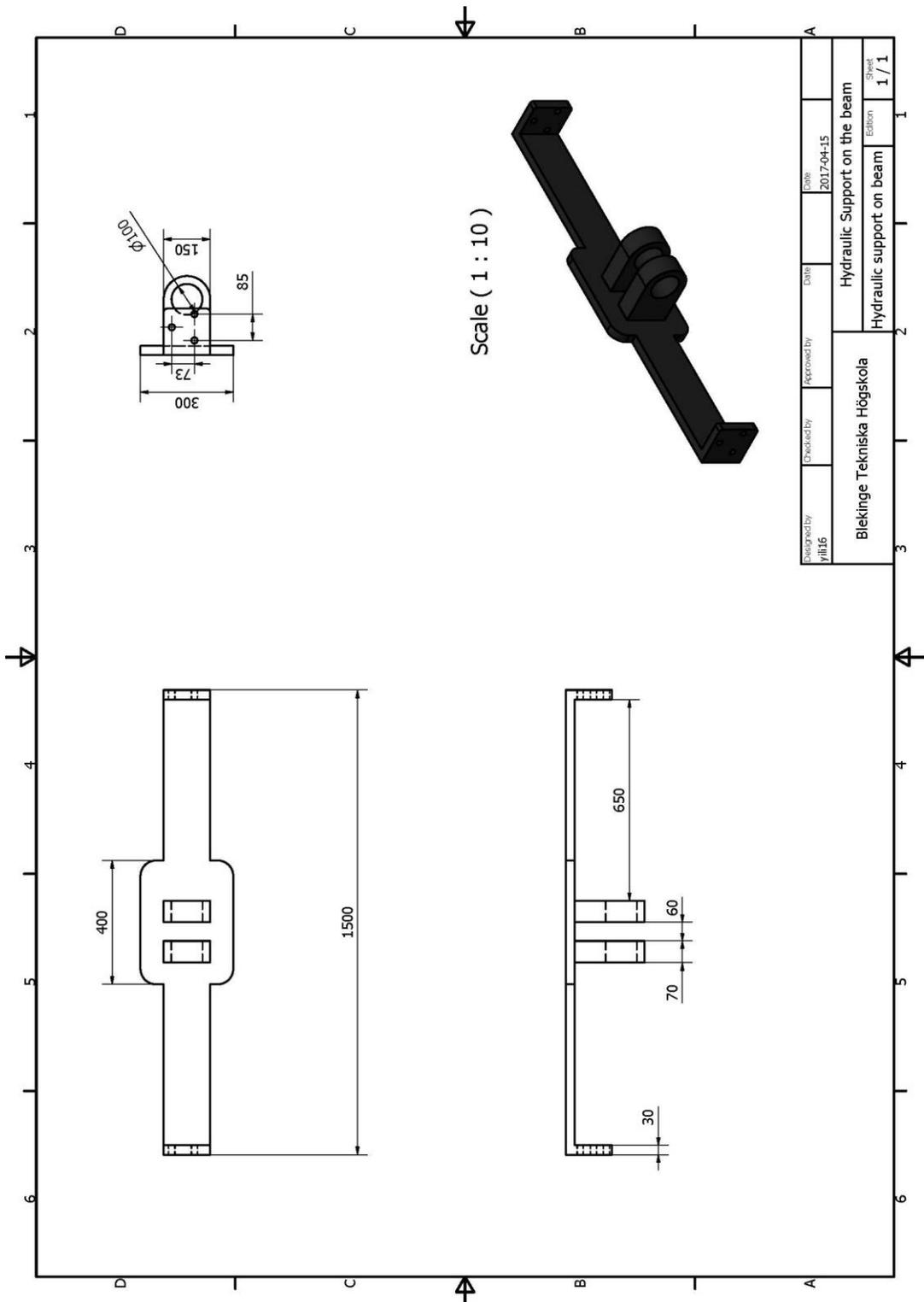


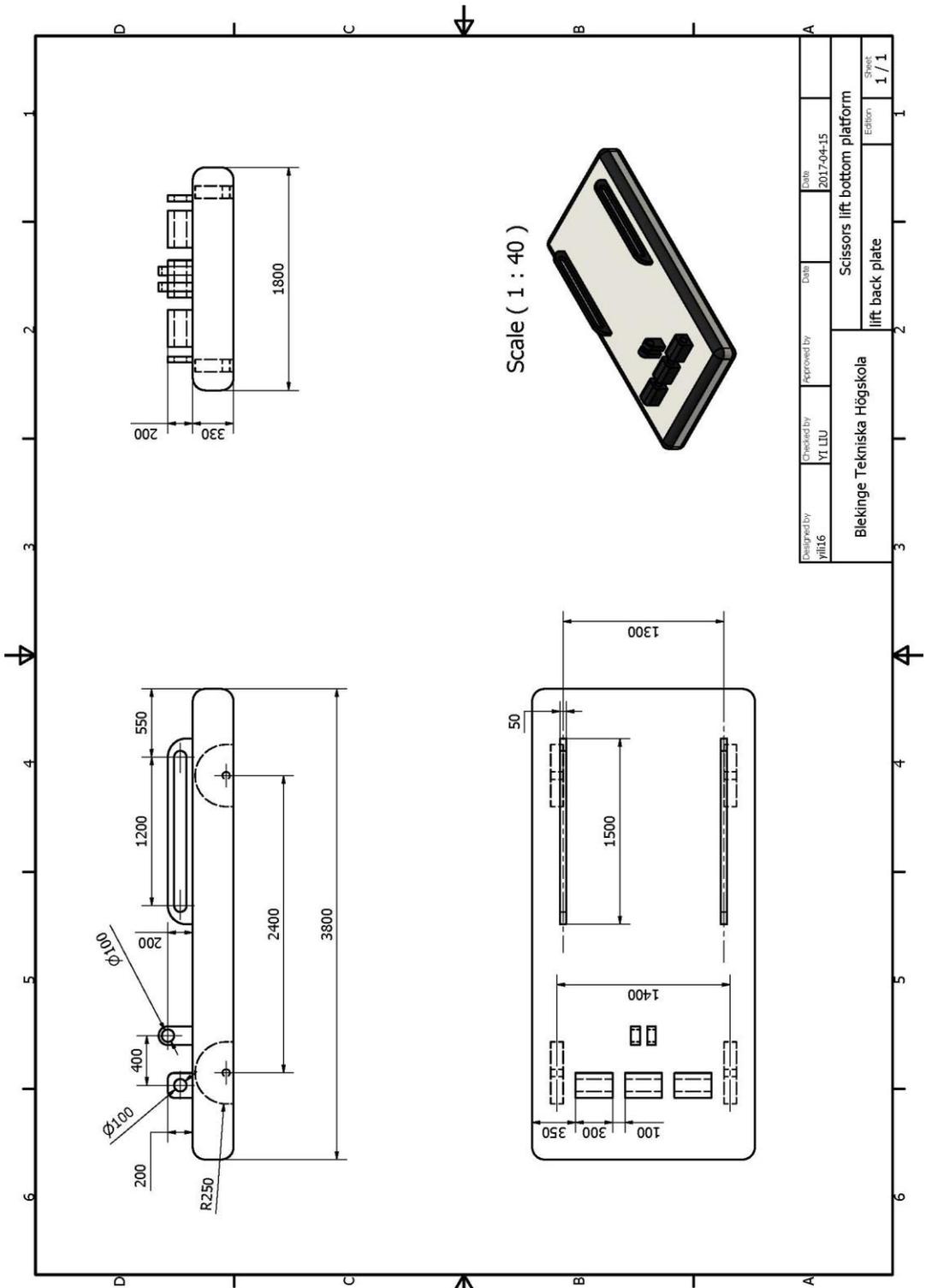
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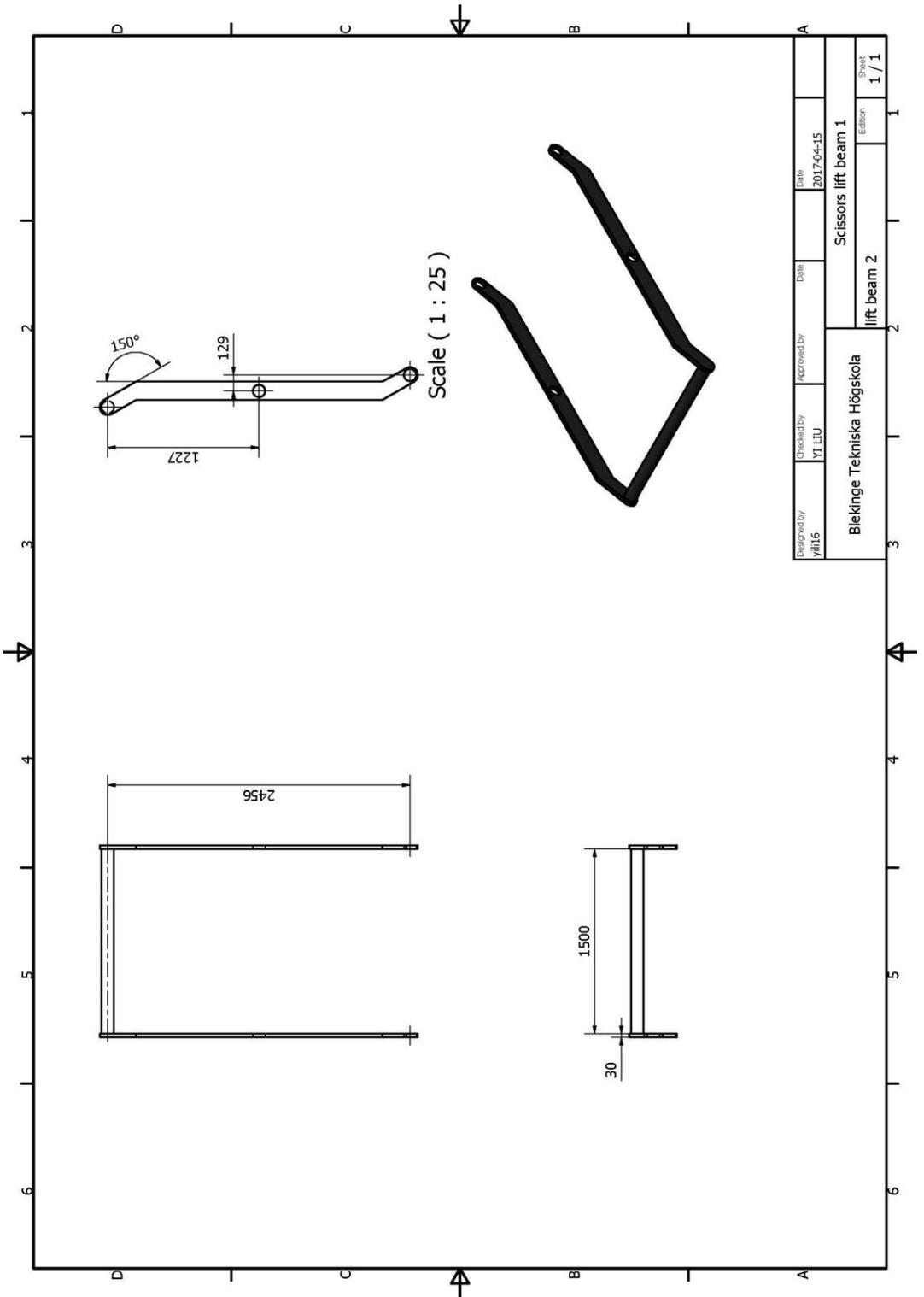
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			Erikson	



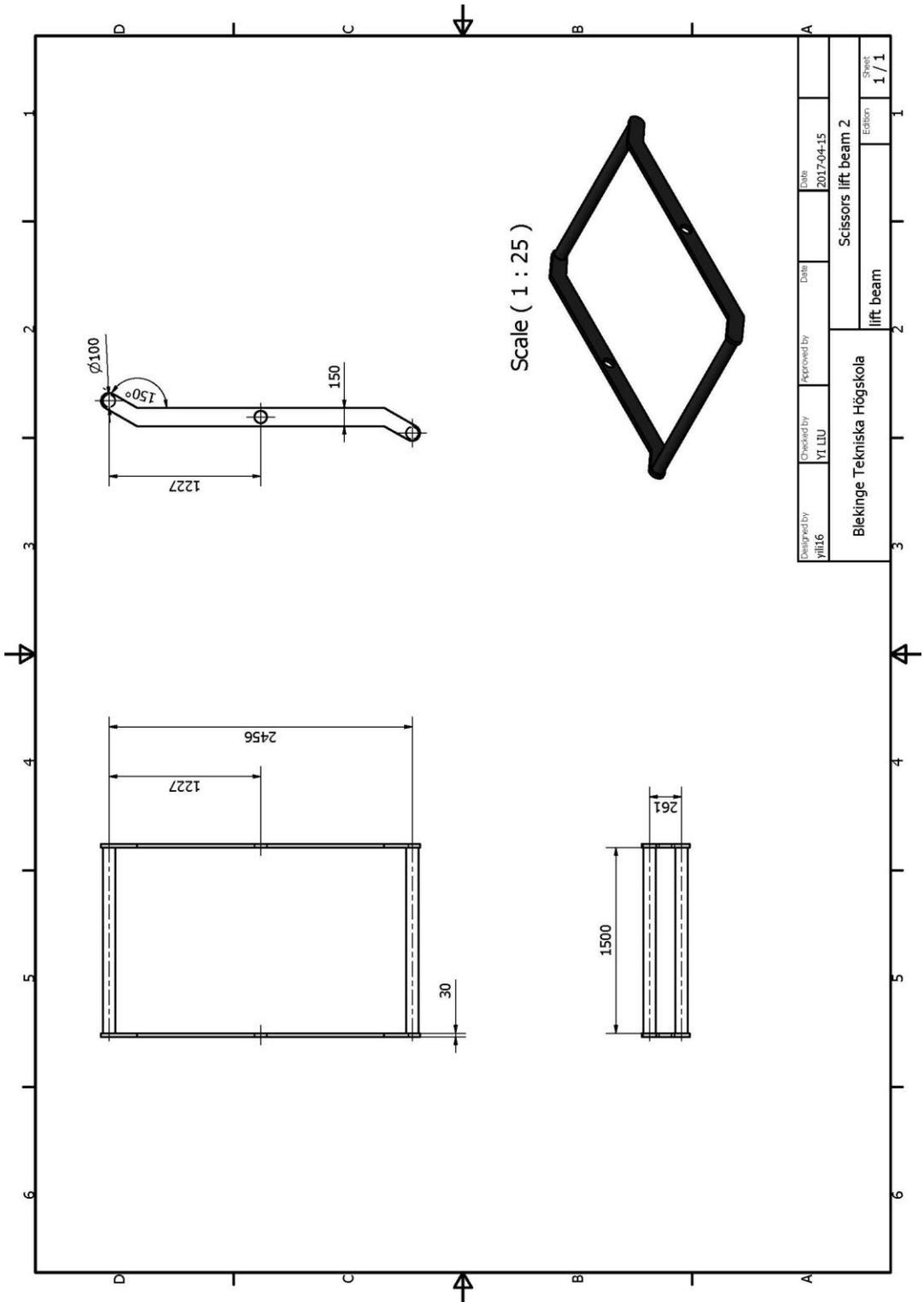




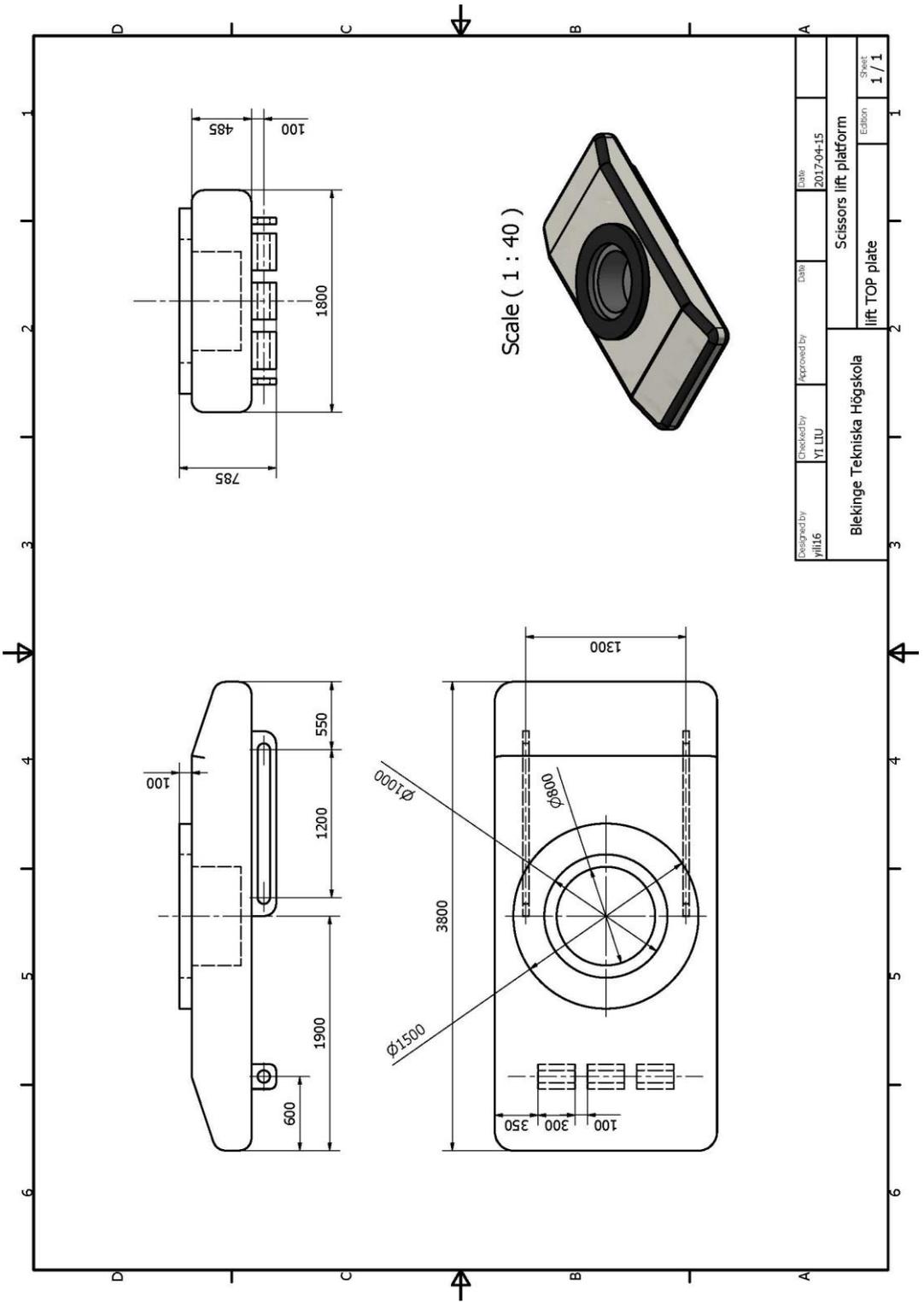
Designed by ylli16	Checked by YI LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Scissors lift bottom platform	
lift back plate		Edition	Sheet
		1 / 1	1 / 1



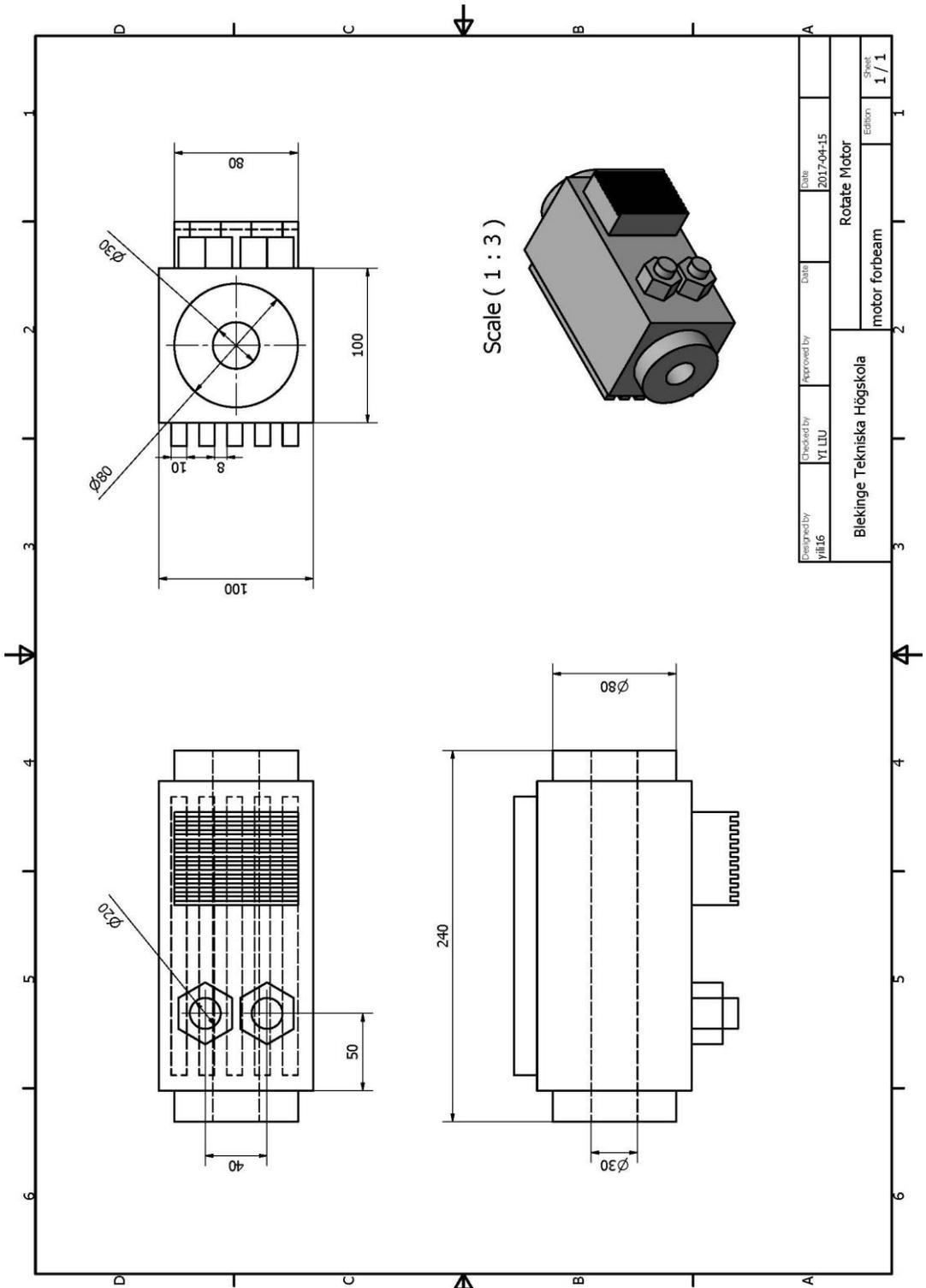
Designed by MILG	Checked by YL LDU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Scissors lift beam 1	
lift beam 2		Edison	
			Sheet 1 / 1



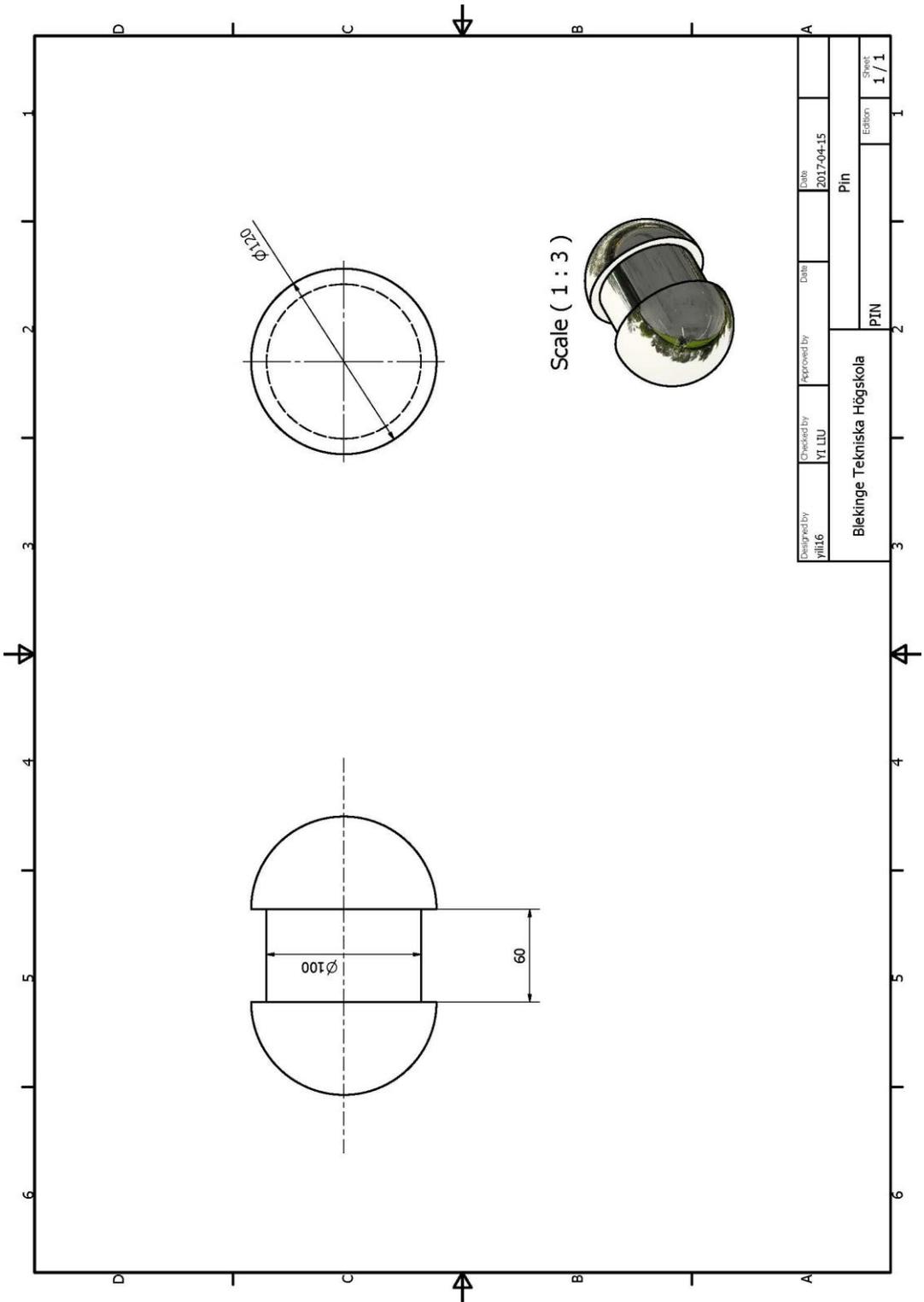
Designed by ylli16	Checked by YI LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola			Scissors lift beam 2
lift beam			Edition 1 / 1



Designed by ym116	Checked by YL LILU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Scissors lift platform	
lift TOP plate		Edsson	
		Sheet 1 / 1	

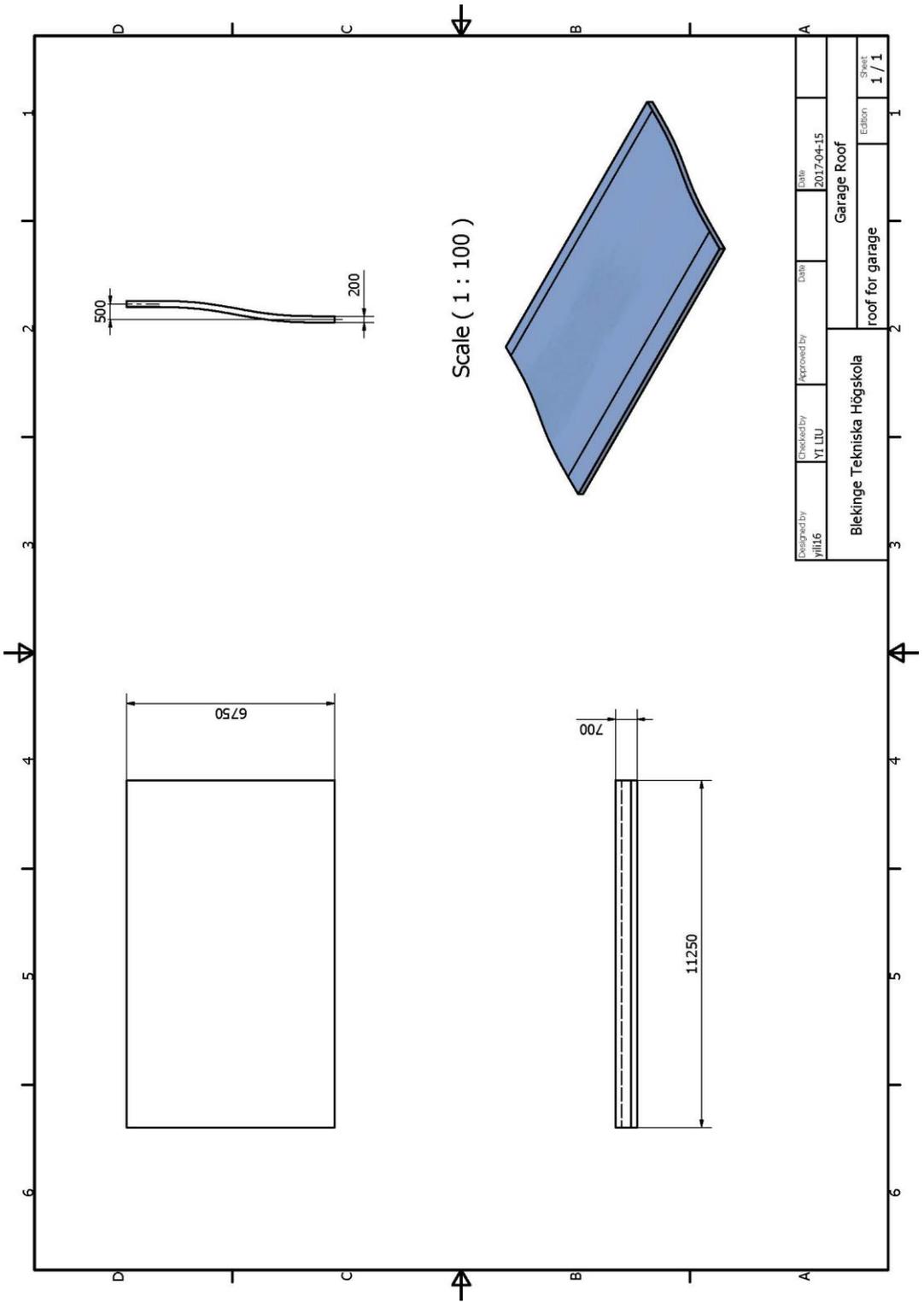


Designed by Vil16	Checked by YI LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola			Rotare Motor
motor förbeäm			Esbom
			Sheet 1 / 1

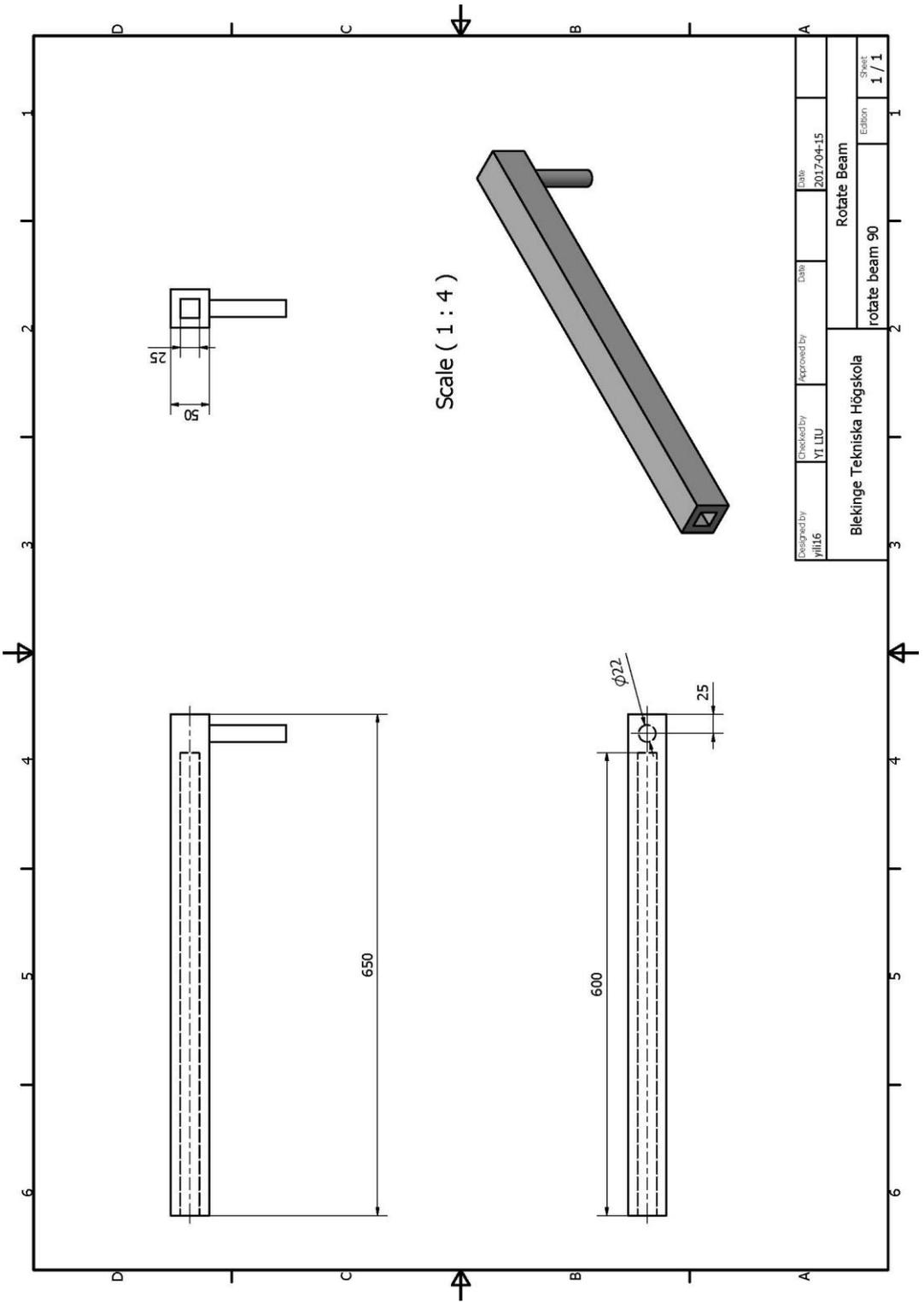


Scale ( 1 : 3 )

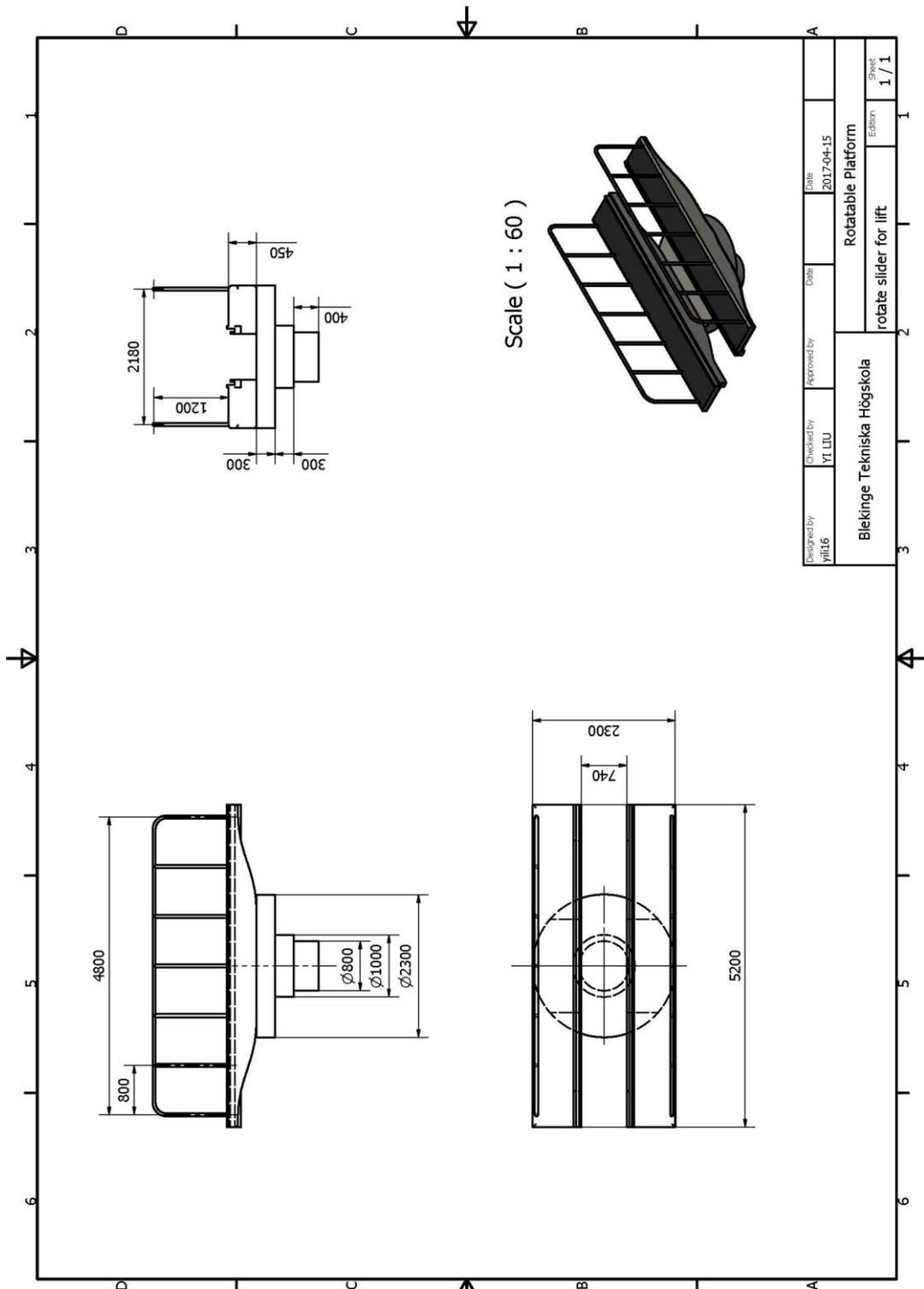
Designed by yhl16	Checked by YT LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Pin	
PIN		Esbom	Sheet 1 / 1



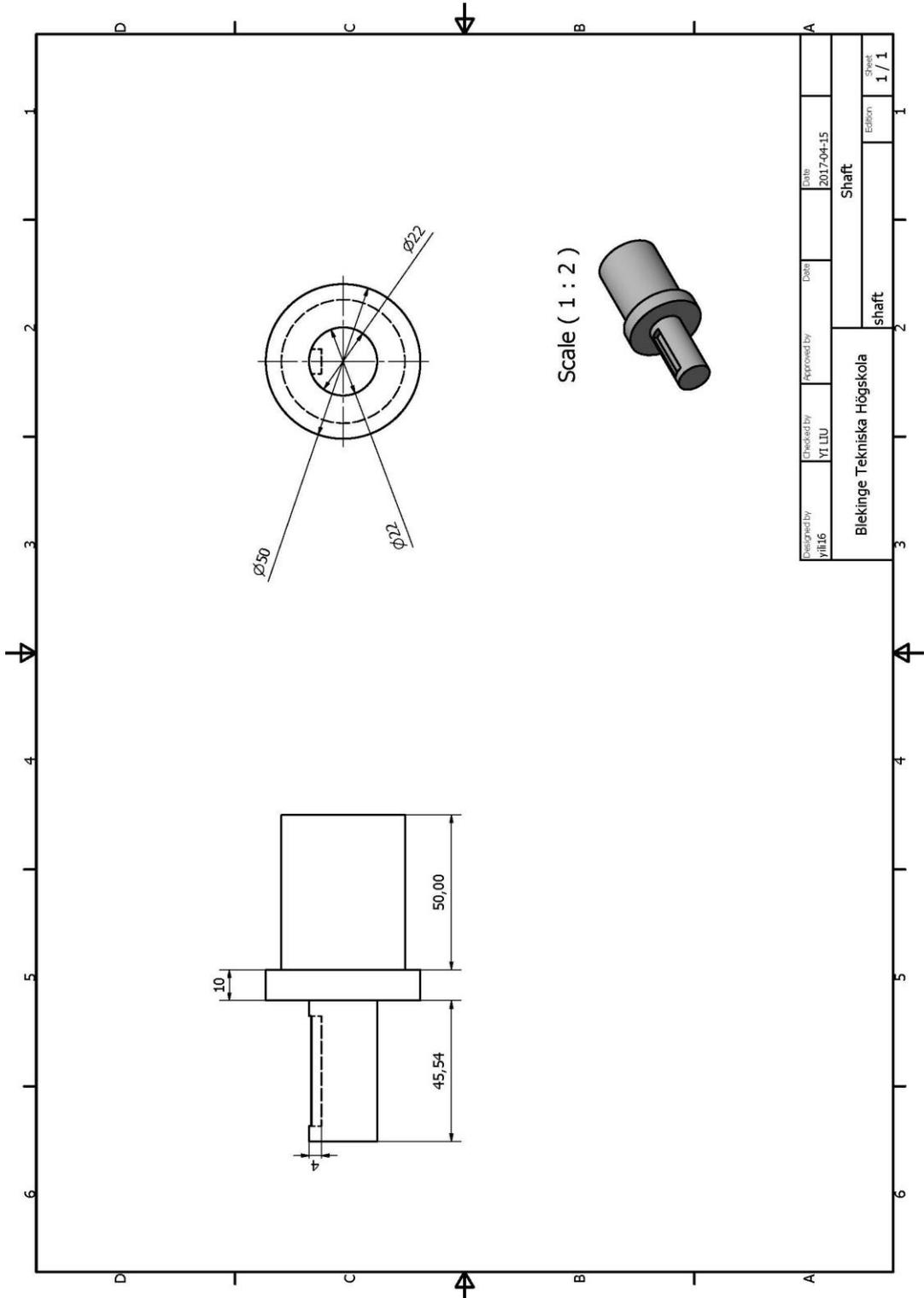
Designed by yjl16	Checked by YI LIU	Approved by	Date 2017-04-15	Garage Roof	Sheet 1 / 1
Blekinge Tekniska Högskola			roof for garage	Ebbön	



Designed by ym16	Checked by YTLIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Rotate Beam	
rotate beam 90		Edborn	
		Sheet 1 / 1	



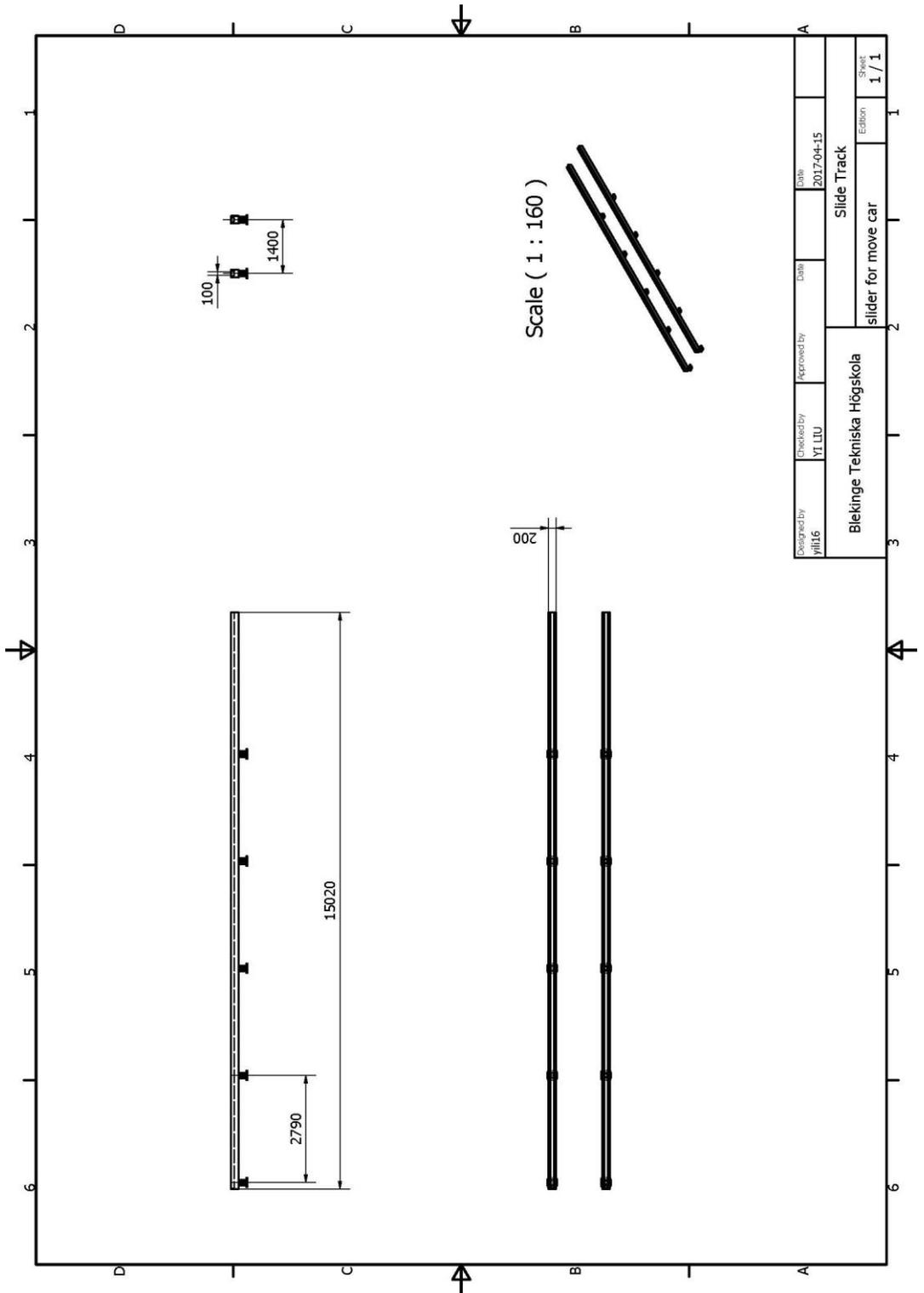
Designed by yjl16	Checked by YT LJU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Rotatable Platform	
rotate slider for lift		Edition	Sheet
		1 / 1	1 / 1

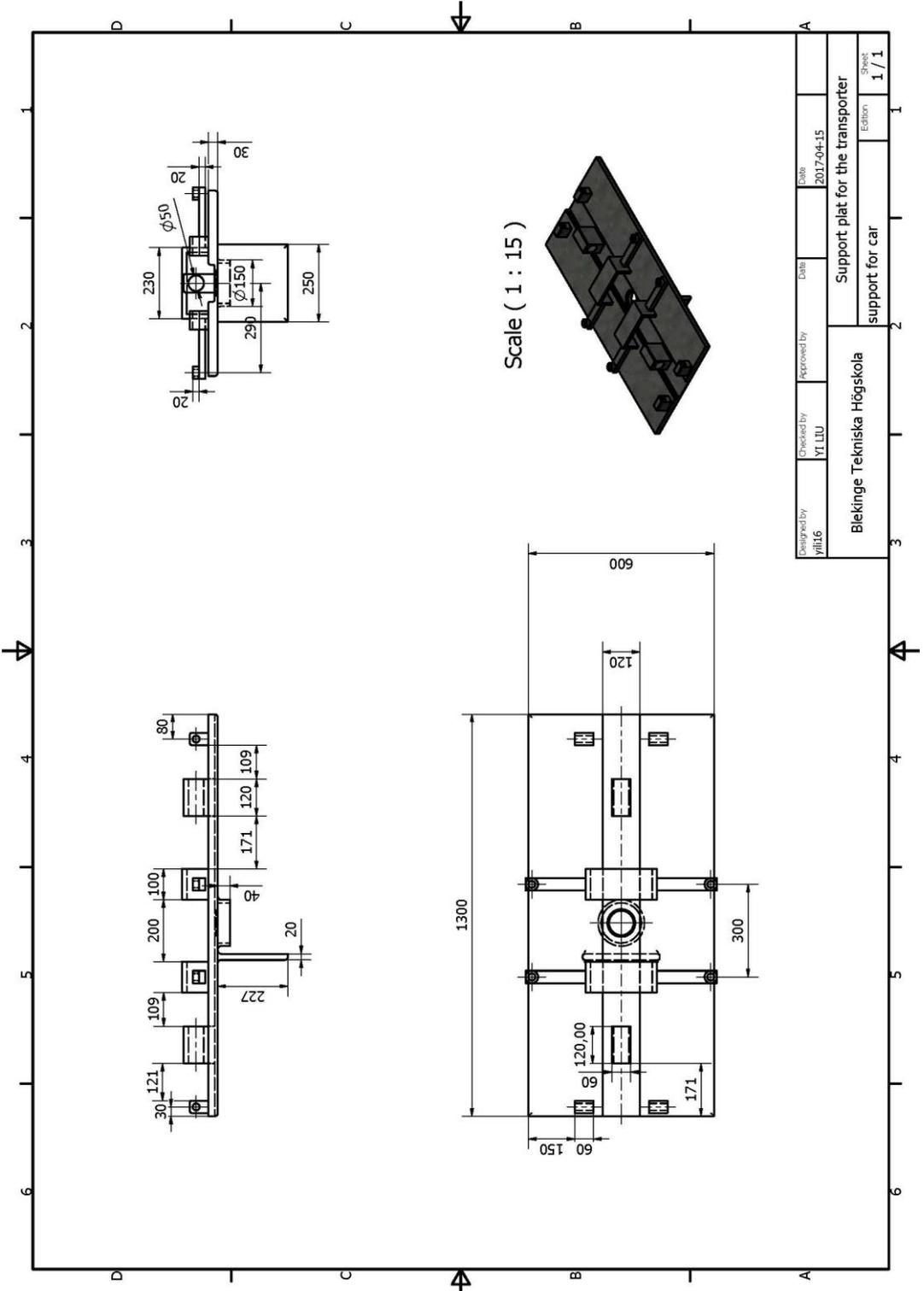


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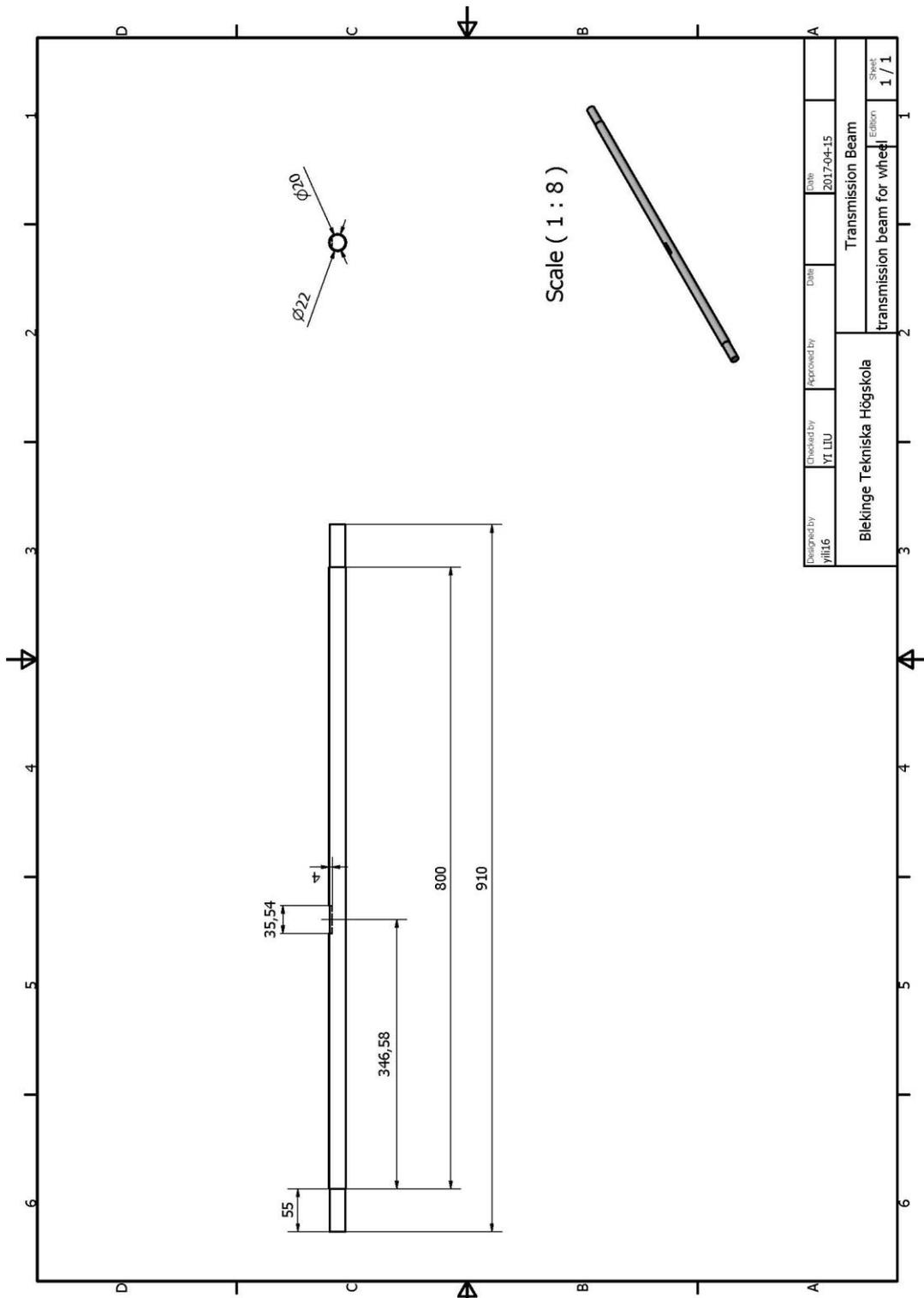


Designed by yifli16	Checked by YI LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola			Shaft
shaft			Sheet 1 / 1

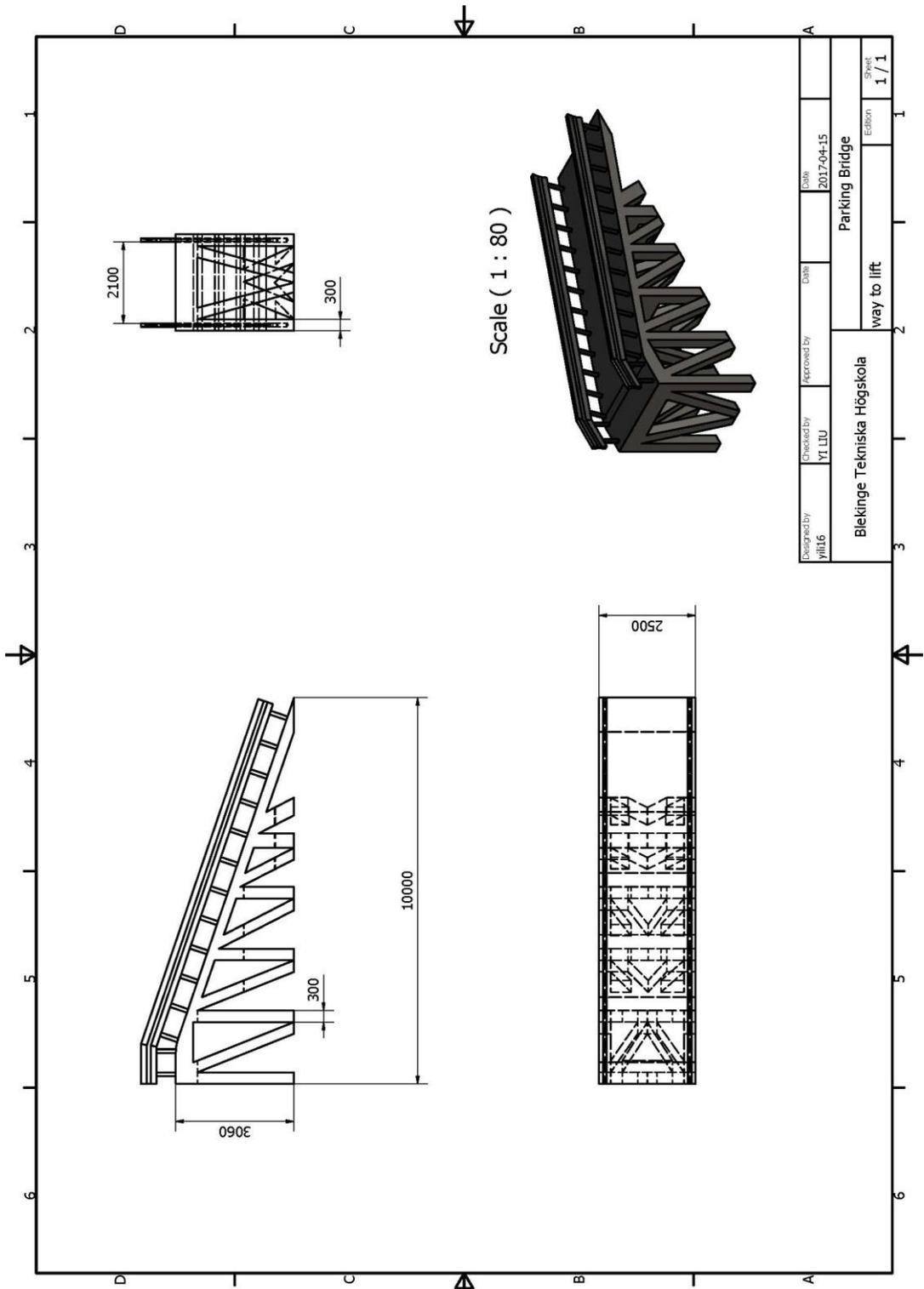




Designed by yhl16	Checked by YT LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Support plat for the transporter	
		support for car	
		Eckhorn	
		Sheet 1 / 1	



Designed by yili6	Checked by YI LDU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola			Transmission Beam
transmission beam for wheel			transmission beam for wheel
			Edition 1 / 1



Designed by ylli16	Checked by YI LIU	Approved by	Date 2017-04-15
Blekinge Tekniska Högskola		Parking Bridge	
way to lift		Esboon	Scale 1/1