University of Twente

Group 21

Design of a Ship to Shore Crane

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1 Summary

The report focuses on improving the design of a STS-crane. This is done by devising 3 different concepts of booms, trolleys and hoisting mechanisms. These concept sketches also include the position of the hoisting mechanism.

Secondly, the functionality concept was chosen as final design and functioned as starting position for further improvement and detailing. The design was further analyzed and designed with according calculations and tables. The design was dimensioned and detailed sketches were made in Solid Works, which were all added to the appendix.

The third step was to assign materials to the different parts of the crane.
For this part first a list of all the important properties that had to be taken into account for all the parts was made. In every part some different properties were taken into account this is based on the importance of the properties of that part. For example in some parts weldability was very important because a welding connection has to be used. Although also properties like yield strength, cold forming, low density, corrosion and the Poisson ratio were taken into account to find out which material is the best to use. With the chosen properties the best materials could be found using the CES-edupack program and articles about materials that are all ready used nowadays in part for an STS-crane.

Now that all the materials are known the more detailed parts could be worked out. Also for this part firstly a list of properties was made to find out which properties are important for the parts. Knowing all the properties a choice for the type of motor, driving system and gearbox can be made. With the material type that is used for the frame and boom known, FEM calculations were done using the poison rate, density and young's modulus of the chosen HSLA steel: ASTM A656. With the FEM program calculation as stresses, inertia, displacements and weight were calculated. The design chosen showed that it was capable of sustaining its form under a load of 100 tons.

Than some machine element calculations of a weld, bolt, key and shaft had to be made to calculate especially the thickness at which the parts can handle the applied stress on it. With this information a detailed design was made in which the known dimensions are displayed.

Finally the chosen system to transfer power and torque through the motor to the drum that collects the cable is gears. There are two motors and one gearbox. The gearbox includes 2 bevel gears, one is connected to the motors shaft and the other is connected to the drums shaft. The chosen motor is the simotics SD motor with efficiency class IE3/premium and IC411-totally-enclosed fan-cooled, because this motor satisfy the most properties that have to be taken into account.

After the final concept there were still some things that could be optimized in the redesign.

2 Introduction

The transportation and relocation of goods is one of the major determinants of a thriving society. Besides the use of vessels to transport freight, cranes are also essential pieces of equipment in the relocation of heavy goods. Around 1500 BC the first cranes were constructed by the Egyptians to build the pyramids. And ever since, the function as well as the construction of these structures have continuously developed.

The first quayside gantry crane, or Ship to Shore crane, was developed in 1959 by the Paceco Corporation to remove the heavy containers from the container ships. Ship to shore cranes eventually developed into high and low profile cranes, both with the purpose to move heavy containers and goods. These kind of cranes are usually judged on their reliability and their operation speed. A faster, more reliable crane is always more desirable. Multiple studies have already been carried out in order to improve upon the design of these cranes.

In order to improve the design of a high profile ship to shore crane, a study was conducted and a new design for this equipment is presented. This is done by discussing the problem; designing multiple concepts; presenting a detailed concept with according calculations and models; and lastly a discussion on this design.

3 Method

The aim of this study was to improve upon the design of the current high profile ship to shore crane in order to improve the lifetime as well as the operation speed.

This was done by first of all setting up a problem definition in which the problem was described more thoroughly; secondly, multiple concepts were created and compared on basis of their capability to fulfill the function of a ship to shore crane; a detailed sketch was created of the final product, with according calculations and assumptions; and a discussion was held in order to reflect on the final design.

The problem was described using multiple requirements, which are used, at the end of the process, to assess whether or not our design fulfills its function.

The second step was to design multiple concepts with clear drawings, pros and cons, and possible considerations in building and operating said design. From these concepts, a final design is chosen and designed more thoroughly. This involves: static calculations, material choices, and clear drawings of the final design.

Concluding this study, there is a discussion on the results and design of the crane. This chapter also focuses on any further studies that may be conducted in order to improve the final design.

Contents

4 Problem Definition

4.1 Problem

A ship to shore (STS) container crane must be designed to load and unload shipping containers from container ships. There are multiple kind of these STS cranes, this study will look at high profile cranes, an example of such a crane is given in figure 1. These cranes have a hinged boom which can lift to clear the ships for navigation. The cranes are also able to lift one container at a time. Based on their working principle and operating conditions, these cranes will be exposed to various loads, including high windspeeds and the load of the container itself. They must be designed to withstand these loads.

This report will focus on the designing of a fully operational STS crane that is structurally sound. It will be assumed that the crane will be designed for a port in the Netherlands. The process begins with an identification of the most important requirements that the final product should satisfy. Once these requirements are set, the key functions of the design are identified, and a range of concepts are brainstormed on how each function can be achieved. This forms the basis of the morphological diagram. From the diagram, three concepts of the hoist-trolley-boom mechanisms are derived by combining the functions such that each concept boasts a particular quality, such as speed or low cost. Then a final choice is made, based on additional requirements, and the chosen concept is fully optimized and analysed.

Figure 1: An example of a ship to shore crane

4.2 Design Requirements

In order to design a viable concept, it is necessary to determine the relevant requirements. Besides the limitations and conditions, there are some other requirements as well.

4.2.1 Primary requirements

- The crane should withstand a load of 50 tons for a single container including spreader.
- The crane should be able to withstand wind loads of 240N/m$\hat{2}$.
- The crane should have a hoisting speed of 1.5 to 2 m/s.
- The crane should have a Trolley speed of 3 to 3.5 m/s.
- The crane can only have a maximum deflection of 5 mm at the boom tip, perpendicular to the gantry rails (along the boom).
- The crane can only have a maximum deflection of 60 mm at the boom tip, parallel to the gantry rails.
- The crane can only have a maximum deflection of 150 mm at the boom tip in vertical direction.
- The crane should be able to unload vessels of maximum length of 300 m, width of 35 m and height of 40 m measured from the waterline to the vessel's highest point.

4.2.2 Secondary requirements

- The crane should not have any flying elements, so all connections should be fully defined and connected to the frame.
- The crane should be able to operate in the temperature range of -40 to 50°C, and thus the ductile to brittle transition temperature should be lower than -40°C.
- The crane should be able to handle containers of maximum length 12 m, width 2.4 m, and height 2.6 m.
- The crane should meet the operational requirements.
- The crane should withstand the load that it is subjected to during its operation (so, loads on the container, spreader, the weight and the wind load).
- The boom, trolley and hoist mechanisms must be fully designed.
- Lifespan of 25 years.
- The crane materials should be protected against the following types of corrosion (this does not necessary mean that the material does not corrode, e.g. a protective layer oxide layer might form):
  - Uniform attack.
  - Galvanic corrosion (important).
  - Crevice corrosion (important).
  - Stress corrosion
  - For the welded parts inter-crystalline corrosion.
  - pitting.

- Parts prone to wear must be easily replaceable.
- The crane should be able to be assembled on the site of application.
- Maintainability ex. Parts prone to wear must be easily replaceable.
- Safe crane access with rigid walkways and elevators, especially on the boom to aid maintainability of trolley components.
- Enclosed machinery for worker's safety.
- Minimum energy consumption.
- Lower emissions.
- Anti-sway reeving.

4.3 Dimensional Requirements

Dimensional requirements are visualized in Figure 2, the dimensions are obtained from

- The crane should have a gantry span (A) of 20 to 40 meters.
- The crane should have a maximum outreach (B) of 45 meters.
- The crane should have a back reach (C) of 10 to 30 meters.
- The crane should have a maximum lift height (D) of 40 meters.
- The crane should have a clearance under the sill beam (E) of 10 to 20 meters.
- The crane should have a travel wheel gauge (F) of 20 to 30 meters.
- The crane should have a distance from wharf to mast top of 70 to 80 meters.

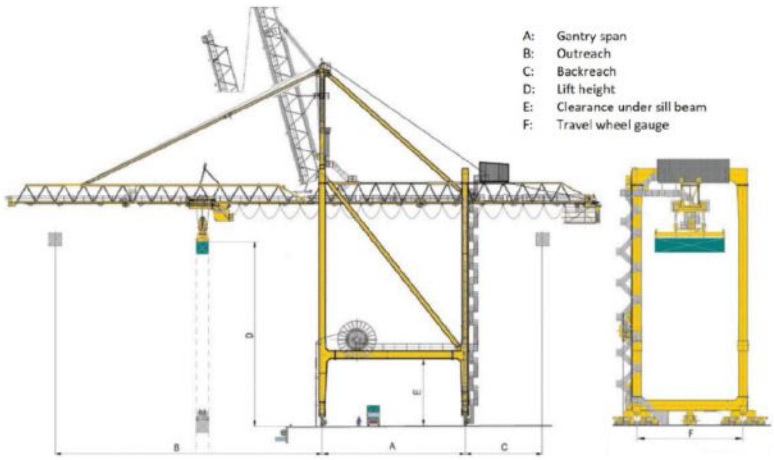


Figure 2: A crane with dimensions

4.4 Functions

In this part of the report, different functions of an STS-crane will be analyzed. This is done by first writing the function down, writing down the necessary parts to fulfill this function, and lastly write down the function of the given part.

To lift containers of 50 tons.

- To accelerate to a hoisting speed of 1.5 to 2 m/s.
  - A type of gearbox.
    - To transmit power.
  - A type of drive system.
    - To provide power.
  - A type of motor.
- To maintain a hoisting speed of 1.5 to 2 m/s.
  - A type of gearbox.
    - To transmit power.
  - A type of drive system.
    - To provide power.
  - A type of motor.

To move containers of 50 tons in horizontal directions once lifted.

- To accelerate to a trolley speed of 3 to 3.5 m/s.
  - A type of gearbox.
    - To transmit power.
  - A type of drive system.
    - To provide power.
  - A type of motor.
- To maintain a trolley speed of 3 to 3.5 m/s.
  - A type of gearbox.
    - To transmit power.
  - A type of drive system.
    - To provide power.
  - A type of motor.

To support the 50 tons of load.

- Different boom designs.
  - Types of frame structures.

To decelerate the spreader/boom.

- Rim brakes.
- Drum brakes.

- Disk brakes.
- Regenerative breaking system.

To prevent the boom from rotating more than 90 degrees.
To lift the spreader using the powered pulley.

- Cable

To lift the boom using the powered pulley.

- Cable

To connect one half of the boom to the other half such that only one rotational DOF remains.

- Pin with bearings.
- To connect the boom to a shaft which is mounted on the frame by bearings or connect the boom to a shaft which is mounted on the other part of the boom.

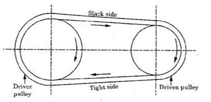
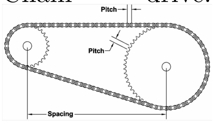
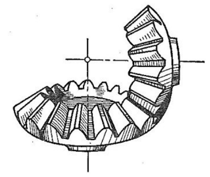
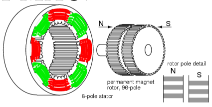
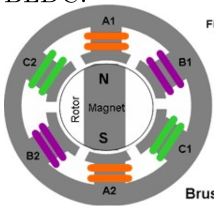
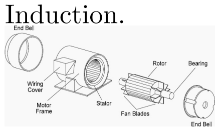
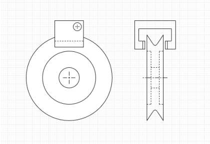
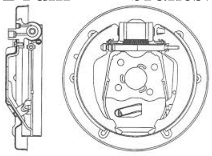
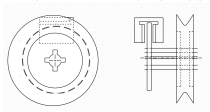
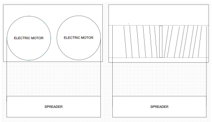
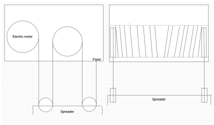
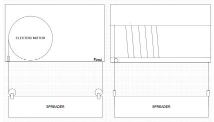
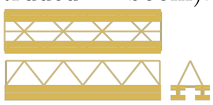
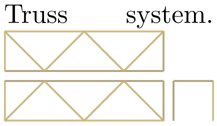
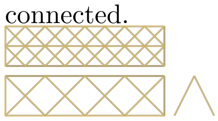
To lift the boom fast as possible. No specific boom lifting speed/acceleration is specified. Time is money, so fast lifting would be preferred.

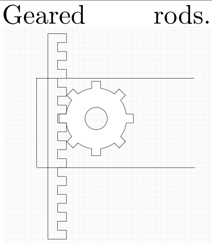
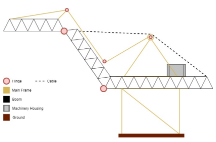
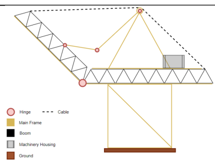
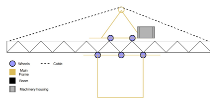
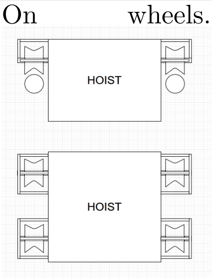
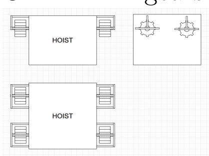
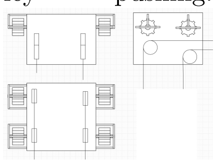
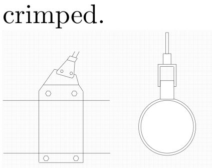
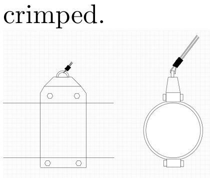
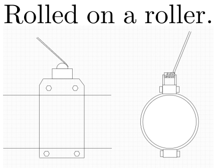
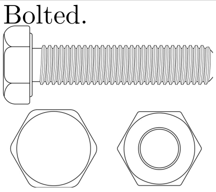
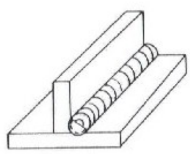
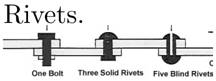
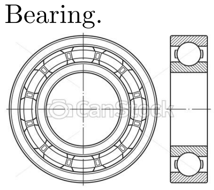
- To accelerate the boom.
  - A type of gearbox.
    * To transmit power.
  - A type of drive system.
    * To provide power.
  - A type of motor.
- To maintain the maximum speed of the boom.
  - A type of gearbox.
    * To transmit power.
  - A type of drive system.
    * To provide power.
  - A type of motor.
- To mount the trolley.
  - Rails, gears.
- To mount the cables.

To connect all elements.

- Bolts.
- Welds.
- Bearings.
- Shafts.
- Pulleys.

4.5 Morphological Diagram

To transmit power.	Belt drive. 	Chain drive. 	Shaft drive. 	
To provide power.	PMAC. 	BLDC. 	Induction. 	
To Accelerate/ maintain a high velocity.	1 Gear gearbox.	2 Gear gearbox.	3 Gear gearbox.	
Decelerate.	Rim brakes. 	Drum brakes. 	Disk brakes. 	Regenerative breaking system.
Lifting the load.	Single pulley on both sides. 	Two pulleys on both sides. 	Single pulley single motor. 	
To support the 50 tons of load (boom designs).	Solid design (extruded boom). 	Truss system. 	Truss system diagonally connected. 	

To lift the spreader using the powered pulley.	Cable.	Geared rods. 		
To lift the boom using the powered pulley.	Cable.	Geared rod.		
To connect one half of the boom to the other half such that only one rotational DOF remains.				
To mount the trolley to the boom.	On wheels. 	On gears. 	Hoist on the frame trolley pushing. 	
To mount the cables to the boom.	Bolted and crimped. 	Looped and crimped. 	Rolled on a roller. 	
To connect all elements.	Bolted. 	Welded. 	Rivets. 	Bearing. 

5 Parts

5.1 Different types of driving systems

5.1.1 Chain drive

A Chain drive has three components: A chain and two sprockets. The teeth of the sprocket fit into the holes of the chain. The two sprockets can have different size. A ratio can be chosen either for high acceleration or for maintaining high speed. The chain can be used to connect the outgoing shaft of the gearbox with the pulley of the hoist/trolley/boom.

Advantages:
Chain drives are suitable for higher torque applications, maintenance of chains is easier than maintenance of belts, since chains are divisible. Chain drives can handle higher temperatures than belts. Shaft alignment for chain drives is less critical than for shaft drives.

Disadvantages:
Chain drives have high maintenance sensitivity, they need to be lubricated always. The bearings experience unwanted forces. Chain drives are noisy and chain drives experience the polygon effect.

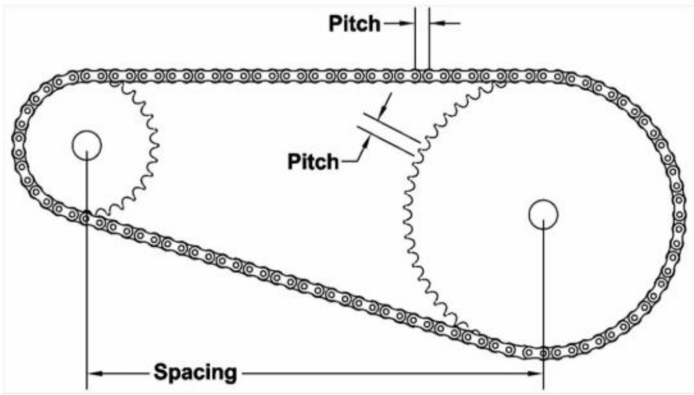


Figure 3: Chain drive

5.1.2 Synchronous belt drive

A belt drive has three components: A belt and two sheaves. One sheave can be fixed to the pulley of the hoist/trolley/boom and the other sheave can be connected to the outgoing shaft of the gearbox.

A synchronous belt is a flexible belt with teeth moulded onto its inner surface. Synchronous belts have matching toothed pulleys. Synchronous belts are applied in cases where slip must be avoided, powering applications for example. This is why synchronous belts could be used as a drive system for the hoist/trolley/boom.

Advantages:

Synchronous belts are a low-cost solution. Shaft alignment is less critical than it is for chain drives and shaft drives. They require little maintenance. A belt drive is smoother and quieter than a chain drive. Belt drives can last for a very long time. Slip is avoided in synchronous belts. Belt drives have a higher transmission efficiency than shaft drives.

Disadvantages:
Belt drives are less efficient than chain drives, and thus there is more power loss in a belt drive than in a chain drive. Advancements in belt technology, like teethed belts, have alleviated some of these problems, but in general chains are more efficient.

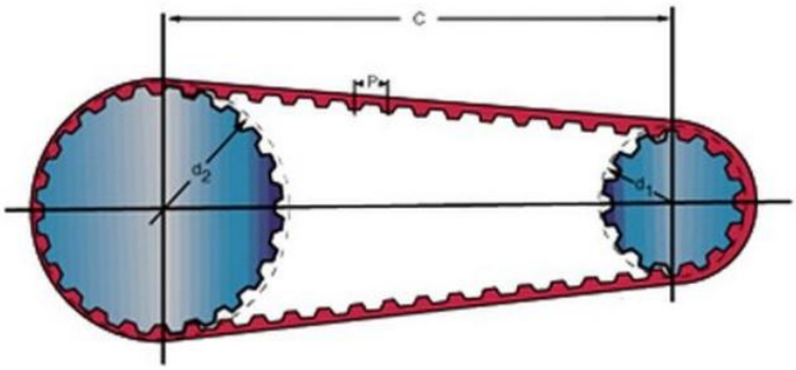


Figure 4: Belt Drive

5.1.3 Shaft system

A shaft system has three components: A shaft with spiral bevel gears at both ends and a spiral bevel gear attached to the shaft of the pulley of the hoist/trolley/boom and a spiral bevel gear attached to the outgoing shaft of the gearbox. The advantages of using this kind of transmission is that it requires little maintenance. It also increases the stiffness of the connection between the pulley of the hoist/trolley/boom and the gearbox. It acts as a stressed member, so it alleviates part of the loads off of connection between the two. The disadvantages of this transmission are a lower efficiency and the danger of a lock up if the down shift does not match speed of the hoist/trolley.

Advantages:
Shaft drives are very reliable, they are very compact, they can handle high torque and they have synchronized movements.

Disadvantages:
Shaft drives are expensive, they are really noisy, they need accurate shaft alignment and they need to be lubricated.

5.2 3 Type's of gearboxes

5.2.1 One gear gearbox

Since only one gear is used in this concept, it is important that the one gear is sufficient for both acceleration and top speed. It costs valuable time if the spreader takes forever to reach its top speed.

5.2.2 Two gear gearbox

Since this gearbox has two gears, one will be used to achieve a high acceleration, while the other will be used to achieve a high speed. The gear for acceleration has a high torque and lower rpm, because a higher force is required when increasing speed compared to maintaining a high speed. This is an advantage compared to the one gear gearbox. The disadvantages of using a two gear gearbox is that there will be more wear because of the coupling. Also a two gear gearbox is less efficient than a one gear gearbox.

5.2.3 Three gear gearbox

For this concept a three-geared gearbox is used. The advantage over a two-geared gearbox is that there is also a gear for 'middle' speeds. This will become more beneficial when loading the container on the truck, where the speed is lower and precision is needed, so no high torque and also no high speed are needed. The downside of using more gears is again loss of efficiency and an increase in wear.

5.3 Different Type's of elector motors

5.3.1 PMAC

For this concept a permanent magnet AC (PMAC) motor is chosen. This motor uses AC power to rotate its rotor, which has permanent magnets embedded into it. When the motor is powered on, an internal magnetic field is generated in the stator, which is filled with densely packed copper coils. This generated magnetic field causes the rotor to rotate. The benefit of a PMAC motor is that it has a high power density and the possibility of having a high speed output at high efficiency and a high torque output at low rpm. This high torque will help the STS crane to overcome the containers gravity, and to be efficient at the higher speeds. Higher efficiency at higher speeds means less energy bills to pay. A negative of this motor would be its price, since it is relatively high.

5.3.2 BLDC motor

It is decided to use a brushless DC motor for this concept. A BLDC (brushless direct current) motor is essentially the same as a permanent magnet AC motor. The BLDC motor is an improvement of the brushed DC motor. The biggest disadvantages of brushed DC motors is that the brushes wear down over time and they create a lot of resistance. The placement of these brushes in a brushed DC motor can be seen in Figure 5. The solution to this problem was to have the magnets turn instead of the coils. In order to allow it to turn at a lower resistance and therefore a higher efficiency it was necessary to use AC power. The name for the replacement of the brushed DC motor would still be called brushless DC motor even though the actual motor is a permanent magnet AC motor.

Brushless DC motors experience drops in torque called ripple. This might be a problem, further research needs to be done.

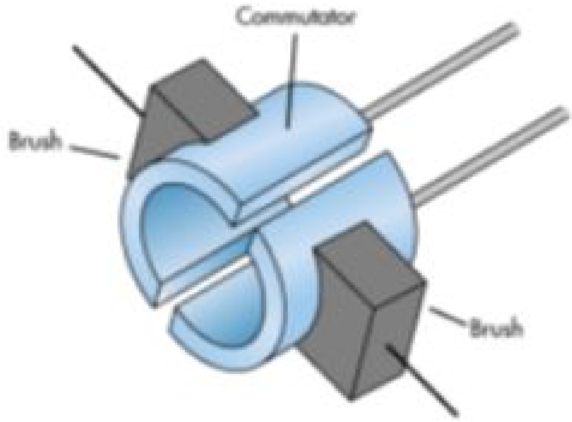


Figure 5: A brushed DC motor.

5.3.3 AC 3 phase induction motor

The AC 3 phase induction motor has a stator and a rotor. The stator is the non moving part located at the outside ring and the rotor is the moving part located on the inside cylinder. When connected to alternating current, the stator produces a rotating magnetic field. A wire that carries current, produces a magnetic field around it. When you supply 3 phase alternating current to 3 coils laying next to each other, the magnitude of the formed magnetic field of all coils can be determined by the sum of the magnitude of the individual magnetic fields of the individual coils. Due to the arrangement of the coils and the fact that the alternating current is not supplied in phase with each other, the sum of the individual magnetic fields of the individual coils will have a constant magnitude but a different direction in time. This results in a rotating magnetic field. When you now put a closed cycle of conducting wire inside this stator with its rotating magnetic field something special happens. According to Faraday's law, when a closed cycle of conducting wire is exposed to a rotating magnetic field, an electromagnetic field will be induced. This electromagnetic field will produce a current inside the conductor. According to Lorentz' law, when a conducting loop carrying a current is put inside a rotating magnetic field, it will start rotating along with the rotating magnetic Field.

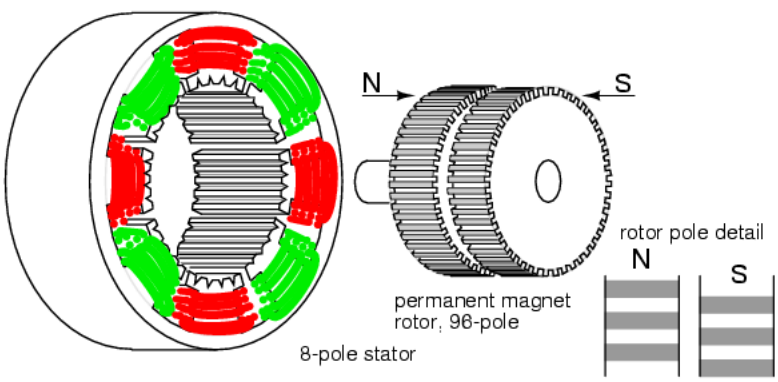


Figure 6: Permanent magnet.

5.4 Motor design:

We will probably need a motor that has its magnets on the inside of the rotor like in the left part of the figure if we use a permanent magnet motor, since the increased diameter provides a mechanical advantages that causes it to have more torque at lower rpm. This type of motor is called ERPM (externally rotating permanent magnet), the type on the right is called IR (internally rotating).

However there are great difficulties with cooling an ERPM motor, since there is no good thermal pathway to the housing as in the IR, since the stator of an ERPM is enclosed by the rotor.

5.5 Motor choice:

3 motors should be chosen for the detailed design. One for the boom, one for the trolley and one for the hoist.

5.5.1 Motor consideration

A torque curve of a certain motor can be used to compare the torque characteristics of the motor with the needs of the application. A torque curve is depicted in figure 7 . Locked rotor torque (A) is produced when the load caused by the container needs to be accelerated from zero velocity. At this point the rotor of the motor is not yet turning. The locked-rotor torque must be higher then the load torque to accelerate the load. Pull-up torque (B) is produced as the load accelerates and the motor speed increases. If the load exceeds the pull-up torque the motor will stall. The maximum torque that the motor can produce in the operating speed range is the breakdown or pull-out torque (C). Without overheating, full-load is the maximum torque that the motor can sustain in continuous operation (D). With no load the maximum synchronous speed (E) is delivered.

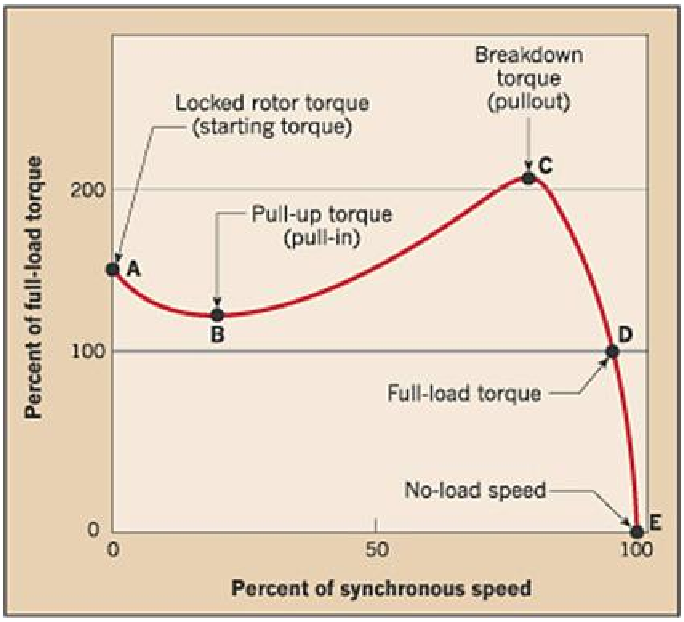


Figure 7: Torque curve

At the starting phase of the motor it is important to look at the moment of inertia of the load. The higher the inertia at the starting phase the higher the heat generated by the motor. All motors will be connected to a variable speed drive of two gears, as motors that are connected to a variable speed drive have less thermal, electrical and mechanical stresses.

5.5.2 Undersized and oversized motors:

The motor has to fit the torque requirements as under sizing the motor will cause overheating, resulting in a shorter lifetime of the motor. Conversely over sizing the motor would lead to a waste of money. You are buying heaver more expensive equipment then you need as well as increasing the running costs as the duty point will be to low on the motor efficiency curve. An oversized motor has low efficiency, as can be seen from figure 8.

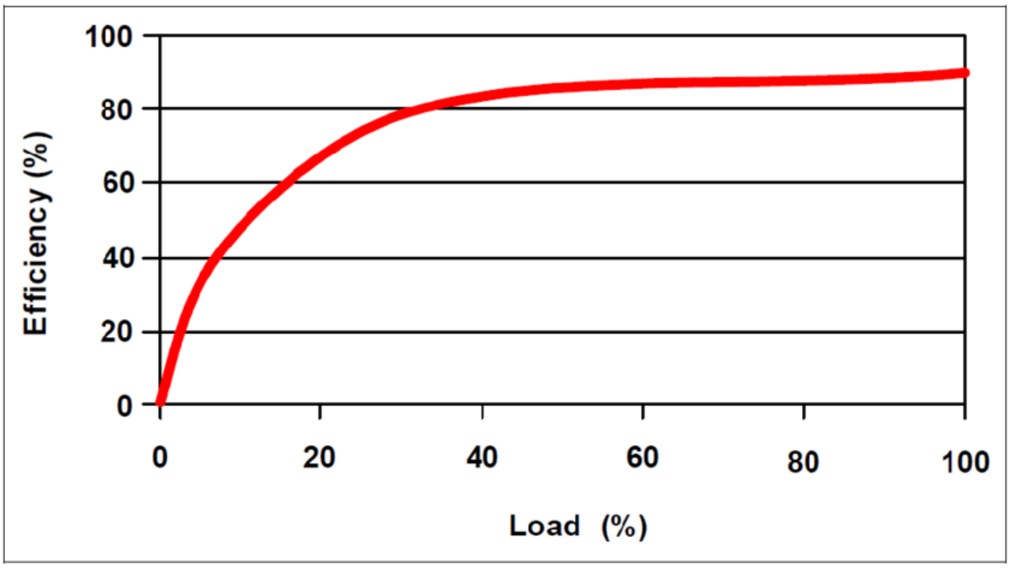


Figure 8: Efficiency against load

Before the required motor power can be determined, the speed and load torque characteristics for the boom, trolley and hoist must be determined.

$$Power(KW) = \frac{Speed(rpm) * Torque(NM)}{9550} \quad (1)$$

It can be seen that at a constant torque the power is proportional to the speed. Selecting a motor with a suitable output rating remains.

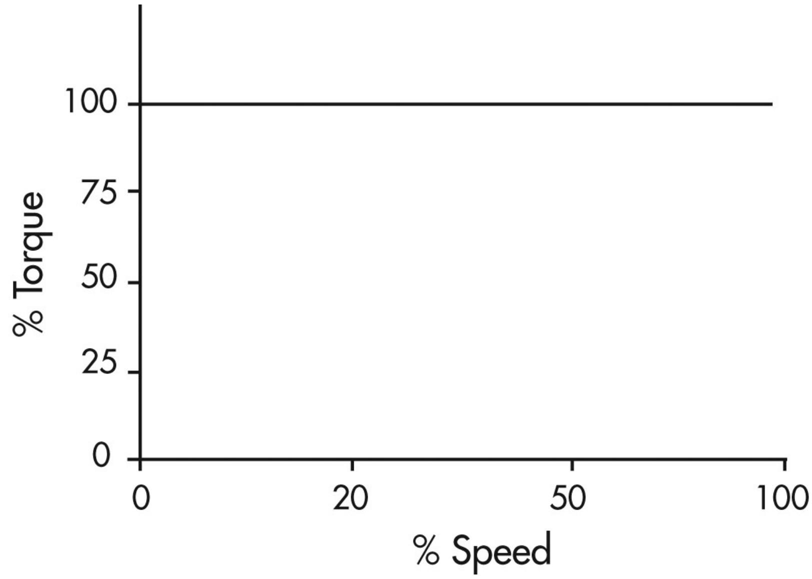


Figure 9: constant torque diagram

The rpm of single speed induction motors depends on the frequency of the mains electricity and the number of stator poles. In Europe the mains electricity has a frequency of 50 Hz and thus the motor will be chosen based on a frequency of 50 Hz. A synchronous motor's speed in rotations per minute for different amounts of poles at 50 Hz are given in table 1.
The speed of the motor when running at full-load is typically 3-4% lower due to slip.

Amount of poles	Synchronous speed [r/min] for 50 Hz	Synchronous speed [r/min] for 50 Hz under full load
2	3000	2880
4	1500	1440
6	1000	960
8	750	720
16	375	360

Table 1: speed in rotations per minute for different amounts of poles at 50 Hz

5.5.3 Duty cycle:

An important design criterium for choosing a motor is the duty cycle. The IEC60034-1 standard shows 10 duty types, listed in table 2.

IEC60034-1 Duty types	
S1	Continuous running duty
S2	Short-time duty
S3	Intermittent duty
S4	Intermittent duty with starting duty
S5	Intermittent duty with starting electrical braking
S6	Continuous operation periodic duty
S7	Continuous operation periodic duty with electrical braking
S8	Continuous operation periodic duty with related load speed changes
S9	Duty with non-periodic load and speed variations
S10	Duty with discrete constant loads and speeds

Table 2: Duty types

The duty cycle of both hoist and trolley motor is S6 as it has sequential identical cycles of running with constant load and running with no load without any rest periods.

The duty cycle of the boom motor is S2 since the motor works at a constant load, but not long enough to reach temperature equilibrium and the rest periods are long enough for the motor to reach ambient temperature (¿60min).

Since the induction motors require reactive power from the network, synchronous compensators or static capacitors should be installed on the STS crane to prevent fines for taking too much reactive power from the network.

Since the motors will be used outside in a harbour, where the motors are likely to get wet, the corrosion protection and the enclosure type of the motors need to be considered. IP standards are used to indicate enclosure protection. The hoist, trolley and boom motor will need an IP 65 enclosure protection, since it is dust tight and resistant to water jets, as stated in table 3.

IP XX			
0	No protection	0	No protection
1	Solid objects greater than 50 mm	1	Dripping water
2	Solid objects greater than 12 mm	2	Dripping water when tilted above 15 degrees
3	Solid objects greater than 2.5 mm	3	Spraying water
4	Solid objects greater than 1.0 mm	4	Splashing water
5	Dust protected	5	Water jets
6	Dust-tight	6	Heavy seas
-	-	7	Temporary immersion
-	-	8	Continuous immersion

Table 3: Types of protection

5.5.4 Cooling methods:

A cooling method for all three motors needs to be considered. Cooling methods are defined by the International Cooling or IC codes. The codes start with the cooling medium, which is usually air, but sometimes water or other fluids. A typical code would look like this:

IC 4(A) 1 (A) 1

In which 4 indicates the circuit arrangement, (A) stands for the primary coolant which is hidden if air is used, 1 stands for the primary coolant circulation method and the second (A) stands for the secondary coolant and the second 1 stands for the secondary circulation method.

The combination IC 411 stands for "totally enclosed, frame surface cooled, Self-circulation of both the primary and secondary cooling medium (air) by means of a shaft-mounted fan".

For all the applications we will chose an IC411 Totally Enclosed Fan-Cooled motor (TEFC motor) since this it the most commonly used motor in ordinary industrial applications today. TEFC motors are more expensive than open motors but they offer protection against dirt, weather and moisture. These motors are cooled form the outside, and high moisture salt water dirty air that's available at the harbours do not interfere with the insides of the motor.

So now we know the requirements of the application; the torque, speed, power, and electrical characteristics of the motor we want, we can narrow down our selection by turning to the international standards that govern the dimensions, efficiency and performance of electric motors. The main international standards are IEC, the International Electrotechnical Commission, and NEMA, National Electrical Manufacturers Association. However, in addition to the main standards there can be national or industry specific standards and even customer specifications that affect the motor selection. Further research can be done on this, but this is out of the scope of this report.

6 Concept

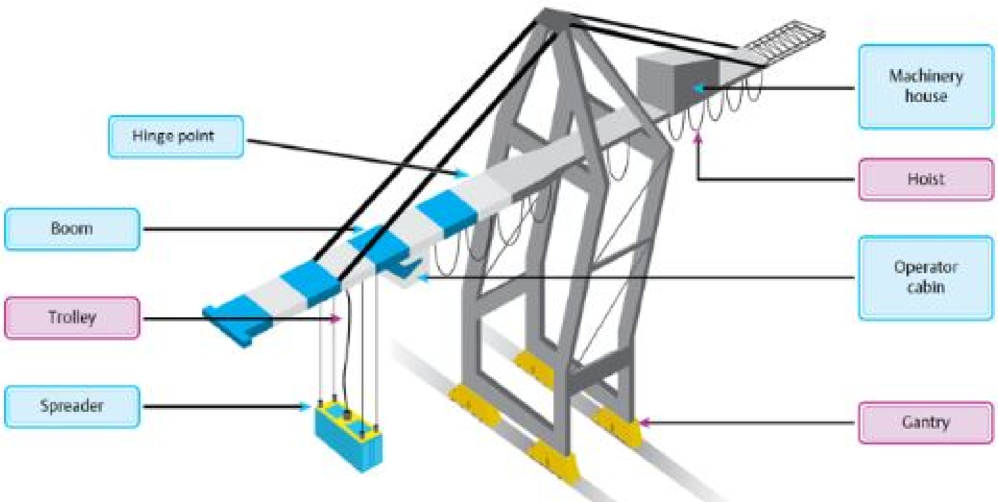


Figure 10: An example of the parts of a ship to shore crane

In order to come up with a viable design it is best to construct a morphological diagram of different parts in the crane. In this study, the hoist, boom and trolley should all be designed and evaluated in order to construct a morphological diagram. First of all, the functions of these different parts should be clear.

6.1 Hoist

- Gear ratio, drums diameter and motor strength can change.
- The hoist mechanism lowers and raises the spreader which is connected to the container. The hoist is attached to the back of the crane as it helps with the weight distribution.

6.1.1 Possible concepts

1. pulley on the hook, motor on the crane
2. pulleys on the hook, motor on the crane

6.2 Boom

The boom is used as an extended rail for the trolley to move along and traverse over the ship. This boom can also be lifted and put upright to allow the ship to clear under the boom when it docks or leaves. Extra support is provided by the steel boom supports on top of the crane, which can be seen in figure 10. The problem that is to overcome lies in the hinge points of the boom, because, when the boom is lowered, the rails on the boom, at the hinge point, should be tight enough to allow the trolley to move over it. This means that the rail is not made out of one part.

6.2.1 Functions:

- Allow the trolley to traverse over the beam.
- Allow the boom to store onto/into the crane and allow the vessels to move underneath it.
- Support/ house the hoist
- Allow for counterweight to be placed

6.2.2 Possible concepts

The concept involves a large solid boom without a hinge, which can be extended and retracted to allow the vessels to traverse underneath the crane. Extra supports can be placed as cables, attached to one end of the boom, going over the mast top, and attaching it to the other side of the boom, as given in figure 11. The counterweight and the hoisting mechanism can be attached at the back of the boom, because the trolley will not travel this far down the boom.

Some wheels that hold the boom in place are powered and are thus capable of moving the beam back and forth. To lock the beam in place brakes on the wheels themselves can be used. In figure 12 a cross-section of the boom is provided. As can be seen, multiple extruded profiles are used to build to boom. The C-shaped extruded profiles on the top of the boom are meant to provide support for the wheels on the main-frame. Extra supporting beams are added in a cross-shape to avoid too much deflection of the boom.

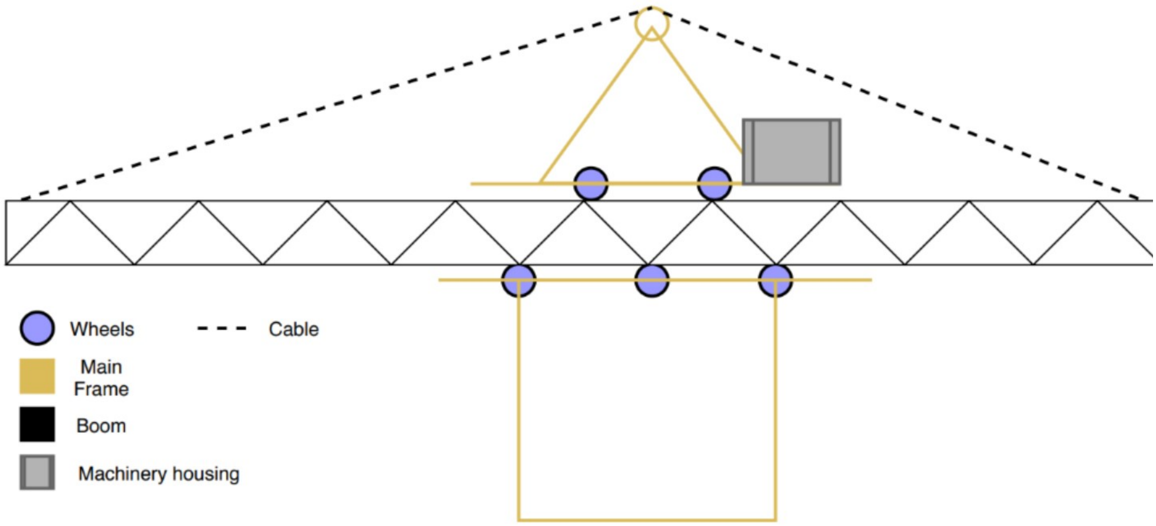


Figure 11: An overview sketch of the crane

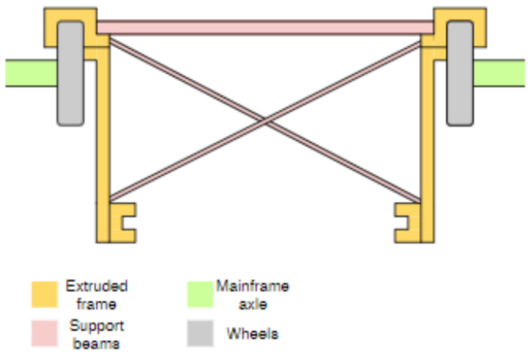


Figure 12: An section view of the beam of the crane

Extra wheels can be added on top of the boom to avoid the possibility of the boom pitching over.

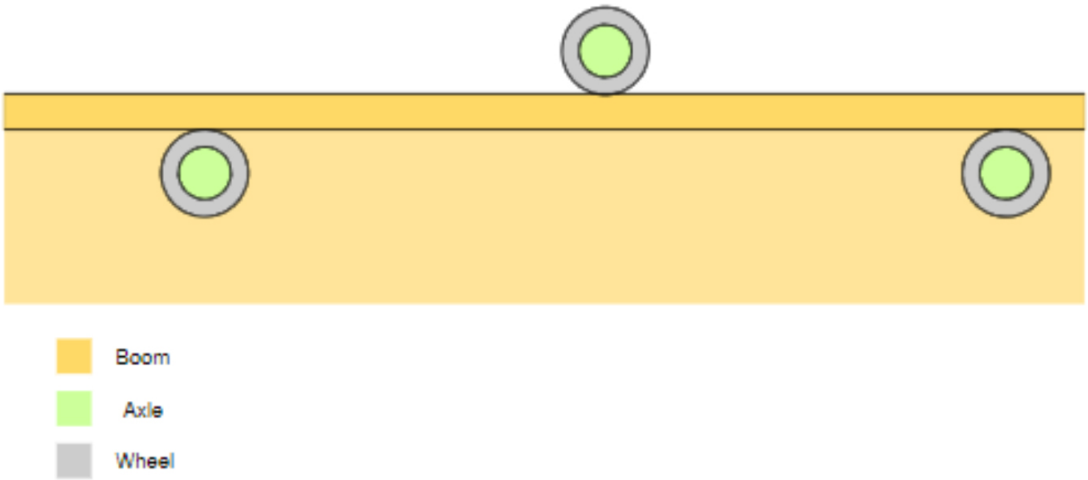


Figure 13: close section sketch

6.2.3 Boom lifting

This is a basic concept that operates with one hinge to allow the part of the boom, that supports the hoist, to be lifted so the ships can navigate. This lifting procedure is done using cables attached to counterweight at the other end of the boom. This can be seen in figure 14.

Since, booms are subject to high amounts of loads, which can cause the structure to bend and eventually fail, it's structure can be strengthened using support beams.

The lifted part of the boom is also held by a support beam in addition to the cables, which is referred to as a fore stay. This is due to the weight of the boom, which cannot be held by the cables independently during working conditions.

The fore stay is connected by hinges and is divided by a hinge in the middle to allow folding when the boom is lifted.

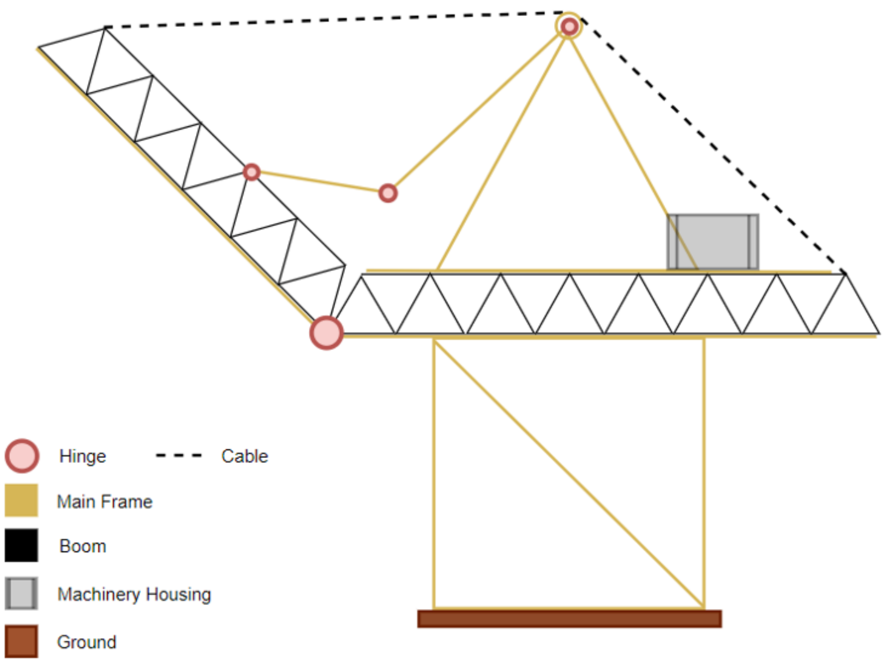


Figure 14: close section sketch

6.2.4 Articulated Boom

This concept, also referred to as the 'goose-neck boom,' involves the use of two hinges, with the second hinge splitting the boom into two sections, and allowing for the top section of the boom to remain horizontal. The purpose of this feature is to decrease the overall height of the structure when height limitations are in place, which is most likely applicable when the crane is in close proximity to an airport.

Supporting cables are attached to the boom. The bottom section of the boom is lifted, in a similar manner to a standard boom, with the main difference being that the top section remains locked in a horizontal position, as seen in figure 15. It is held in this position via the use of supporting beams, or "fore stays," that are fixated to the top section of the beam (not connected by hinges).
The combination of an inner and outer fore stay (two fore stays) can also be utilized, and is a commonly adopted means of support for the boom.

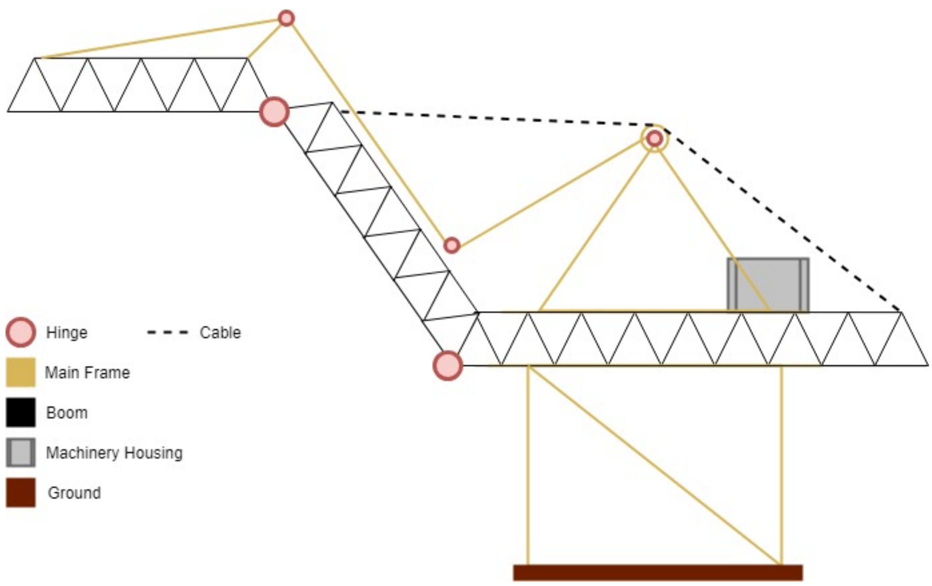


Figure 15: close section sketch

6.3 Trolley

Electric motor strength and gear ratio as well as the diameter of the drums used. The trolley may be made to work with gears. Make notches on the boom and have a gear inside the trolley. The trolley allows the movement of the spreader along the boom. It uses drums an electric motor and cables to operate. The trolley and the hoist are connected to the spreader; thus, they work together.

6.3.1 Possible concepts:

- Different Trolley rails are possible
- Trolley has wheels and a cable pulls it. (motor put on the crane)
- Powered trolley (motor on top of the trolley) Notches on the boom and a gear in the trolley.

For the rails it's important that the wheels of the trolley really less contact surface with the rails is obtained to avoid friction as much as possible.

6.3.2 Movement Trolley

One motor at the trolley and one motor at the back of the boom.
The motor on the back of the boom rails the trolley in like a fishing rod. While this happens the trolley should be able to move freely over the rails on the boom
When the trolley need to go to the front of the boom, the motor on the back of the boom should be of, and the powered pulley on the back of the boom should be able to move freely. The motor on the trolley will be powered, and this will make the trolley move along the boom.
There should be some kind of locking system which prevents the trolley from moving once it is at the desired location.

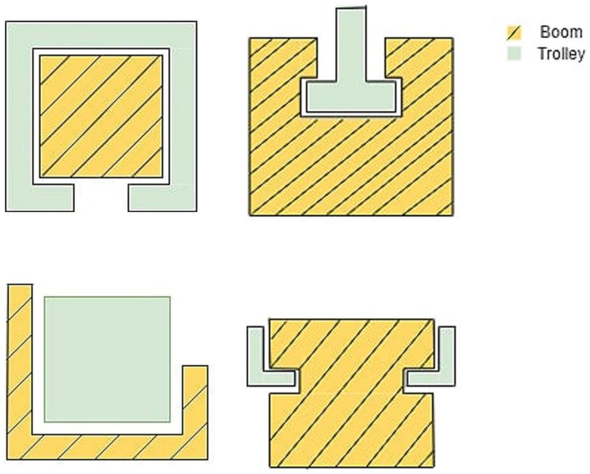


Figure 16: 4 different type's of trolley to beam connection

6.4 Concepts

6.4.1 Time Saving (Maintainability) Concept

Belt drive
A belt drive requires no lubrication and is not made out of metals therefore it is corrosion proof. The belt itself can also be produced to the dimensions required by another firm.

Brushless DC electric motor
Brushless DC motors are highly efficient and allow the direction of the spin to be reversed. Brushless DC motor have a longer lifetime, because unlike the brushed dc motor there are not component in contact which can experience wear due to rubbing, therefore it is having a longer lifespan compared to brushed DC motors and induction motors.

A 3-gear gearbox. The gear needed for the optimum rpm can be chosen for a given torque in order to achieve maximum trolley speed. Stress experienced by the cogs and the maintenance period can be extended.

Disc Brakes
Pads are durable, easy to change and the brake maintenance does not interfere with the pulley directly.

Single pulley single motor.
The least number of components used. Additionally, the single pulley ingle motor design does not make use of pulleys which means the hoisting speed is maximum.

Truss system
A truss system is lighter than a solid boom design, gets effected by the wind much less as well. The system can be assembled on the field as the truss system is made up of smaller pieces of metal.

Cables to lift spreader
Cables require less maintenance than geared rods, can be purchased from another firm and are easier to produce, transfer and install than geared rods. They are also cheaper and are easier to maintain, weight less.

Cables to lift the boom
Same reason as above.

Drawer boom
The drawer boom is quicker to 'pack' compared to a hinged boom design.

Bolted cables to the boom
This system uses a crimper and a looped metal piece connected to the boom. The crimper is also used in the bolted and crimped system yet that system requires the use of bolts to the connected to a special piece on the boom. Looped and crimped does not. It is easy to install and manufacture compared to rolled due to the number of parts needed. No rollers are used, just a simple loop of metal is enough.

Welding
No need for bolt holes and measurements, parts can be welded on the field. Quicker to produce than bolts.

6.4.2 Cost Efficient (Cheap) Concept

Belt drive
Among other kinds of drives, the belt drive has a less initial cost than a chain drive. The belt drive uses pulleys instead of the gears seen in a chain drive and shaft drive, which is considerably cheaper, as the manufacturing of the pulley does not require the accuracy and the compliance to tolerances that the gear would generally require. The belt is also sold at a lower cost that a chain.

Induction motor
In comparison to other selected motors, the induction motor does not require brushes or commutator since it is already an AC motor. This would see a cost advantage.

One gear gearbox
It is assumed that the dimensions of the gears used in all three gear boxes will be the same. Therefore, the cost of this gear box will prove to be the cheapest in comparison to its counterparts. This is simply because only one gear is manufacture, as only one gear is utilized.

Rim brakes
Across all the considered braking systems, rim brakes are the simplest and the cheapest, but consequently require regular maintenance.

Single pulley single motor
Among its counterparts, this method of lifting the load is the lowest in cost. It uses no pulley system and also utilizes the lowest number of motors possible, hence is the cheapest.

Truss system
In terms of the boom design, the truss system will be used for cost efficiency. The lattice structure of the boom consists of multiple individual bars which, in spite of the number of bars, will be cheaper than a twin-girder boom with cross bracing, as it uses to large, solid I-beams, and will therefore require more material. On this basis, the truss system will be cheaper as a result of its sparse use of material.

Cables to lift spreader
A cable is one component, and is made of a material that boasts a relatively low cost. Its alternative is the geared rod which consists of more than one component and, much like the drives, is more expensive to produce because of the strict tolerances required for the production of the gear and the teethed rod itself. Therefore, the cable is cheaper.

Cables to lift boom
The explanation of this choice coincides with the explanation above.

One hinged boom
This is the cheapest option, as the truss system of a one hinged boom only consists of two separate section, separated by the hinge itself. In comparison, the articulated boom consists of three divisions of the boom, using two hinges, and requiring extra mechanical components that maintain the horizontal position of the top section of the boom. The drawer boom design has no hinges, but does require a set of wheels and an extra supporting structure to secure the boom during transverse. Since the one hinged boom does not require these considerations, it is the cheapest option.

Hoist on the frame trolley
This design would fuse the hoist and the trolley into one individual component, which would reduce its cost.

Cables mounted to the boom using a bolted and crimped connection
The difference in costs here is assumed to be insignificant, so the most optimum choice was made.

Bolts
This is the cheapest means of connecting all elements, which can be bought with standard price. Bearings are simply more expensive, and upon assembly, bolts and nuts are not dependent on equipment, unlike rivets and welding.

6.4.3 Functionality Concept

Chain drive
A chain drive is easy to install and easy to maintain as changing a chain can be done with a link breaker. If lubricated the chain lasts as long as belts and shafts. Chain is better in a corrosive environment than a shaft because a chain would still work if rusted yet it can be fatal for shafts. This is due to the way chains transmit energy, the parts on the cogs all experience a force, but on a shaft system the number of teeth experienced a force is much less. The corrosion problem for the chain can be solved using lubrication or by using a cover for the chain to be housed.

Disc brakes
Disc brakes are easy to maintain. The brake is separated from the pulley. Disc brakes use a caliper that allow the change of brake pads to be done with ease compared to rim or drum brakes. In the case of a disc failure the disc can also be changed easier than the pulley for the rim brake and the pulley with the drum in the case of the drum brake. Disc brakes also work under various conditions. Drum brakes may experience problems with overrating at the maximum operating temperature given.

Two pulleys on both sides
Using two pulleys lowers the weight on a single cable by a factor of 4. Using this system on both sides lowers the weight experienced by the cables by a factor of 8. Although the maximum weight to carry is 50 tones, the cables experience 6.25 tones. This rough calculation excludes the Wight of the spreader.

Truss design
The truss design lowers the weight of the crane; it is easier to transport when compared with a solid design. Parts of the truss system can be shipped to the location and be built on the field. A truss system gets affected by the wind much less than a solid design as its cross-sectional area is much smaller.

Cable
Can be bought from other firms and be installed easily compared to geared rods. The rods also need to be custom made for the cranes which increases the cost and complicates the manufacturing process. Cables are manufactured continuously by many firms.

Single hinge
Less moving parts on the boom and therefore less complication in the manufacturing. The tolerances are likely to be higher for the construction of the boom compared to the hinges. Lowering

the number of hinges ease the manufacturing system.

On wheels
Wheels can be bought from an outside firm and are easy to manufacture compared to gears, as wheels can be turned. The gears also require the boom to have a section notched where the gears can fit. With wheels the boom just needs to have a cylindrical section for the wheels to sit on.

Bolted and crimped
Securing the cable to a plate can be done using a crimper and securing that to the boom can be done using bolts. This system is superior to looped because looping the cable around a metal piece puts stress locally and wears down a single spot on the cable, the spot where the cable touches the loop. It is also superior to the rolled method, because the cable rolled on a roller adds weigh ton the boom due to the length of the cable needed for the roll and the drum the cable is rolled on. Additionally, the cable needs to be rolled on the drum which means the drum needs to spin and be secured. One may argue that this needs to be done only once, yet this is an extra step in securing the cable and is a compilation if the cable needs to eb taken out. Using the bolted and crimped system bolts can be loosened.

Trolley on the wheels, hoist on the frame
Keeping the hoisting mechanism on the main frame lowers the weight on the boom and the weight moving with the trolley. Lowering the trolley weight lowers the wear rate of the wheels and the rails that the wheels sit on. When the trolley moves out towards the end of the boom, the stress on the supports increase. Increasing this weight increases the moment experienced on the hinge and the stress experienced by the boom. Wheels are a better option than gears due to its cost and ease of manufacturing. Wheels can be bought from another firm. Gears on the other hand need to be custom made. Gears also give raise to another problem, the boom needs to have teeth that fits the gears, which would also be custom built. For the wheels, cylindrical rods on both sides is sufficient.

Mixture of bolts and welds as well as bushings

7 Concept Choice

Requirements	Factor (1-3)	Cost effective Concept (1-5)	Functionality Concept (1-5)	Time saving Concept (1-5)
Withstand XX wind	2	4	5	4
Hoisting speed	2	4	3	4
Trolley speed	2	4	4	4
Unloading vessel of various sizes	3	3	4	3
Replace ability of parts	2	5	5	5
Safety of the operator/ workers around during operation	3	3	5	3
Ease of maintenance	3	2	5	4
Resistance to corrosion	2	3	4	2
Maintenance period	1	2	4	2
Ease of operation	2	5	5	5
Resistance to wear due to use	3	2	4	2
Cost of assembly	1	4	4	4
Upgradability	1	5	5	3 (most are welded)
Cost of raw materials	2	2	1	2
Cost of manufacturing	2	4	4	3
Ease of assembly	2	3	3	3
Total:		**53**	**60**	**51**
Total with factor		**110**	**126**	**109**

Table 4: Marking table

7.1 Considerations of requirements

Withstanding $240N/m^2$ **wind:** How much the frame and boom deflect under wind. 5- No major deflection, 1- A lot of deflection.
Hoisting speed: The speed of the containers being lifted and lowered. 5 is the fastest and 1 is the lowest.
Trolley speed: The speed of the trolley moving across the boom. 5 is the highest and 1 is the lowest
Deflection parallel to the gantry: The amount of deformation experienced by the frame parallel to the ground. The maximum available value is 60mm. Minimum deflection is given the score of 5 and maximum deflection is given the score of 1.

Vertical deflection of the boom tip: The displacement of the boom tip when loaded with 50 tonnes and its own weight. 50-ton load is considered as a point load and the weight is considered as a distributed load. Minimum displacement gets the highest score.

Unloading vessels of various sizes: The span of the boom and the frame. Can be measured by length only as the boom or the frame does not rotate to place containers on the sides but just along the boom. Longest boom gets the highest score.

Replace ability of parts: This criterion refers to the ease of taking parts off the crane. For example, welds, they are not reversible like bolts, therefore more welded parts used the lower the score.

Safety of the operator/ workers around: The likeliness for the components to fail. A failure would cause damage to its surrounding therefore it directly relates to safety. This also refers to what could happen in case of a failure. A trolley failure where the only hoisting cable go through is much safer than a trolley failure with electric motors and the hoisting mechanism inside.

Ease of maintenance: Occurrence of ports and compartments designed for easy Maintenance. The skill and number of workers required in order to service parts. A boom that requires its surface to be painted is easier to maintain than a boom which requires amortization, although it unrealistic to anodize the boom it demonstrates the criterion concisely.

Resistance to corrosion: The resistance of the frame and components to different types of corrosion. This is highly relevant tot eh design as the crane will be placed on the port, next to a body of salt water. Salt increases the rate of corrosion. Additionally, the crane will have parts under stress, which increases the rate of corrosion as well. The more resistant the better.

Maintenance period: The time which a maintenance has to repeated. Repainting the boom every 6 months is not a viable option while repainting it every 4 years is acceptable. Greater the period of maintenance the better.

Ease of operation: the skill required to operate the crane.

Resistance to wear due to use: The wear and tear experienced by the components due to expected use. This refers to parts as, the trolley wheels, hoist pulleys, gears and chains in the system, fatigue on the boom. Lower wear is favoured.

Cost of assembly: The price it takes to build up the crane at the port. A pre-assembled crane would have a lower cost.

Upgradability: The availability of replacement parts: If a part for the crane has been custom made, for example the pulley due to the attachment to the axle then it is difficult to replace. More standard parts, dimensions used the higher the score.

Cost of materials: The cost of the raw materials.

The cost of manufacturing process: The price of producing the parts needed for the assembly using the raw materials.

Ease of assembly: the skill and number of workers required to assemble the crane.

7.1.1 Safety

An important factor that should be taken into account is the safety of the design. This is because the (STS) crane is operated manually. It has to be saved for the operator to come into the operator cabin. However, it also has to be safe for the people that works around the crane for example for the Maintenance people that works on the crane when something has to be prepared. A ladder with safety cable along want it fall protection equipment can obtain the safety during climbing the (STS) crane.

7.1.2 Maintainability

This factor is important for the user of the crane, because when it is easy to dissemble parts and it is simple to come near parts have benefits. The crane works almost 24/7, so maintainability cannot take much time. When it is easy to change parts and clean parts, the crane does not have to take out of operation. Besides parts should be replaceable at the harbour and have not to be fully shipped to a workplace. For cleaning all parts have to be fully accessible and this should also be safe to do. For painting and lubricating parts, it is also important parts are easy to asses.

7.1.3 Durability

The durability is important to take into account, this is because most of the (STS) crane will be shipped to the harbour where it has to operate for a quite long time. To give the crane a long life spans the wear and failures of the crane have to be minimized. Especially corrosion is an important factor. This is because of the fact that the (STS) crane operate close to the sea were salty water causes an influence on the corrosion rate. To counteract the corrosion a protective layer can be applied. This layer should be replaced once in a while when the resistance is not sufficient enough anymore.

7.1.4 Functionality

This factor will say how well the crane does its works. The crane has a lot of functions, but the main function is moving container from ship to shore and the opposite way. The crane has to work fast, but still has to be precise, because otherwise the spreader cannot be connected with the container. Therefore, the trolley and hoist speed have to be very fast. Besides it has to be easy for the worker to control the trolley mechanism.

7.1.5 Cost

Additionally the price of the crane should not be too high. The main influences on the price are the manufacturing of the parts, but also the materials and the use of standard parts. When parts of the crane can be produced with easy tactics, this will lower the price. The use of materials which are easy to get and are cheap will also be beneficial for the price. Beside the use of standard parts have benefits for the price, because these parts are very cheap.

7.2 Consideration of grading

The grading of the requirements is based on the importance of the requirements. To take the importance into account a factor between (1-3) is used in which 3 means that the requirement is very important and 1 means that is less important. The requirements are then marked based on the three different concept. A number between (1-5) is used in which 5 means that the requirement fits well within the concept design. And 1 means that the requirement will not be met within that concept. When looking at the total amount of points in which the importance factor is also taken into account, it seems that the functionality Concept satisfies the most important requirements.

8 Materialization

The structural integrity of any construction is heavily dependent on the materials that are selected. This must be done by taking into account the working conditions and working principle of each component. For this crane, materials were assigned to the frame, the boom, and the individual components of the lifting mechanism.

For the three components, the assignment of materials depends primarily on online research. This is to ensure that only the most relevant materials are chosen. When additional limits need to be considered, CES EduPack will be used in order to narrow down the material candidates. Examples of limits include the ability of a material to be welded or cold worked, which are specific limits that some components of the design will require. Also, CES is used to ensure that the material is resistant to corrosion due to humidity, as a result of the cranes close proximity to the sea.

Additionally, when CES is used, the materials will be charted based on a simple performance index that minimizes both price per kilogram and density, unless stated otherwise. This is done in an effort to isolate 'exotic' materials that are available at characteristically high prices.

For each selected material the key properties are listed in a table.

8.1 Frame

No sources were found that provide detailed information on materials used for the frame, besides that the I-beams are conventionally constructed of structural steel. This implies steel with a carbon percentage of 0.3 should be used. The frame of the construction consists of individual I-beams that will be connected using nuts and bolts. This implies that the chosen material does not need to be weldable. Furthermore, the manufacturing method for the I-beams will be cold extrusion. During cold extrusion the metal is cold worked, improving strength. But to be able to use this method the material needs to have an acceptable ability to be cold formed. So, the relevant limits are as follows:

Metal Cold Forming: Excellent

Base material: C (Carbon), Fe (Iron)

C (Carbon): $< 0.3\%$

The frame of the crane is loaded, and should be constructed of a material that can withstand these loads. To account for this, a simple performance index is used for the frame, which should be minimized:

$$PI = \frac{Density}{Yieldstrength}$$

Price is neglected here to ensure the strongest material is chosen. When applied in CES, the results are as shown in figure 17, with the index itself on the y-axis.
As seen, the highest scoring material the low alloy steel. CES provides further information, stating that the material is used regularly for 'general construction.' Therefore, it is confirmed that the material is applicable and available in sufficient quantity. The set limits have also confirmed its ability to shaped. No information is given by CES regarding a resistance to corrosion. However, the alloy does contain 0.3 - 0.5% chromium, which is known to improve resistance to such corrosion. Key properties of this material are provided in table 5.

Key Properties	**Minimum**	**Maximum**
Young's Modulus (GPa)	206	216
Poisson's Ratio	0.285	0.295
Density (kg/m^3)	7.8e3	7.9e3
Yield Strength (MPa)	1.4e3	1.71e3
Tensile Strength (MPa)	1.55e3	1.9e3

Table 5: Chosen material for main frame: Low alloy steel, AISI 94B30, oil quenched & tempered.

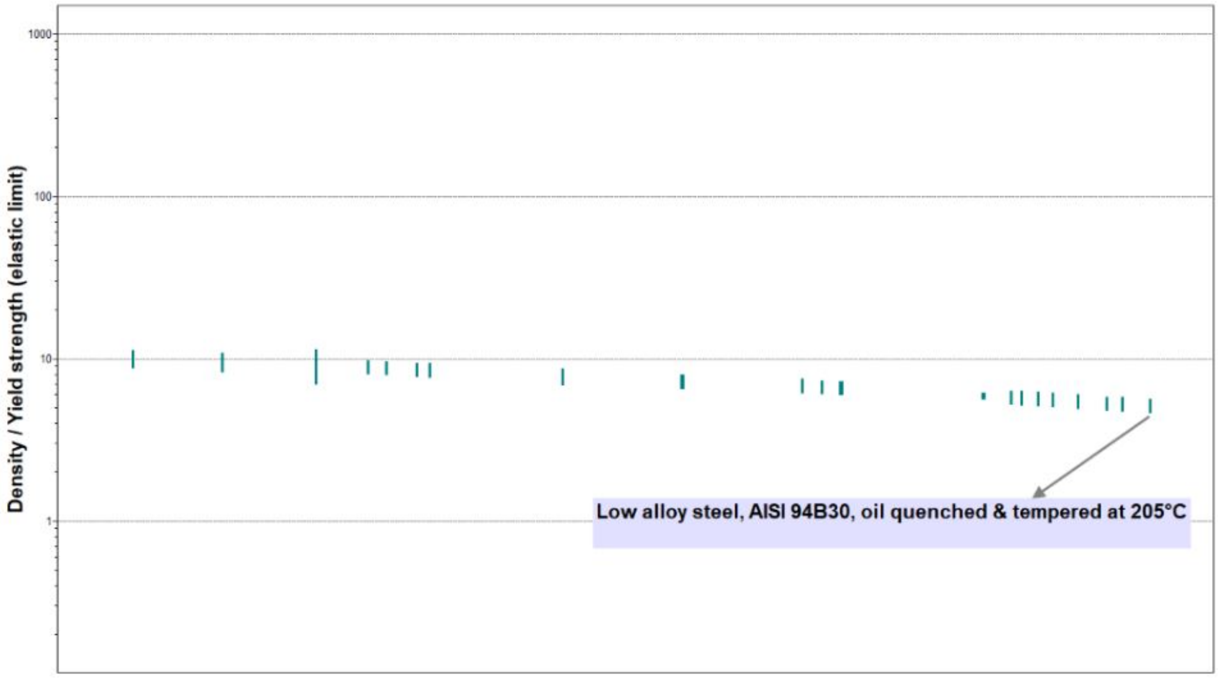


Figure 17: Density VS Yield Strength

8.2 Lifting Mechanism

The lifting mechanism of the crane consists of the trolley, hoist and boom. For all parts of all components, with the exception of standardized parts, materials were assigned.

8.2.1 Boom (Truss Design)

The chosen boom design for the final concept is the truss design, which is to be constructed of individual I-beams that will be welded together. Therefore, the constraints in material choice include weldability which is an important processing property due to the design of the boom.

Such structures requires high strength materials as well due to heavy weights it lofts during operation. The most suitable materials are high-strength-low-alloy (HSLA) steels which contain about 0.05% of carbon in addition to other alloying elements such as chromium which makes them more resistant to corrosion. Hence the are more suitable for welding than carbon steels.

ASTM A656 is a commonly used HSLA steel for crane booms. It is a grade of ASTM A572, which is a HSLA steel, a commonly used steel due to being economically priced. Its alloying element include Vanadium, Columbium, and Titanium to enhance strength. As well as Nitrogen to add corrosion resistance.

8.2.2 Hinge

Stainless steel is mostly used in humid environment application due to its corrosion resistance. In addition, it has great physical properties such as high strength, which makes it widely used for most engineering applications including constructions.

8.3 Chain Drive

8.3.1 Sprocket:

The sprocket is a teethed wheel to which the chain is attached, and is used to transmit the rotational motion created by the chain. Sprockets are often manufactured via traditional machining, such as hobbing, cutting and milling.

According to research, sprockets used for chain drives are made of steel. Based on this, it is already confirmed that steel is a widely used material for this application, and is available in sufficient quantity. To ensure the material can be shaped according to the above manufacturing methods, an appropriate limit will be added, seen in below:

Metal Cold: Excellent

Base material: Fe (Iron)

The low alloy steels are the lowest in price. Upon further inquiry within CES, it is seen that these low alloy steels are typically used for gears, which are very similar to sprockets. All of these steels score the same in accordance to the performance index, as seen in figure 18. One higher scoring material is the bake hardened steel, which is not relevant for this application.

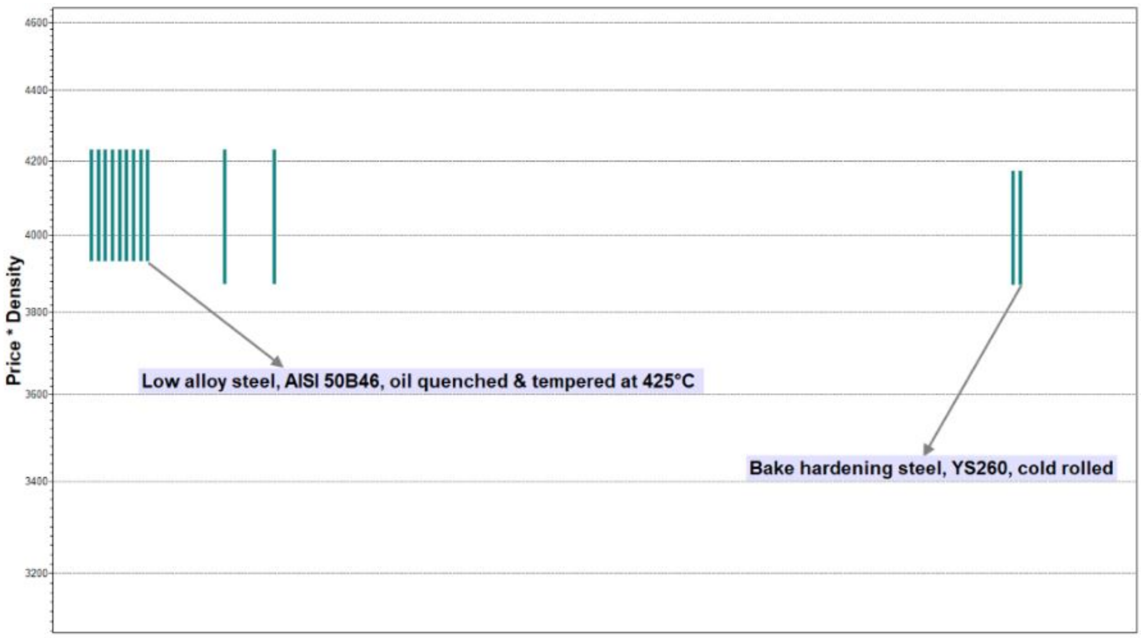


Figure 18: Density VS Price

Since the low alloy steel satisfies the limits, it is chosen for the chain drive sprocket. Key properties of this material are provided in table 6.

Key Properties	**Minimum**	**Maximum**
Young's Modulus (GPa)	201	212
Poisson's Ratio	0.285	0.295
Density (kg/m^3)	7.8e3	7.9e3
Yield Strength (MPa)	1.12e3	1.38e3
Tensile Strength (MPa)	1.25e3	1.54e3

Table 6: Chosen material for sprocket: Low alloy steel, AISI 50B46, oil quenched & tempered.

8.3.2 Shaft:

The sprocket will be mounted to a shaft, which will transmit the torque created by the rotation of the sprocket itself. Shafts are often manufactured using turning or extrusion.
Medium carbon steel 1045 Alloy such as S45C is also a good choice for shafts, mainly due to its wear resistance during high speed applications. In addition to its strength and hardness making it suitable for use in applications of shafts as well as gears, and machine parts.

Chosen material for chain drive shaft: AISI 1045 steel C45 carbon steel.

8.4 Gear Box

8.4.1 Gears:

The chosen material for the gears is S45C which is carbon steel that contains 0.45% carbon. It is a widely available and commonly used material in the production of spur gears, helical gears, and other types of gears. Components of a gearbox are insulated from the corrosive environment, therefore corrosion resistance does not play a role in the selection of steel. However, steel has high strength to weight ratio and high resistance to wear.

Chosen material for gears: S45C carbon steel.

8.4.2 Shaft:

The gears are mounted to the shaft. They transmit torque from one shaft to the other. The properties of this shaft are similar to those of the chain drive shaft and thus the same material is assigned.

Chosen material for gear box shaft: AISI 1045 steel C45 carbon steel.

8.4.3 Keys/Spline:

Keys are used to secure the gears to the shaft. The manufacturing method for the keys is milling.

4330 Alloy steels are alloy steels used for power transmission applications that require high strength, wear resistance, as well as impact resistance and have a good availability at North American distributors.

Chosen material for keys: AISI 4330 Alloy Steel.

8.5 Trolley

Wheels and Bearings are standardized.

8.5.1 Pulleys:

Nodular cast iron pulley wheels are commonly used in heavy duty STS cranes. They are a result of alloying Grey cast iron with Magnesium and increasing Carbon and Silicon composition which improves its physical properties such as yield strength, wear resistance and fatigue resistance. In addition, Grey cast iron is very cheap and is available in almost any foundry.

Like the chain drive sprocket, pulleys are most often made of a cast iron.

8.5.2 Rods:

The rods are made out of the same material as both shafts.

Chosen material for the rods: AISI 1045 steel C45 carbon steel.

8.5.3 Frame:

The rods and wheels of the trolley are mounted on the frame. The trolley transverses along the length of the boom, and thus its weight should be minimized. The frame has a complex shape but does not require extreme precision or an excellent surface finish, so it will be manufactured using casting.
According to research, the frame of the trolley is more likely to fail due to cyclic loads than to fail because of static loads. For the material selection, this implies that the selected material should have a high fatigue strength; it should be able to withstand high stresses for a given number of cycles before failure. In order to account for this, the performance index will maximize fatigue strength while minimizing density and price per kg:

$$\frac{Price*Density}{Fatiguestrength}$$

Additionally, the material requires an acceptable ability to be metal casted, seen below:

Metal Casting: Acceptable

Among the highest ranking materials are cast irons, as displayed in figure 19.
The cast iron does meet the limits and can therefore be shaped accordingly. It is also widely available. No information about corrosion resistance was provided by CES.

Chosen material for trolley frame: Cast iron, austempered ductile, ADI 1600.

8.5.4 Cables:

The cables used to lift the spreader and to lift the boom will be wired ropes. According to the given Machine Elements lectures, wired ropes that are used for cranes are typically constructed of a "hardened steel, tensile strength 1770-1960 MPa."

Chosen material for cable: Hardened steel, tensile strength 1770-1960 MPa.

Figure 19: (Density VS Price)/Fatigue

9 FEM-Calculations

Matlab is used to determine the deflections in the boom. This is done by determining certain nodes in a 3-dimensional space, connecting these nodes using elements and determining the size of each element. To improve calculation speed, FEM only offers circular frame members, the final model will feature different shapes of beams , such as I beams and T beams. Still, the calculations will give an estimation on how the design will perform.

In the first part only the boom will be taken into account while the rest of the structure will be neglected, this is done to determine the deflection of the boom relative to the main frame and to see if the boom design can be improved any further.

Only the deformation caused by the load will be taken into account, because the maximum load created by the wind is only 240 N/m^2. With the largest area on the boom being $48m * 4m = 192m^2$. This would result in a force equal to $46kN$

Also, the boom of a regular crane will be compared to the new improved design of the boom. Both of them are made ASTM-A656 alloyed steel (high strength-alloy steel) with a young's modulus of 200 GPa and a density of 7805 kg/m^3.

This is done in order to compare both of them on basis of their structure and dimensions, not on the material that is used. The improved boom will be optimised to decrease the mass, this is done with 3 iterations. In the last chapter, Mohr's circle is used to determine the maximum stresses occurring in one of the beams.

In the next part, also the frame is included in the calculation in order to calculate the forces in the points of support.

9.1 FEM-Calculations of the Boom

The regular boom of a crane is composed of triangular shapes with a triangular cross-section. This can also be seen in figure 20.

The model in Matlab is constructed as shown in figure 21. In this model the dimensions are as follows: the height of the beam is 3 meters and is 4 meters in width, to allow the trolley to traverse between the 2 lower beams. It is worth noting that only the part reaching over the ship is calculated in this part, so from hinge point to tip of the boom.

The total length of the beam is 48 meters and the main beams running the whole length have a diameter of 50 cm and a thickness of 5 cm. The smaller beams in-between have a diameter of 30 cm and a thickness of 1 cm.
Figure 22 shows the deformed state of the boom with a factor of 500, this takes the deformation and multiplies with 500, thus seeing the deformation becomes easy to the eye, it does not effect the calculations, but only the diagram. during operation the load at the end of the boom needs to be 50 tons or 490 500 N. In simulation, this force is doubled and distributed over 4 points. This is done to accommodate for the deviation that can occur on the trolley wheels. It makes it useful to utilise a safety margin into account.

Figure 20: STS crane, source: https://www.wagenborg.com/royal-wagenborg/news/sts-crane-to-larvik

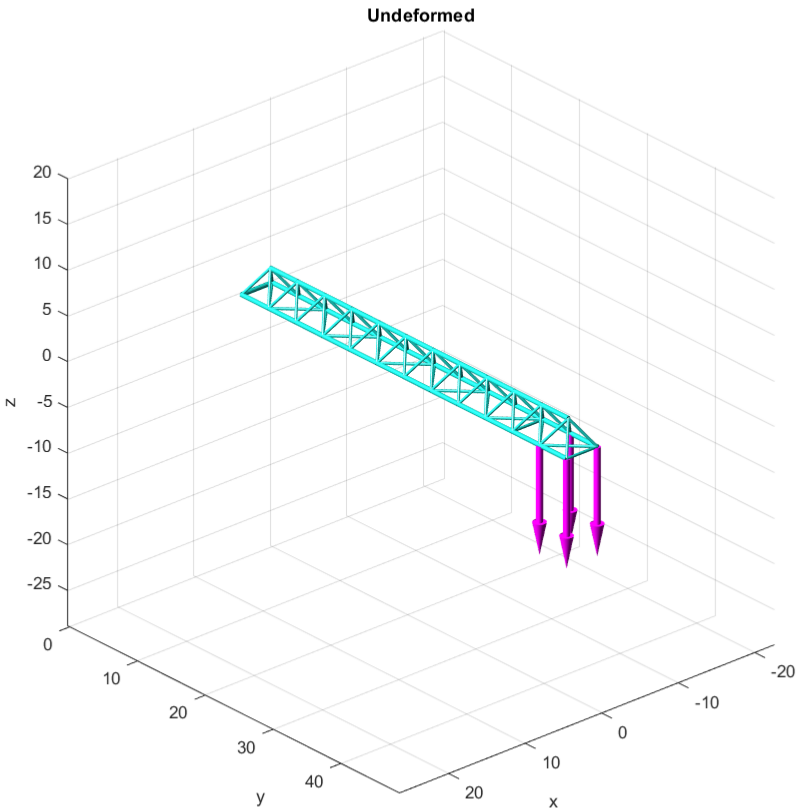


Figure 21: Regular crane boom in FEM

The models show that the maximum deflection at the end of the boom is 51 mm, which is still within the limit of the requirements (150 mm). The maximum stress is 210 MPa.

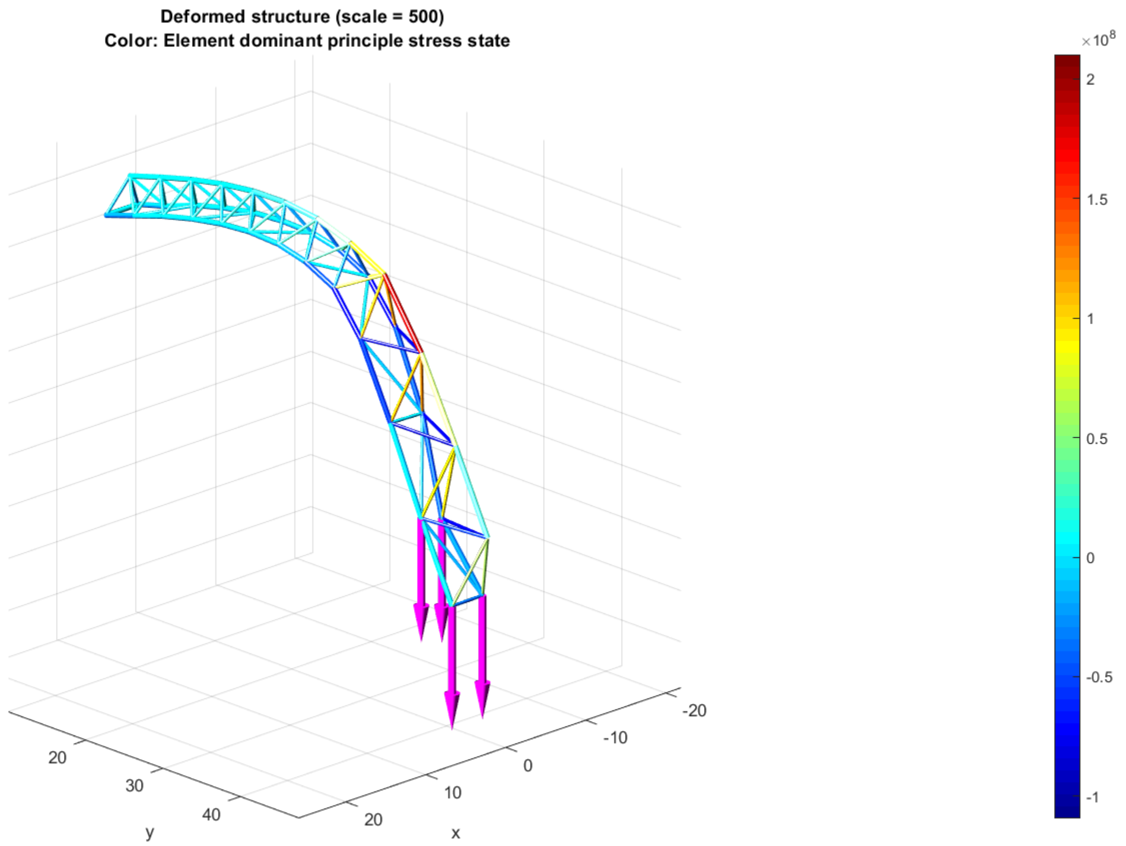


Figure 22: Deformed state of the regular crane boom

9.2 FEM calculations of the improved boom

The material of the improved boom is the same as the previous design in order to compare fairly. This means that the Young's modulus', densities and Poisson ratios are the same. The differences occur within the dimensions of the boom and the beams used to construct the boom, therefore the number of beams used.

In a real life situation, I-beams will be used instead of circular beams, however, in order to compare the regular crane boom with the new design, and the FEM package has limitations with the shape of the beam cross section , for example no I beams, the new design will also use circular beams.

Figure 23 shows the unreformed state of the boom. What can be seen is that the regular boom and the improved boom have some similarities. The improved boom however has extra beams on the bottom to add mass on the outer perimeter in order to reduce bending.

Also, a fifth beam is added down the middle of the boom. This also means that the new and improved beam also weighs more, this is also taken into account in the calculations, however this does have a negative impact on the price of the boom.

The 100 ton load is divided into 4 points again on the end of the boom in order to simulate a trolley system on the tip of the boom. Fixtures are added at x = 0, in order to simulate the connection to the crane, these constraints are (translation wise) in x-,y- and z-direction and

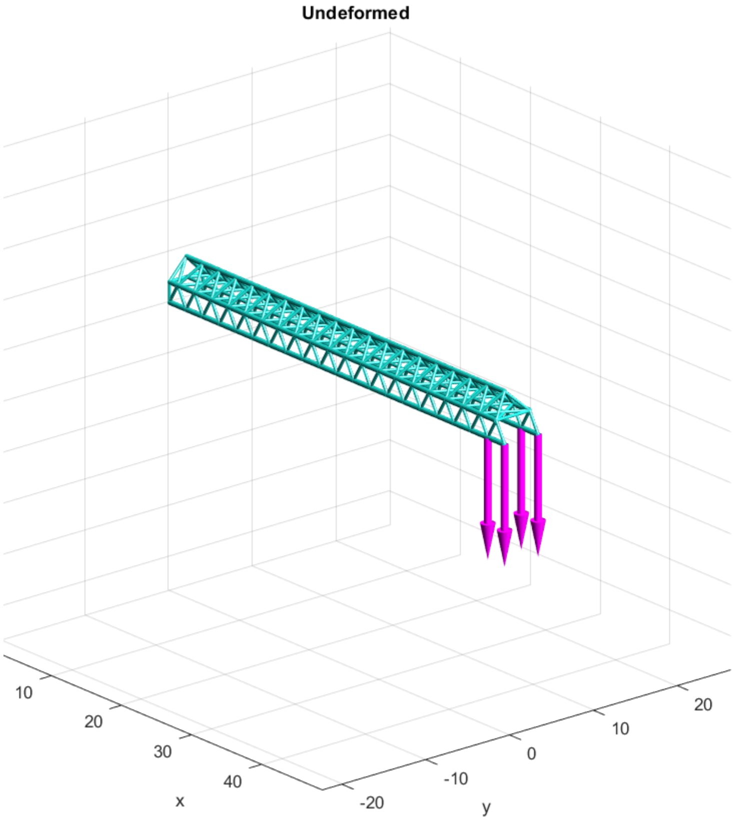


Figure 23: Underformed state of the improved boom

(rotation wise) in z- and x-direction. Also, another fixture is added at x = 34 meters. This is the point where the cable connects to the boom and constrains the boom movement in the z-direction. This cable will not constrain any other translations or rotations, because it is not a stiff element and only counteracts tensile forces.
The maximum deformation at the end of the boom is 34 mm and the maximum stress is 141 MPa. Comparing this to the regular crane boom, the deflection is lowered by 17 mm and the maximum principle stress is lowered by 69 MPa.
More iterations were made and the results are given in table 7.

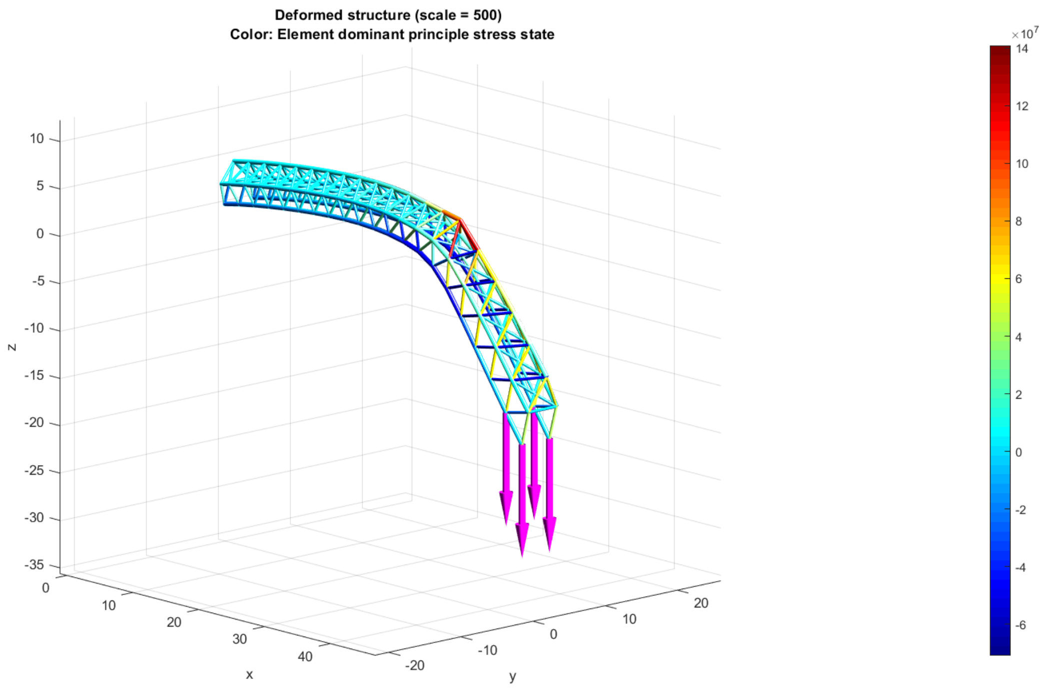


Figure 24: Deformed state of the improved boom

	max stress (MPa)	max deformation (mm)	diameter large beams (m)	thickness large beams (m)	diameter small beams (m)	thickness small beams (m)
normal boom (small thickness)	210,04	51,01	0.3	0.01	0.15	0.05
new boom (small thickness)	140,86	34,56	0.3	0.01	0.15	0.05
normal boom (large thickness)	137,10	34,57	0.3	0.06	0.15	0.07
new boom (large thickness)	126,29	23,68	0.3	0.06	0.15	0.07
normal boom (ultra small thickness)	943,95	276,23	0.3	0.007	0.15	0.04
new boom (ultra small thickness)	505,75	174.56	0.3	0.007	0.15	0.04

Table 7: Table with all the iterations and corresponding results of a load

The table shows what would happen if the thickness of the beams is reduced even more (in the ultra thin configuration), both beams collapse. Thus the best option is to choose small thickness beams with the dimensions given in the table.

9.3 Area moment of inertia of the boom

The boom itself will bend due to the force at the tip of the boom and of its own weight. This bending can be reduced by making the area moment of inertia of the boom about centroidal y-axis as high as possible. This was done by adding more weight far away of the centroidal y-axis. The total area moment of inertia of the beam is 1.39 m^4.The calculation of the moment of inertia is placed in the appendix. The calculations where done by making a intersection of the boom. Only this section changed where you cut the beam. Therefore the parts which changed at different section are calculated with a factor 0.1 times this area. The cross section of the boom can be seen in figure 25.

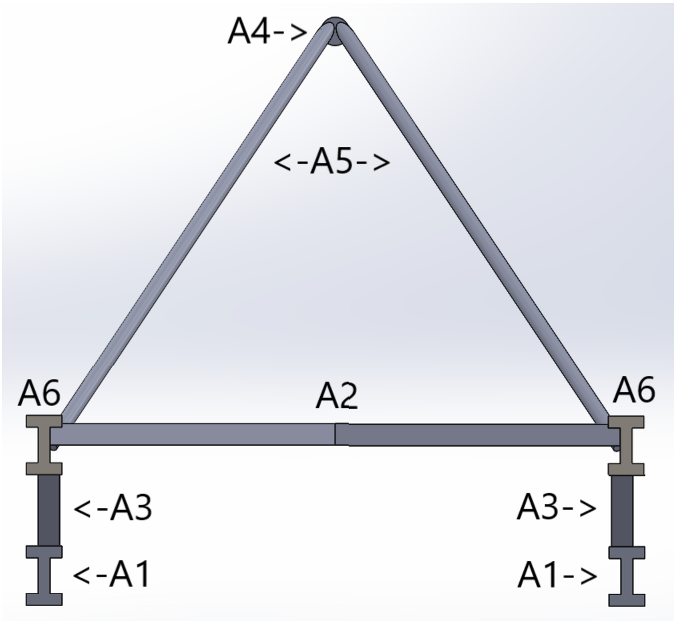


Figure 25: The cross section of the boom

9.4 Conclusion from the FEM calculations of the boom

According to the calculations performed using the supplied FEM package, the new and improved beam shows better performance than the regular crane beam. However, the improved beam also uses more material, which has a negative impact on the price and weight of the beam. The mass of the beam is lowered as much as possible by testing multiple iterations of the design.

9.5 FEM-Calculations of the frame

The frames of the STS crane have some standard shapes. Different parts of different STS-cranes are used in our design. Some of the dimensions are already mentioned in the requirements. Some dimensions are free and these are optimized for lowest stresses and deformations. The final design has one top point were all cables are connected. The boom itself is connected at two points at the hinge of the boom. The boom was first connected with one metal connections seen at figure 23 .Although it will add more weight the final design has three metal connections, because this has a huge improvement on the stresses in the boom. There are also cables connected to the boom, only one of these cables is unstressed during operations. All diameters of the beams are optimized, so these beams have still less stress than 60 MPa and the mass is as low as possible.

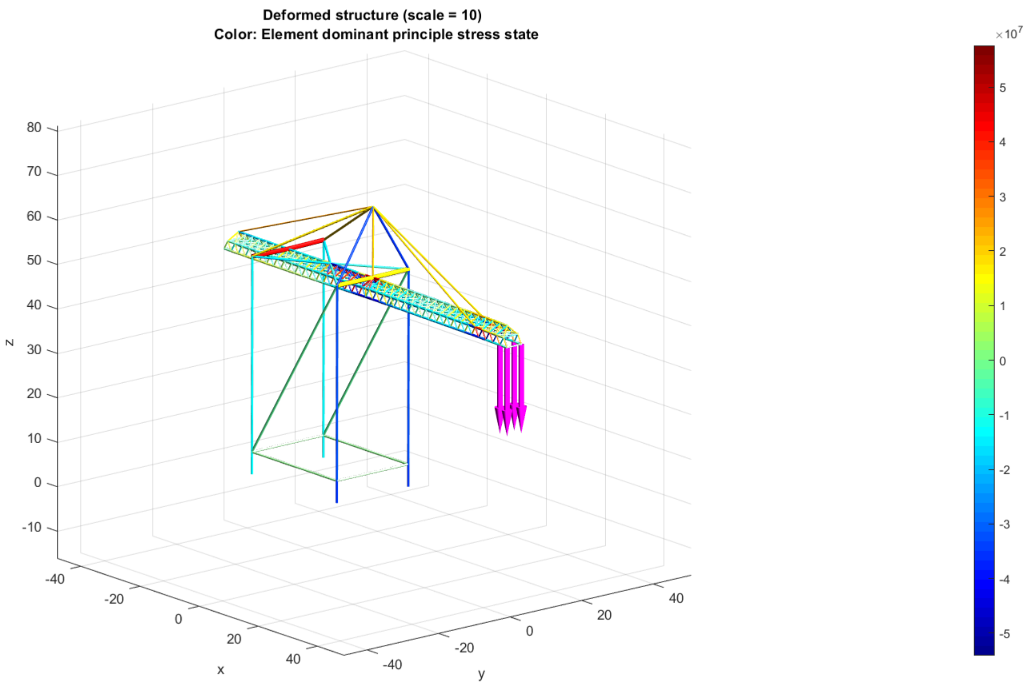


Figure 26: The frame of the crane

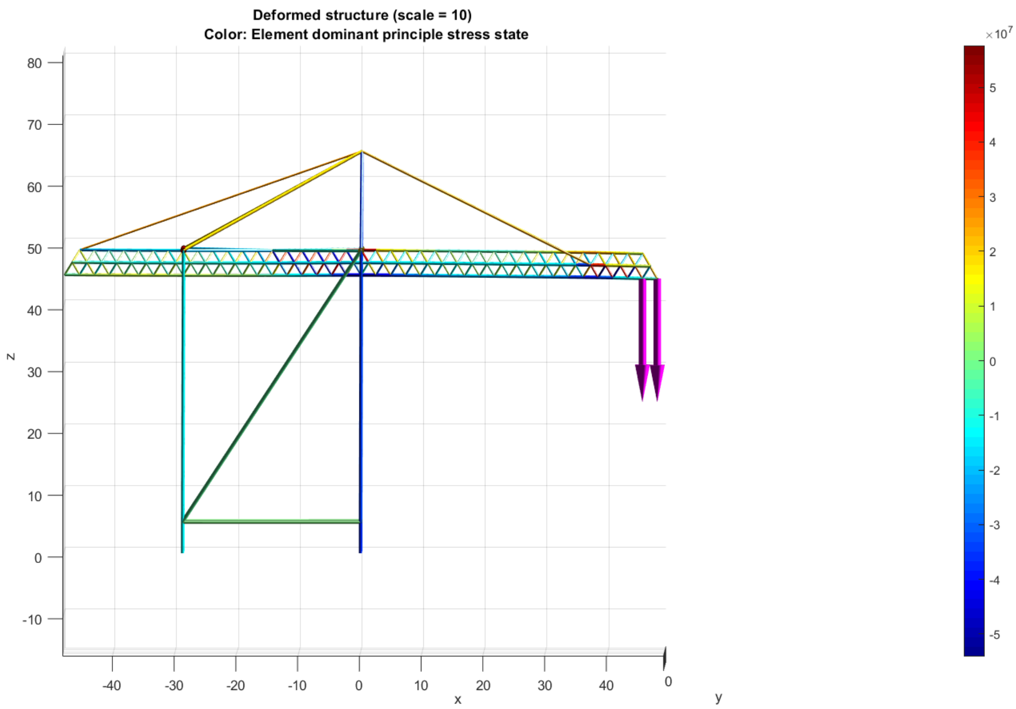


Figure 27: The side view of the frame of the crane

Therefore the total mass of the frame is 1695 tons, this is much lower than the first design of the frame. This design has a weight of over 3000 tons. Lowering the weight of the boom was done by lowering the thickness of beams of the frame while the stresses are still lower than 60 MPa and the deformations are still within their respective limits. Also the frame was changed a lot by adding and removing support beams until the optimal weight and lowest stresses were achieved. The safety factor is still very high, because for all calculations a force of 1 million newton is placed at the boom, this value is twice as high as the maximal requirement. The maximum deformation at the tip of the boom is 7.38 cm and this is much lower than the requirement of a deformation of 15cm.

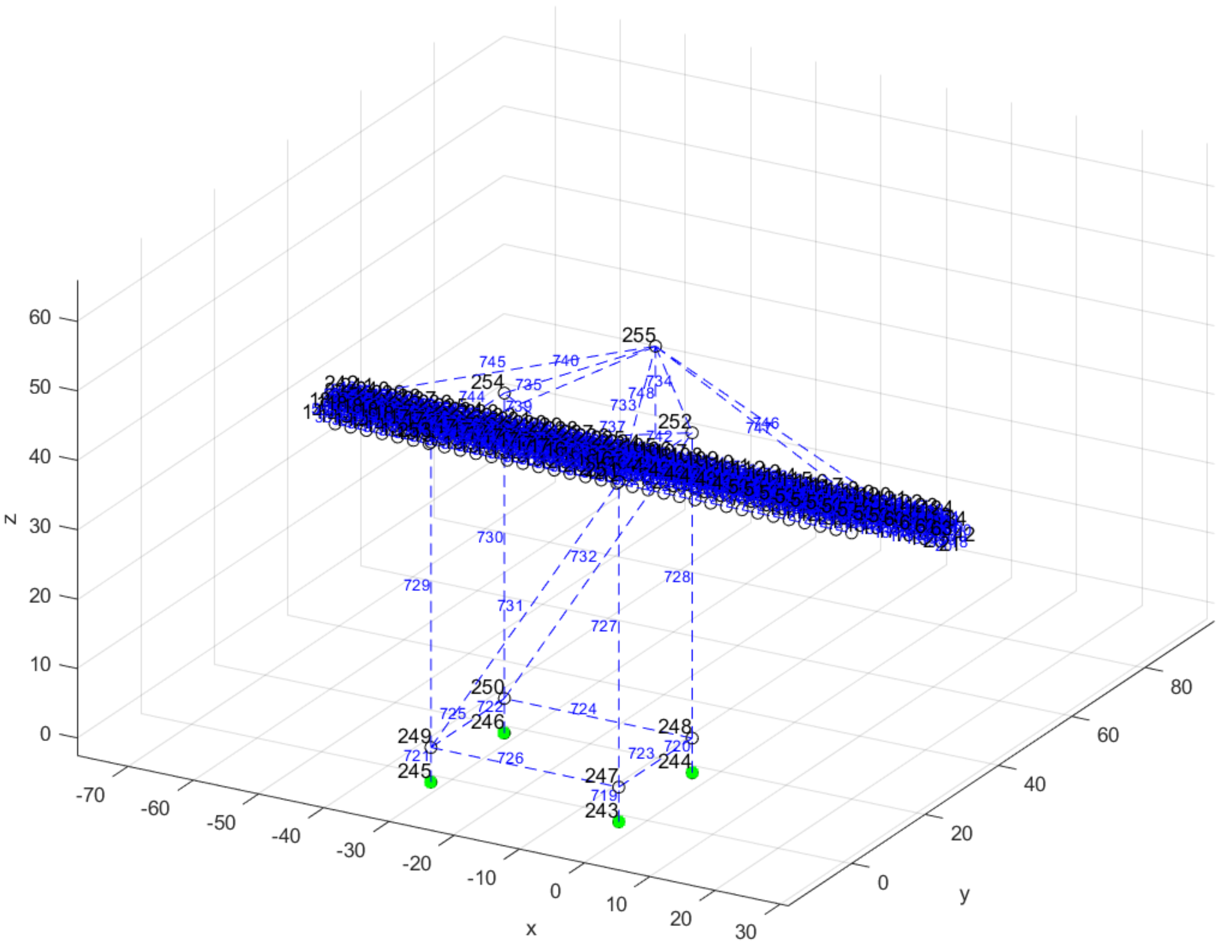


Figure 28: The nodes of the frame which are connected with the ground.

The beams which are used as ground supports are all in compression. The two beams which are connected in the front are fully constrained, these have node-numbers 719 and 720 seen in figure 28 . The stresses in these beams are 37,9 MPa. The two nodes which are at the back are rollers and are the nodes 721 and 722 seen in figure 28 The stresses in these beams are 12.7 MPa. All the beams of the frame which are connected with the ground are in compression. Therefore the centre of gravity is somewhere between the front and back beams which are connected with the ground. The reason therefore is when some of the these beams where in tension the centre of gravity will be between these beams. Because the centre of gravity is in the middle between the beams the crane is considered stable. All the calculations are made in Matlab and the code of this is placed in the appendix. All values of the nodes and the beams are also placed in the appendix. There are the displacements of the nodes placed and also the stresses in the beams of the frame.

9.5.1 SolidWorks drawings

Below the figures of the solidworks drawings of the boom are shown. in which the locations were the boom is welded is given and the hinge-point is zoomed in. In the zoomed in picture the location of the cylindrical roller bearing is given. Each site of the boom consist of one bearing together with one shaft.

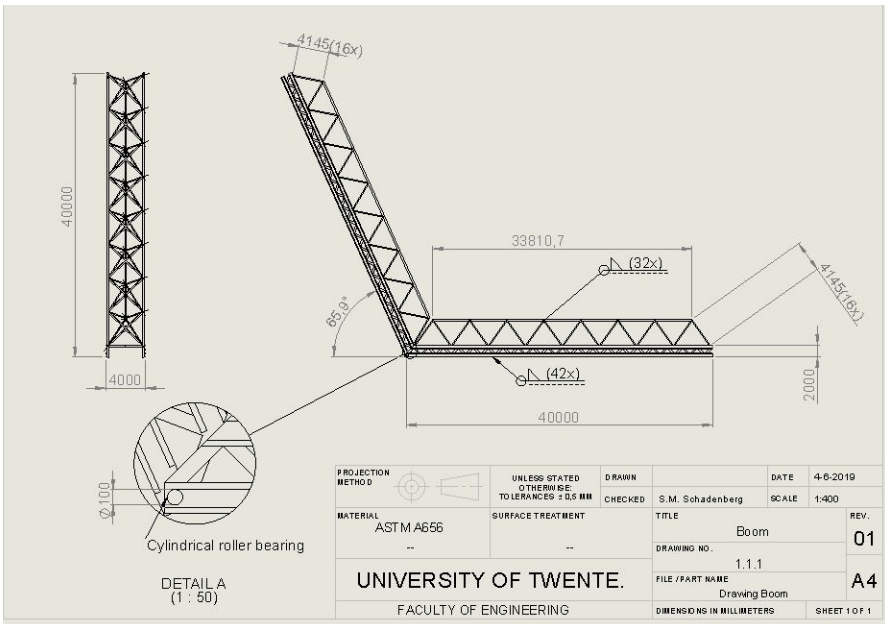


Figure 29: Solidwork drawing of the boom

10 Mohr's Circle

Mohr's circle describes the normal and shear stresses on a infinitesimally small particle in the beam.
Mohr's circle is described for the elements with the highest possible stresses. This includes the element with 210 MPa for the regular crane boom, and the element with 140 MPa of stress for the improved crane boom.

First of all, FEM calculates the stresses on each element in the structure. These stresses are calculated at the point of maximum bending stress in the xx direction of an infinitesimally small particle. The xx direction in these cases are in longitudinal direction of the slender member. This is because the FEM package uses a different local coordinate system for every beam.
The relation between a local and global coordinate system are 2 different angles. With these 2 different angles, the local coordinate system can be transformed into the global coordinate system.

10.1 Improved Crane

10.1.1 Situation sketch

The beam that is under the highest load, is the beam that also connects to the cable to lift the boom. This boom can be seen in figure 30. The beam with the highest stress is coloured red.

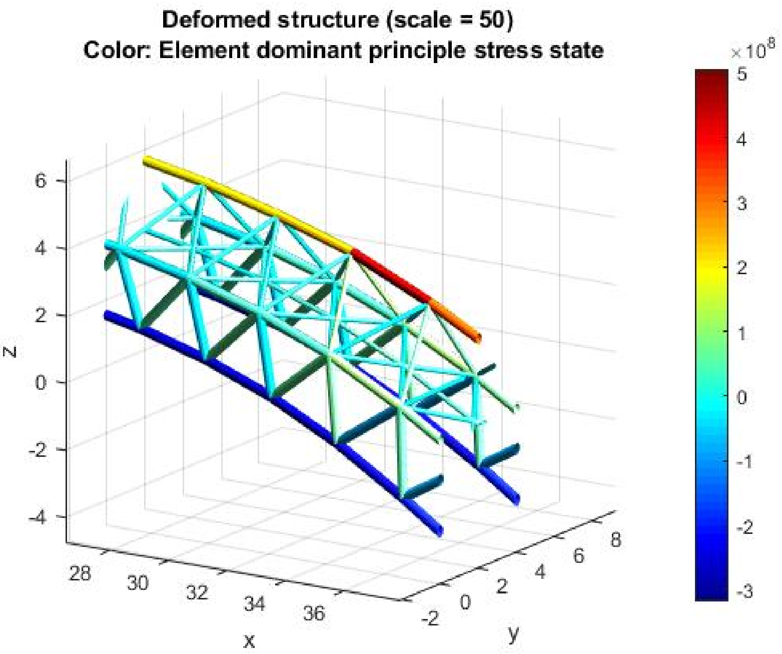


Figure 30: Situation sketch of the highest loaded beam

10.1.2 FBD and critical point

Because the boom is considered a frame, also moments are considered in the connections to other beams. Showing this in a FBD, it will look like as shown in figure 31.

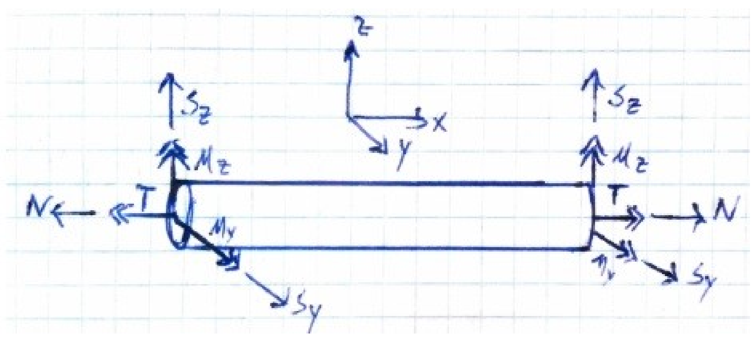


Figure 31: FBD of the element

However, all these external forces have an impact on the internal forces, take the following examples. A shaft, given in figure 32, will have different internal stresses when looking at an infinitesimally small particles distributed over its cross-sectional area.

This is also the case for bending, normal and shear stresses. However, FEM calculates all these stresses in the point with the maximum bending stress and adds the internal stresses together. E.g. the stress (in normal x direction) created on a particle due to a normal force, will be added

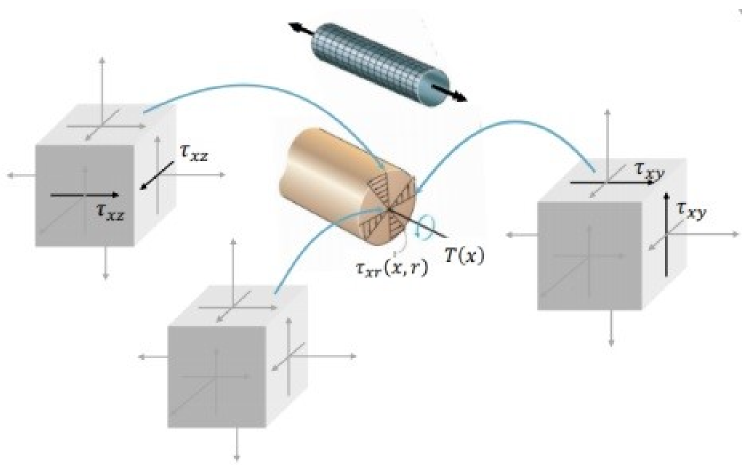


Figure 32: Section of a shaft under torsional loading

to the stress (in normal x direction) created by the bending moment.

With these forces calculated, will calculate the maximal stress in normal x, y and z direction, as well as the shear stress in xy, xz and yz direction.

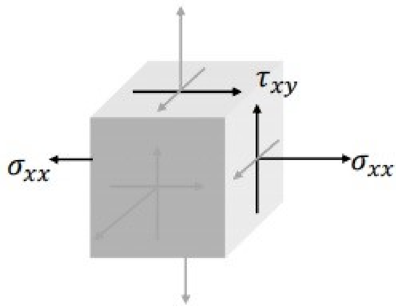


Figure 33: Infinitesimally small particle under internal loading

With these stresses figured out, the FEM package will start to calculate the principle stresses acting on the particle by means of rotating it and calculating the resulting stresses again. Plotting the resulting shear and normal stresses a circle of Mohr can be constructed.

One can see in figure 34 that the shear stress in the correct orientation of the boom is almost negligible. This can be seen from the fact that both circles almost lie on top of each other and thus the maximum shear force by turning almost equals the absolute maximum shear force.

With the calculations from matlab, the table 8 was constructed.

Maximum Normal Stress [MPa]	Average Normal Stress [MPa]	Maximum absolute shear Stress [MPa]	Maximum in-plane shear Stress (theta = 45 degrees) [MPa]
141	70.5	70.6	49.9

Table 8: Stresses on an infinitesimally small particle in the improved boom

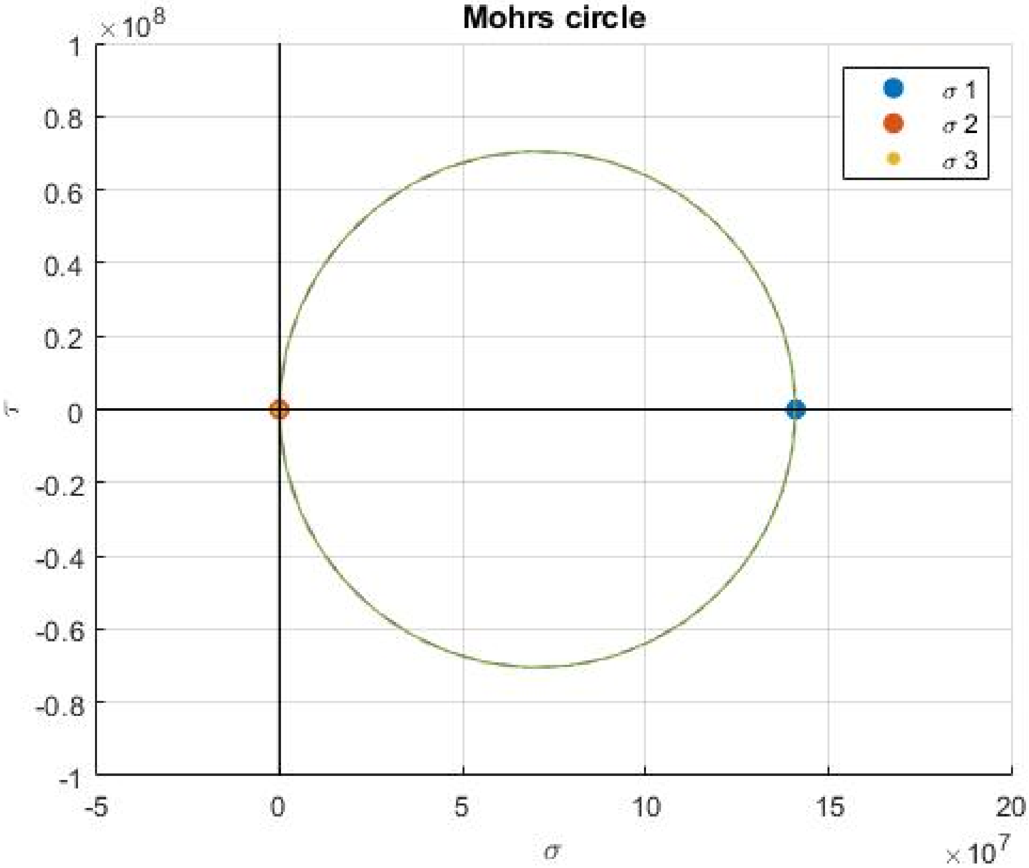


Figure 34: Mohr's circle for the improved boom: [S1 = 1.41e8 Pa, S2 = 0 Pa, S3 = -1.48e5 Pa]

The maximum in-plane shear stress is calculated, because this is the position in which the planes of the metal lattice can shift and thus give rise to plastic deformation.

10.2 Regular crane

In the same manner as the calculations for the improved boom, the circle of Mohr of the regular crane boom was constructed.
One can immediately see in figure 35 that the absolute maximum shear stress is almost the same as the maximum shear stress by turning the beam. This means, that the additional shear stress, which is also there when the beam is in the theta = 0 degrees position is almost negligible.

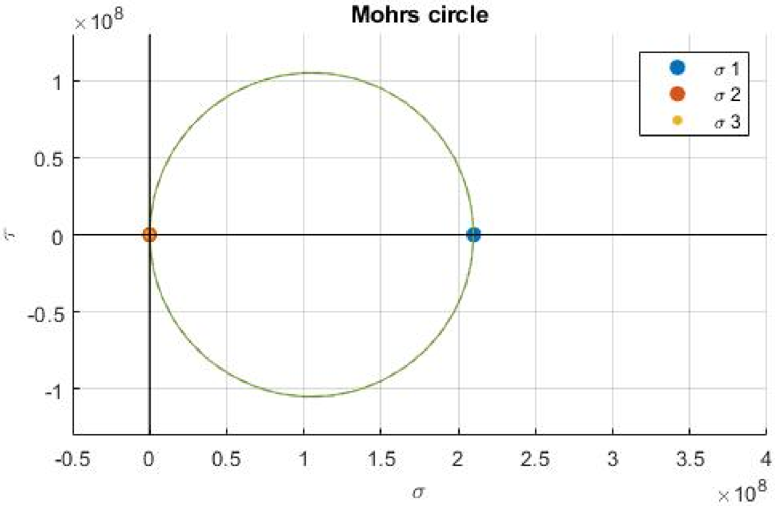


Figure 35: Mohr's circle for a regular crane boom: [S1 = 2.1e8 Pa, S2 = 0 Pa, S3 = -92855 Pa]

With the values that were deduced by calculations in the matlab script, table 9 was constructed.

Maximum Normal Stress [MPa]	Average Normal Stress [MPa]	Maximum absolute shear Stress [MPa]	Maximum in-plane shear Stress (theta = 45 degrees) [MPa]
210	105	105.1	74.31

Table 9: Stresses on an infinitesimally small particle in the regular boom

10.3 Comparison between Mohr's circles

There are rather large differences between the 2 diagrams and values. The absolute differences are given in table 10.

Maximum Normal Stress difference [MPa]	Average Normal Stress difference [MPa]	Maximum absolute shear Stress difference [MPa]	Maximum in-plane shear Stress difference (theta = 45 degrees) [MPa]
69	34.5	34.5	24.4

Table 10: Differences between the improved and the regular boom

The differences are rather large and all in favour of the improved boom design.

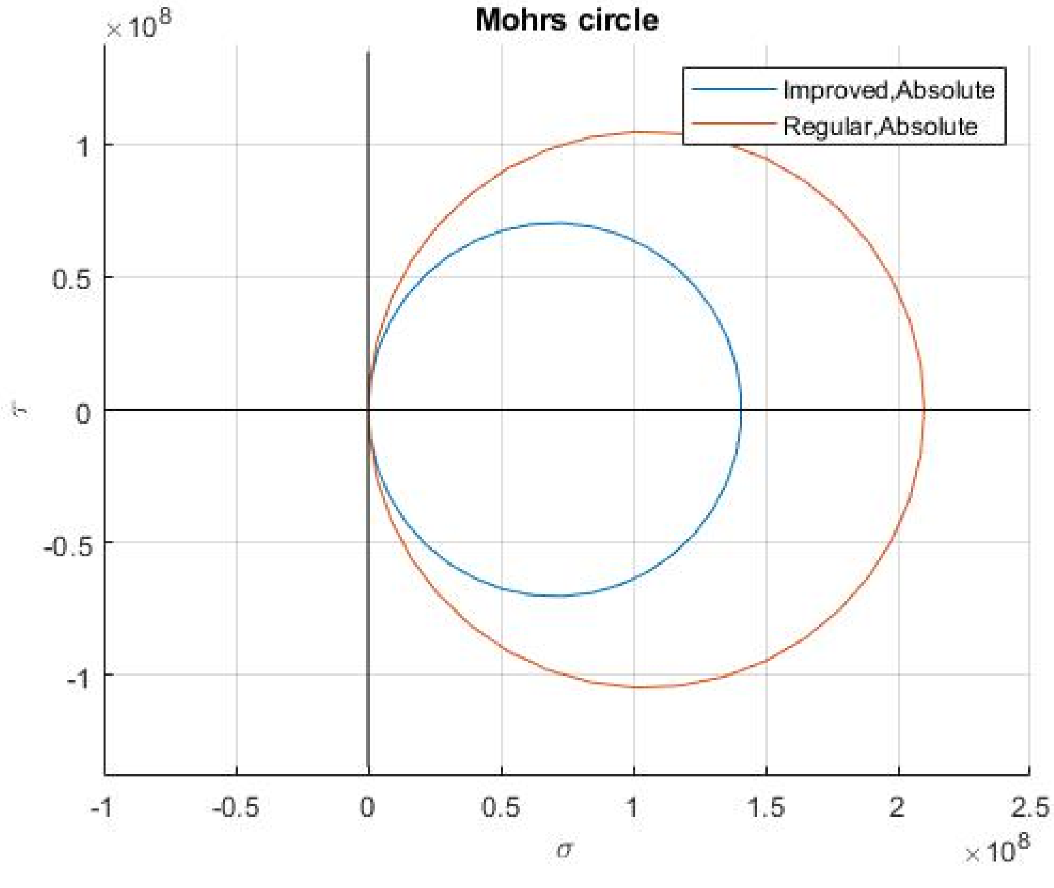


Figure 36: (Absolute) Mohr's circle for both the improved and the regular boom

Given in figure 36 are the 2 circles in 1 diagram in order to compare them better. Also, from this diagram it is clear that the improved boom design has lower stresses than the regular crane boom. This will result in a more reliable crane with less chance of failure.

10.4 Conclusion on Mohr's circle

The chapter has shown that the maximum stress in the improved boom is 141 MPa and the maximum absolute shear stress is equal to 70.6 MPa. Because the yield strength of the steel equals 690 MPa the steel will not yield. Keep in mind that in all these calculations a safety factor of 2 was incorporated by doubling the expected load.

11 Machine Elements

11.1 Motor Selection

The type of supply for the motor is line feed. The line frequency European frequency is 50 Hz, the line voltage is equal to 400V (power current), it needs to supply enough energy so that the motor can spin at 3000 rpm. The coolant is air. The cooling type is IC411-totally-enclosed fan-cooled (TEFC). Using the load for each motor and the maximum hoisting speed the power demand was calculated to be 500 kW. The efficiency class is IE3/premium since that is requirement of the government, this is done in order to decrease the environmental impact. Choosing IE3 will result in an expensive motor, but it will be payed back within 3 years due to energy savings. The protection class is IP 65 and the frame material is grey cast iron. The minimum and maximum ambient temperature requirements are -40 and 50 degrees Celsius respectively , the motor can operate in the range. The motor fulfills the IEC motor norm.

The motor requirements, table 11, and the motor characteristics, table 12, are displayed below.

Portfolio	SD – Serve duty
Motornorm	IEC
Type of supply	Line feed
Line frequency	50 Hz
Line voltage	400 V
speed	3000 rpm
Coolant	air
Cooling type	IC411 – totally-enclosed fan-cooled (TEFC)
Power demand	500 kW
Efficiency class	IE3 / Premium
Protection class	IP 65
Frame material	Gray cast iron
Ambient minimum temperature	-40 degrees Celsius
Ambient maximum temperature	50 degrees Celsius

Table 11: Requirements of the motor

From these requirements the Simotics SD motor was selected. The Simotics SD motor full fills all requirements and has the following motor characteristics:

In order to find the torque values on the outgoing shaft , the locked rotor torque, the rated torque and the breakdown torque where calculated, and displayed in table 13.

$Lockedrotortorque = 8.9 * ratedcurrent = 7533Nm$
$Ratedtorque = Lockedrotortorque/3 = 2511Nm$
$Breakdowntorque = 3.8 * Ratedtorque = 9542Nm$

Type	Simotics SD
Output	500 kW
Size	355 L
Rated current	846.44 A
Rated speed	2988 rpm
Derating factor	1.00
Efficiency class	IE3
Efficiency at 4/4 load	95.8 %
Efficiency at 3/4 load	95.7 %
Power factor at 4/4 load	0.89
Power factor at 3/4 load	0.86
Locked-rotor / rated current	8.90
Locked-rotor / rated torque	3.00
Breakdown / rated torque	3.80

Table 12: Chosen motor

Torque type	Torque in Nm	Percent of Rated torque in %
Rated torque	2511	100
Locked rotor torque	7533	300
Breakdown torque	9542	380

Table 13: Torque Characteristics

11.2 Gears and shafts in the motor

The chosen system to transfer power and torque through the motor to the drum that collects the cable is gears. There are two motors and one gearbox. The gearbox includes 2 bevel gears, one is connected to the motors shaft and the other is connected to the drums shaft.

The motors are on either side of the pinion gear. The gear ratio used is 1.944 and was aimed to be 2. It is not exactly 2 because the occurrence of a common divider between the pinion and the driver gear causes what is called a hunting tooth. This refers to the uneven wear of the gear teeth. A hunting tooth is the one that is worn out a lot more than the rest of the gear, and can cause failures such as pitting or fracture. Using numbers with no common divisors mean that the teeth on the pinion gear do not mate with the same teeth on the driver gear, giving the gears even wear characteristics. The bevel gears have teeth cut with 12 degrees and the contact angle is 20 degrees of involute. These angles are commonly used and therefore will not cause extra expenses and time during production.

11.2.1 Method of design

Initially the number of teeth for the pinion gear was set. this was done using a guideline table. the table stated that a hoisting operation may use gears with teeth number ranging from 14 to 20. Therefore 18 was chosen. 18 is closer to 20, meaning the radius can be kept small when the suitable module is chosen. Initially the calculations were done using module 6, yet this yielded stress levels too high,contact stresses about 55 MPa. Therefore module of 8 was chosen, it is also one of the commonly used numbers. Module of 8 gave bending stress of an average 23.6 MPa, and an average contact stress of 41.3 MPa. Using the module the diameters of the gears and the number of teeth were chosen, then finally using the number of teeth and the formula $i = \frac{N_2}{N_1}$. the shaft calculations were initialized after the axial and radial forces were known.

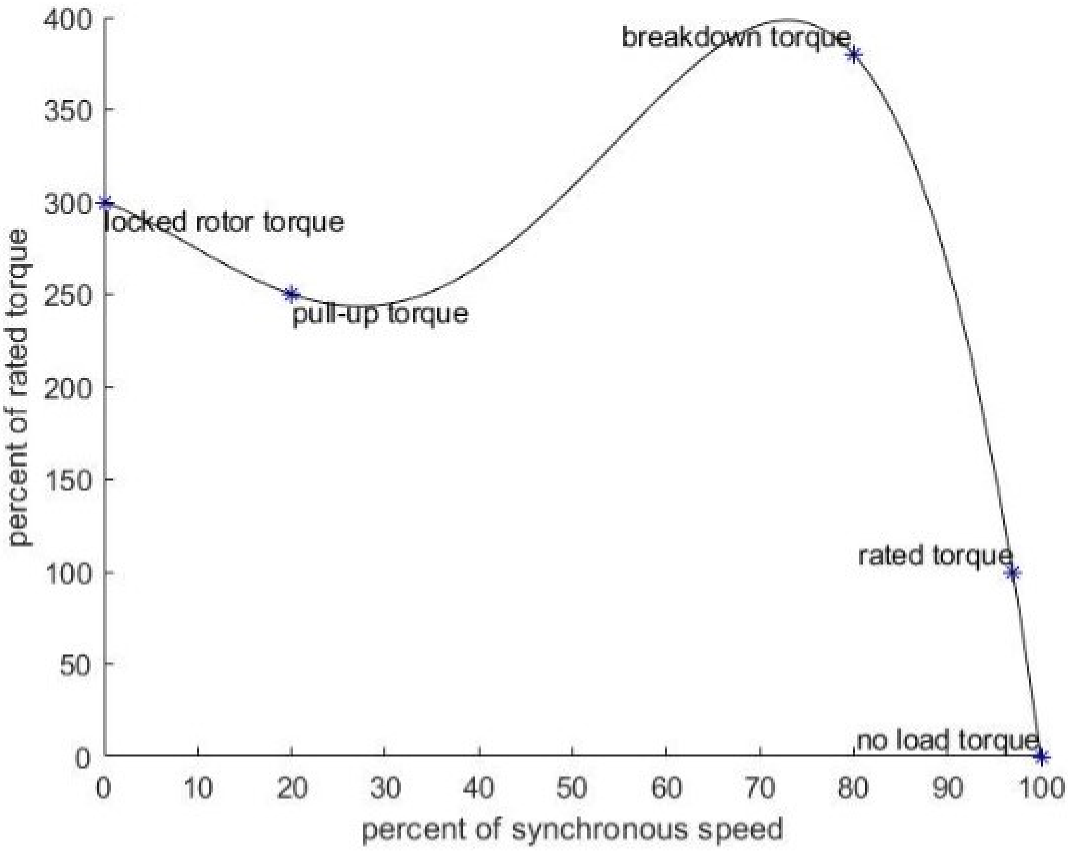


Figure 37: Torque curve.

11.3 Shaft

The shafts are of adequate length. There is 2.5mm of free space between the gears and the bearings. This allows the use of spacers to tolerate uncertainties during production. There is a bearing on each sides of the gears in order to minimise friction and wear. Needle roller bearings have been chosen as they have more surface area than ball bearings and are able to support more weight. This is significant as the weight being hoisted consists of a 50 000 ton container and the spreader, the weight of the cables is negligible compared to the container and the spreader. Firstly all the external forces were defined. One bearing is not constrained as this would cause over-determination. One side of the shaft has forces in x , y , and z directions and the other had it in x , z directions. The drum applied a torque, moment in x , y and z axis. After the external forces were determined the shaft is cut into 3 pieces, before the gear, after the gear,

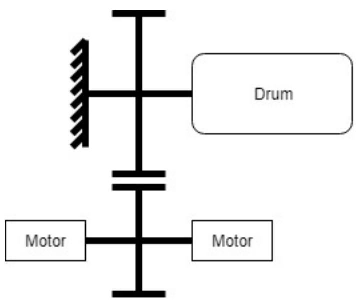


Figure 38: Transmission from motor to drum

after the first bearing. These cuts allowed the plot of the internal force and moment diagrams, which were dependant on the positions of the cut on the x axis. The diameter was found using the formula

$$D = \sqrt[3]{\frac{32}{\pi} * \sqrt{(\frac{K_t * M}{S_n})^2 + \frac{3}{4} * (\frac{T}{S_y})^2}}$$
$$D_{min} = \sqrt{(2.94 * K_t * VN) \div (S_n)}$$

The design factor was chosen to be 2, max moment was calculated at $2.7174e6$ Nm and the maximum torsion was calculated at 15328 Nm. The modified endurance limit output 5519 and the yield strength of the material, when quenched in 430 degrees Celsius was 730 MPa. A sled runner type of key slot have been used this yields to a key factor of 1.6. When all the numbers were put in the previous formula, given above, the result came out as 53.51 mm. the edges are filleted to avoid stress peaks in the material.

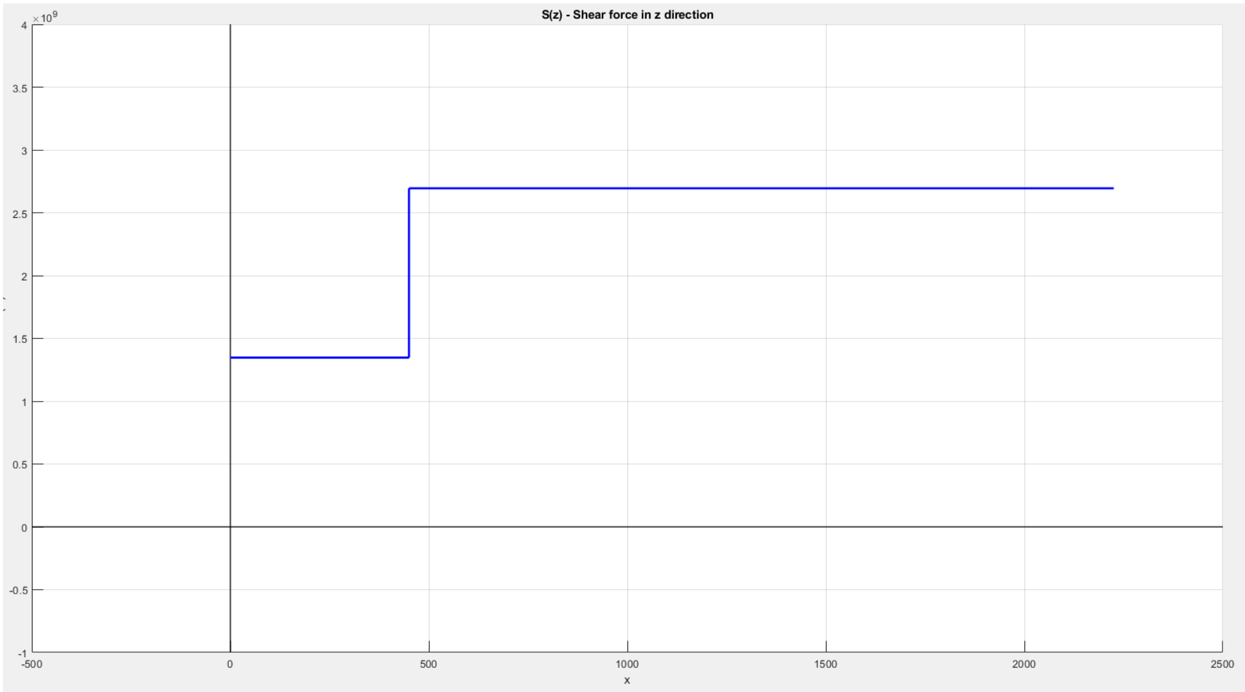


Figure 39: Shear force in z direction

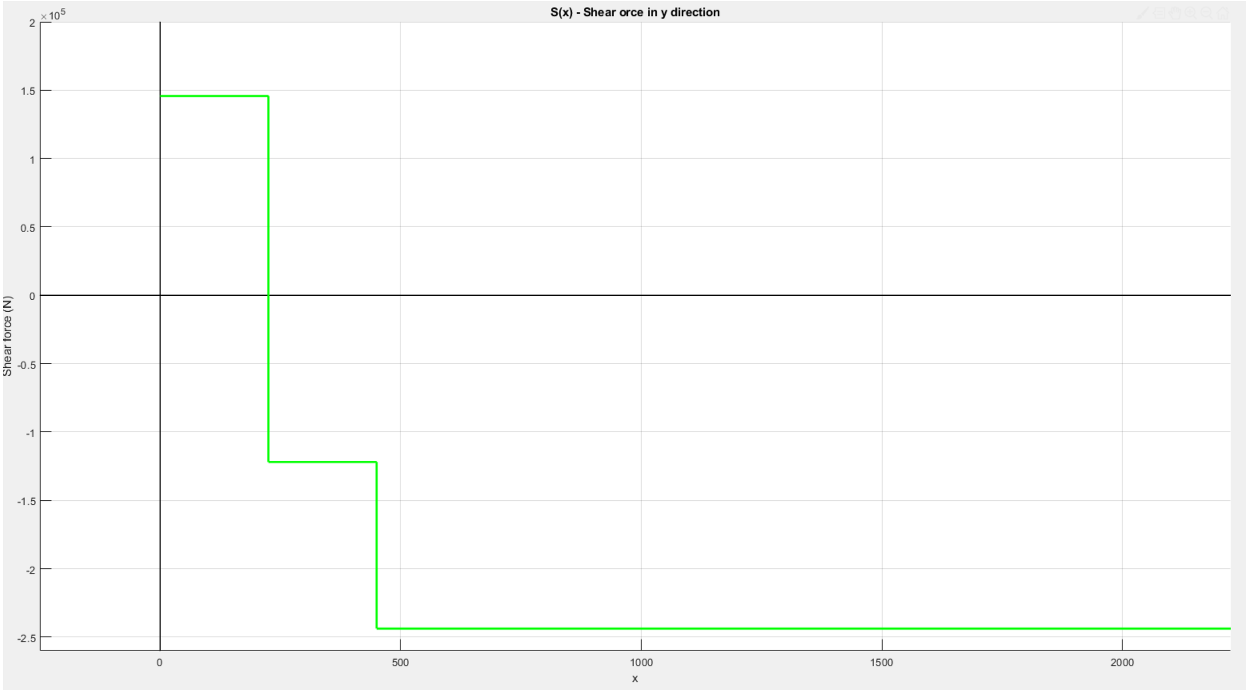


Figure 40: Shear force in y direction

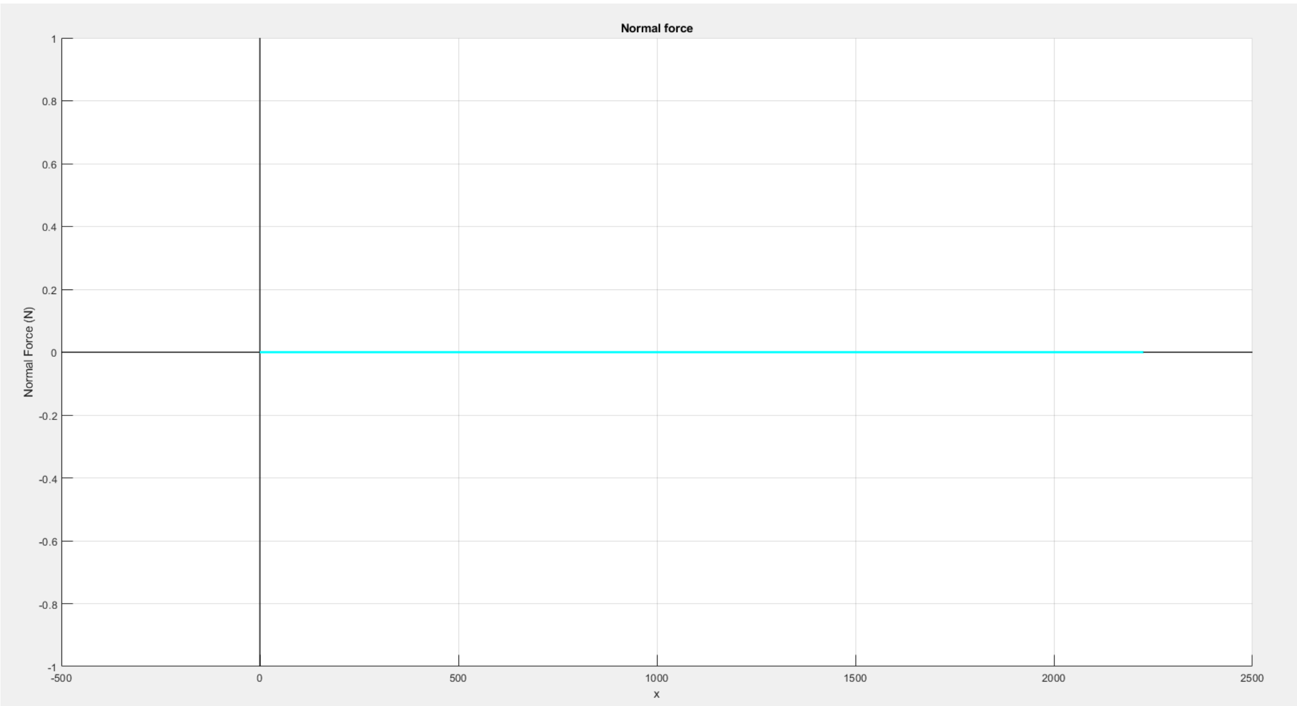


Figure 41: Normal force

Using the diagrams, the maximum moment and forces were found and the diameter of the shaft is determined to be 65 mm. The shaft utilises a key, instead of splines, this is due to the difficulty of making splines in the middle of a shaft and not the ends. Machining a shaft like that is expensive and time consuming. The design of the key will be discussed in the next chapter.

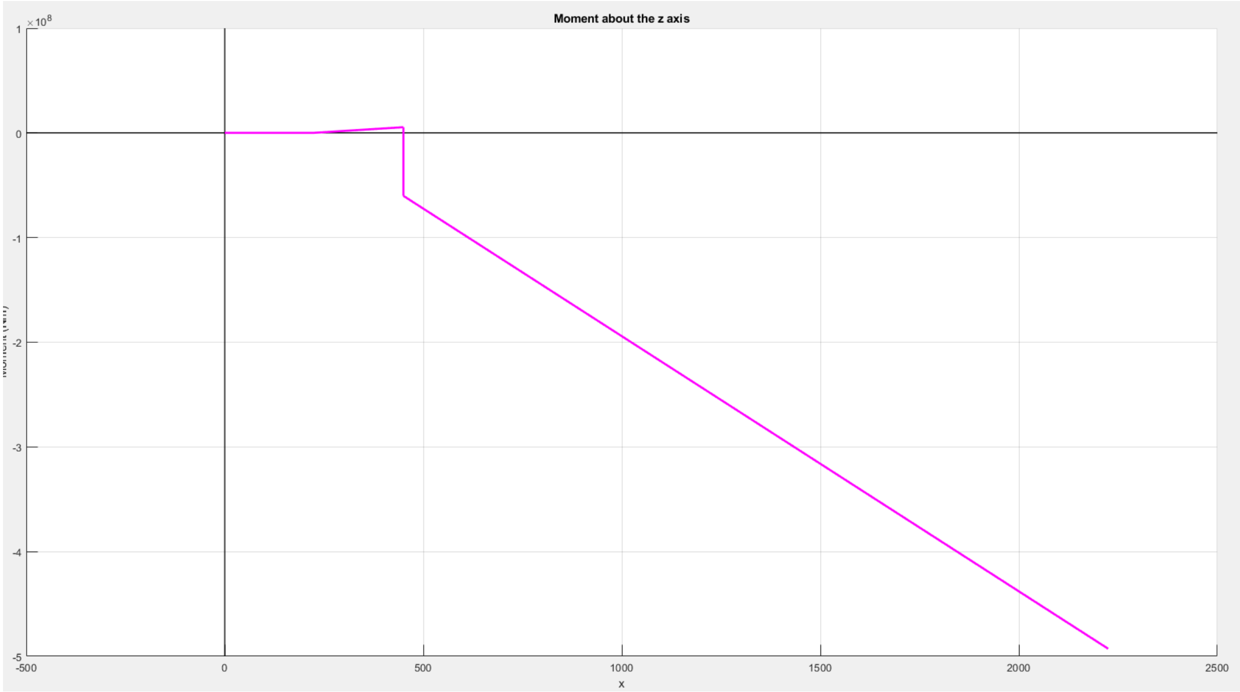


Figure 42: Moment about the z-axis

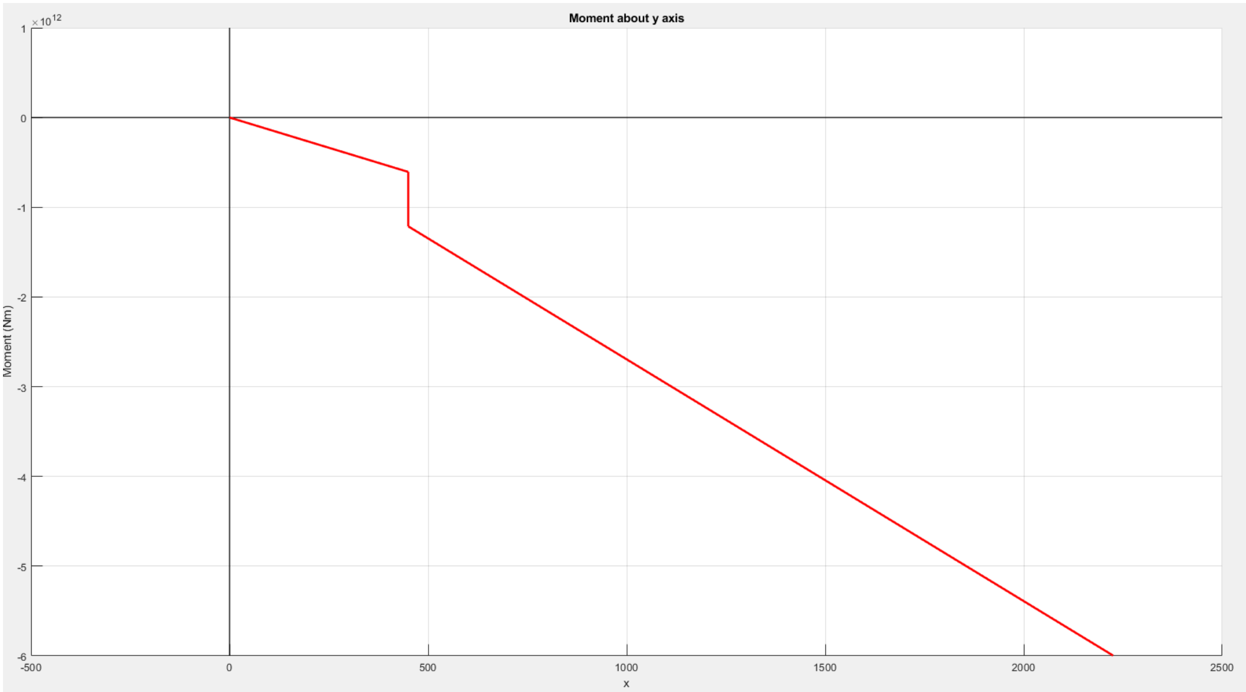


Figure 43: Moment about the y-axis

11.3.1 Key design

To connect the gears to the shaft either a key or a spline can be used. If loads are small enough, a key will be sufficient. First it is assumed that the loads are small enough, and the size of a key that would suffice will be calculated. If the calculated length of the key happens to be larger than the thickness of the gear, a key does not suffice, and a spline calculation will have to be done. A key calculation was done first, since keys are cheaper than splines.

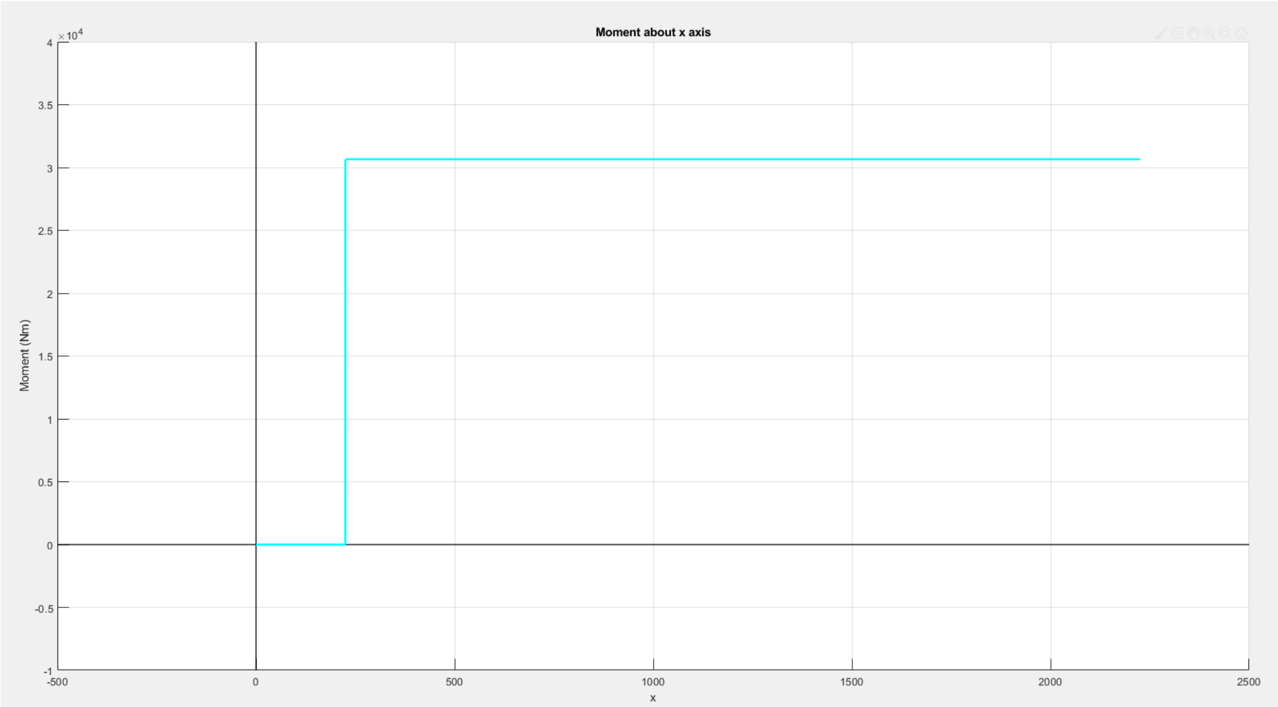


Figure 44: Moment about the x-axis

The width and height of the key can be determined according to DIN 6885. As previously calculated, the diameter of the shaft connected to the drum is 53.58 mm. A shaft with a diameter between 50 and 58 mm requires a key width of 16 mm and a key height of 10 mm.

The chosen material for the key is AISI 4330 Alloy Steel, with a yield strength of 690 MPa. The chosen material for the shaft is AISI S45C Carbon Steel, with a yield strength of 310 MPa. A safety factor N of 2 is used.

With this information, the allowable compressive and shear stresses can be calculated.

$\tau = \frac{0.5*\sigma_y}{N} = 172.5N/mm^2$

$\sigma = \frac{\sigma_y}{N} = 155N/mm^2$

Using the gear with the highest torque T, 8091400 Nmm (8091.4 Nm), the minimum length of the key is calculated using the equations below, in which h is the height of the key, b is the width of the key and d is the diameter of the shaft that the key will be applied to. Minimum lengths are calculated below.

$\tau = \frac{2*T}{d*b*l}; l = 109.4mm$

$\sigma = \frac{4*T}{d*h*l}; l = 389.7mm$

The minimum length obtained due to compressive stresses is far more decisive in this case. However, the length of the key is longer than the width of the gear; the width is 336 mm. A spline is an alternative, and is suitable for high torque situations, but it is costly to position the spline on the shaft correctly. Instead, in order to lower the length of the key, multiple keys can be used to distribute the stresses.

11.4 Weld, Bolt, Cable and

11.4.1 Shaft of the hinge-point of the boom

Using the obtained values for the forces on the shaft, the diameter of the shaft was calculated. In order to analyze the shaft it was important to determine whether the shaft was in dynamic or static load. Since it is a hinge shaft and the rotations per minute are lower than 10 it is considered to be under a static load.The following equation had to be used for this shaft.

$D_{min} = \sqrt{(2.94 * K_t * VN) \div (S_n)}$

Where D is the minimum diameter, N is a safety factor, K_t is the stress concentration factor, M is the applied moment, S_n is the Endurance strength or fatigue limit of the material, T is the applied torsional moment and V is the shear force. K_t depends on the radius of the fillets of the changes in diameter of the shaft and since this shaft has a wide fillet diameter to prevent high stress concentration the value of $K_t = 2.0$ was used. Using the FEM model for the boom, it can be deduced that the forces acting on the hinge have a resultant radial force, and hence, shear force of 380 KN. As a result, the force is distributed evenly between both bearings and for each end, V = 190KN. A safety factor was already used in the FEM model of the boom, hence the for this calculation $N = 1$ was used. The material of the hinge is grade 316 stainless steel, which has a yield strength of 206 MPa, and hence, and modified endurance strength of about have the yield strength, S_n =103 MPa. Finally, the minimum shaft diameter is found to be around 100 mm.

11.4.2 Bearing for the hinge point

The hinge operates on static load. The bearing is subjected to a radial force which is equal to resultant of the shear forces acting on it (190 kN). While no axial forces act on the shaft, and hence the bearing, the axial force to radial force ratio is equal to zero yielding to an equivalent force which is equal to the radial force, $P_0 = V$.

The static load rating is C_0 is equivalent to the load that produces 0.01% permanent deformation on the roller diameter. Since the safety factor was incorporated in the fem model of the boom, the static safety factor taken is $S_0 = 1$. Hence, the static load rating is the same as the equivalent load, resulting in $C_0 = P_0$.

Knowing the minimum shaft diameter, and the maximum static load rating, it was then possible to select a suitable bearing. Finally, single row cylindrical roller bearings were chosen since their diameter is 130 mm which is higher than the minimum diameter, and their static load rating is 166 KN. Cylindrical roller bearing have better load distribution due to larger supporting surface compared to ball bearings.

Inner Diameter (mm)	Outer Diameter (mm)	Dynamic basic load rating (KN)	Static basic load rating (KN)
130	200	165	224

Table 14: Properties of the chosen cylindrical bearing

11.4.3 Bolt calculations

For the bolt design, a bolt in the frame was chosen. This bolt is situated at the supports of the frame. The compressive stress between the support and the lower frame part is 37.9 MPa, however, not all this stress will be counteracted by friction from bolts. Approximately 1% will be counteracted by the friction from bolts, and because this stress has to be counteracted by friction, the bolts will have to be preloaded. The necessary preload is calculated using the equation below.

$$F_{kl} = \frac{F_q}{\mu * n}$$

At the supports 8 bolts, per support will be used. The friction coefficient of steel lies between 0.5 - 0.8. so in order to make a worst scenario calculation, a friction coefficient of 0.5 will be used.

Filling in the calculation, one comes to the conclusion that the clamping force should be 95 kPa per bolt. The safety factor was already incorporated in the load.

The bolts are made out of grade 10.9 steel. This gives it a yield strength of 900 MPa. This means that the minimum tensile area of the bolt should be:

$$A_t = \frac{F}{\sigma} = \frac{95}{9e5} = 105mm^2$$

This would mean that the tensile stress area of an M14 bolt would suffice.

11.4.4 Cable

For the calculations of the cables that are supporting and lifting the boom, the maximum force on the cables is exerted in an ideal situation when the boom is lifted for an infinite small distance. However in these calculations this distance is assumed to be 0 so the boom is calculated in horizontal position.

For the cables to be exposed to the least amount of force and also for the motor to deliver the lowest amount of work, the cables have to be mounted to the boom in most right position (see Figure 45). However obviously it can't be more than the height of the crane since the cables can't be in a higher position than this top when the boom is lifted.

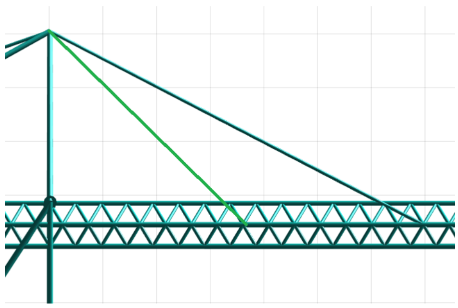


Figure 45: Cable positioning on boom

For the calculations of the tensional force in the cables a free body diagram is drawn, see Figure 46.

In figure 46 point A is the hinge of the boom. Point B is the distributed load (drawn as point

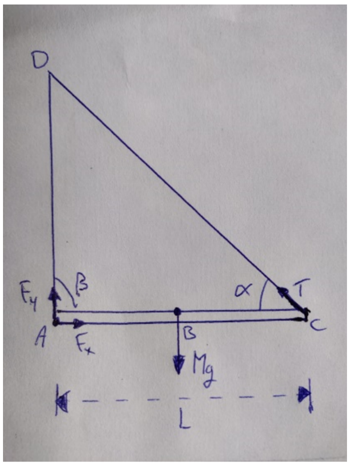


Figure 46: Free Body Diagram of the cables

load) of the weight of the boom which is Mg = 200 tons. Point C is the point where the cables are mounted to the boom. Angle alpha is the associated angle, which is 45 degrees. Point D is the top of the crane. Force T is the tensional force in the cable that has to be calculated.

To calculate the force in the cables in static position the following equilibrium equations are made.

$$\sum Fy = 0:$$
$$Fy + \tau y = 0$$
$$Fy + \tau sin(\alpha) – Mg * a = 0$$
$$Fy + \tau sin(45) – 200.000 * 9,81 = 0$$

$$\sum Fx = 0:$$
$$Fx - \tau x = 0$$
$$Fx - \tau sin(\alpha) = 0$$

$$\sum \tau = 0:$$
$$\tau Fy = 0$$
$$\tau Fx = 0$$
$$-\tau + \tau = 0$$
$$Mg * a * \frac{1}{2}L - T * L = 0$$
$$Mg * a * \frac{1}{2} - Tsin(\alpha) = 0$$
$$Tsin(\alpha) = Mg * a * \frac{1}{2}$$
$$T = \frac{Mg * a * \frac{1}{2}}{sin(\alpha)}$$

$$T = \frac{200.000 * 9,81 * \frac{1}{2}}{sin(45)}$$

$$T = 1.386.343,5N = 1.386kN$$

After the tensional force in the cables is calculated, the type of cable can be chosen. The variables that are needed to be taken into account are the material, diameter and type of weave. The material is already chosen which is a steel wire rope.

The cables are mounted to the boom on both sides so the maximum tensional force can be divide by 2 which makes the force 693 kN per cable. The most suitable cable fitting these requirements is a 7 x 19 (WSC) steel wire cable with a diameter of 32mm and a minimum breaking load of 1,960 N/mm^2. This cable can be exposed to a force of 727 kN, which gives a margin to the 693,67 kN. The type of weave of this cable is shown in figure 47. This cable also fits the requirements for the minimum bend radius of the drum.

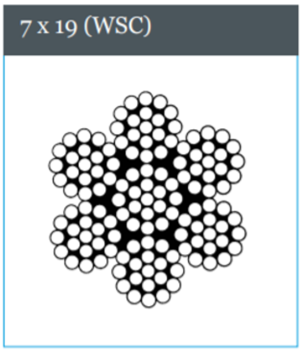


Figure 47: 7 x 19 (WSC) steel wire cable

11.4.5 Fold-able support

The green diagonal rod is supporting the boom when it is in it's lowest position (horizontal). At this position, the construction is exposed to the maximum load while lifting the containers. When the boom is lifted, this rod bends at a hinge point. For the calculations of the position of this hinge point, it is to be mentioned that the point where this rod is connected to the boom is not at the same height as the hinge point of the boom. Both hinge points are shown by black dots in figure 48. For the calculations this difference (yellow triangle in figure 48) is assumed to be negligible since the hinge point is calculated for the boom in complete vertical direction. However, the boom only needs to be lifted up to an angle of 70 degrees, which gives a small margin for the positioning of the hinge point. The small difference of the actual position and the calculated position is small enough to fit this margin. Due to this assumption, the position of the hinge point can be calculated for a right-triangle (green triangle in figure 48) using Pythagoras. The total length of the rod is 38.3 m. The hinge point is positioned at 9.75 m, measured from the top of the rod.

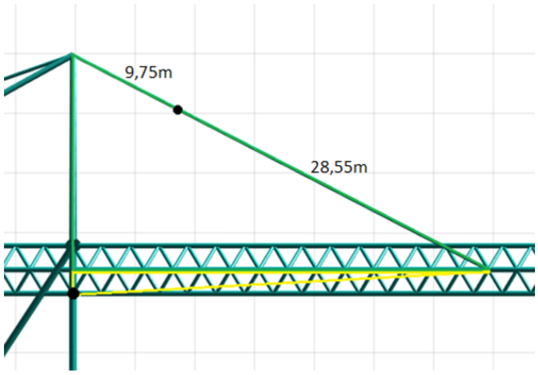


Figure 48: Hinge point rod supporting boom

11.5 Inertia

The resistance that the motor experiences due acceleration can be described using the moment inertia. Two motors of the hoist need to overcome the resistance caused by the moment of inertia of the motors the motor shaft, the gears the drum shaft, the pulleys and the linear inertia of the container. These can be calculated using density, volume and formulas given for inertia calculations. The density and volume are required in order to find the masses.

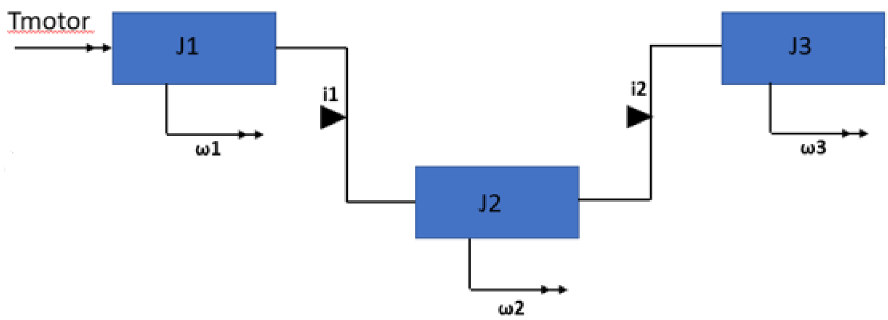


Figure 49: Inertia Scheme

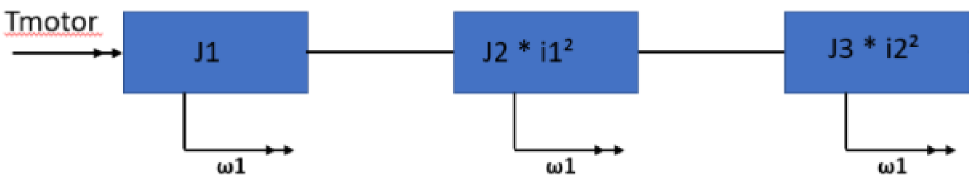


Figure 50: Inertia Scheme

$J = \frac{1}{2}m * r^2$; (for a solid cilinder.)

$J = J_1 + J_2 * i_1^2 + J_3 * i_1^2 * i_2^2$

$J_1 = 0.48kgm^2$
$J_2 = 818.7kgm^2$
$J_3 = 196200kgm^2$
$W_1 = 155.52rads * s^-1$
$W_2 = 80rads * s^-1$
$I_1 = 8$
$I_2 = 1.944$
This would mean that J on the motor side equals 47.3e6 kgm^2.

11.5.1 Weld calculation

The element that is chosen to perform the calculations on lies in the lower part of the frame. This frame element has nodenumbers 247 to 249, or element number 726. The stresses in this element are mostly bending stress and normal stresses. The forces at the connections are 1.23 MPa in perpendicular direction to the weld connection.

The diameter of this element is 0.5 m and its length is equal to 28.8 m. The chosen weld connection is an all-around circular weld connection. The normal stress in the beam is in the x-direction and is 1.22 MPa. The allowable shear stress of the weld for a weld made by a electrode type E70 is 145 MPa. The allowable normal stress of the weld is 0.6 times the shear stress and this is 87 MPa. By using a fillet weld leg of 5 mm the stress in the weld will be 30.7 MPa and the weld has a safety factor of 2.8. An example of this weld can been seen in figure 52.

Giving the following calculations:

$$A_w = \frac{\pi(D+a)^2}{4} - \frac{\pi(D-a)^2}{4}$$
$$A_b = \frac{\pi((D)^4}{4}$$
$$A_b = s \cdot A_b$$
$$S = \frac{F}{A_w} \cdot 10^6$$
$$Safety - factor = \frac{S_t}{S}$$

12 Final Concept

The final concept will consist of the parts mentioned in the previous chapter in order to best fulfill the requirements given at the start of the report. The boom will look as portrayed in figure 23. This is to minimize the deformation and the internal stresses in the boom and to stay below the given threshold of both. The boom will be made out of ASTM-A656 alloyed steel (high strength-alloy steel) in order to deal with these stresses and not fail.

The results from the FEM calculations show us that the boom has lower deflections than was asked for. This means that the boom meets structural requirements.

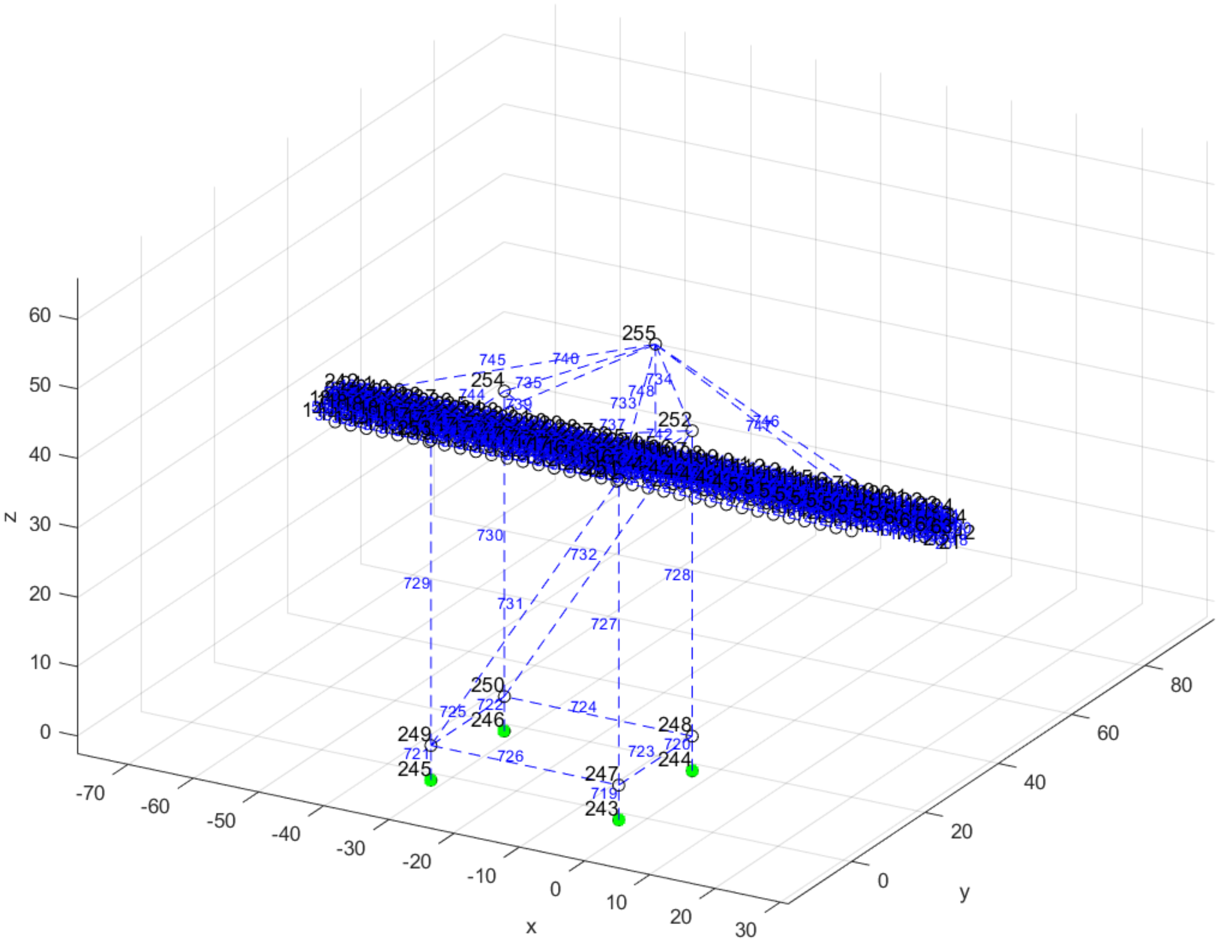


Figure 51: The nodes of the frame which are connected with the ground.

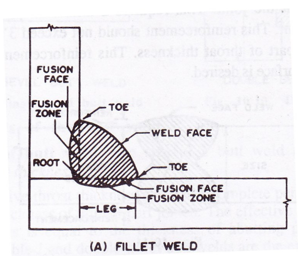


Figure 52: A picture of the weld

Another requirement was that it should be able to unload a vessel 300m in length, 35m in width and 40m in height (from the waterline). This is something that is taken care of by adjusting the dimensions of the boom. So this requirement is also fulfilled. The hinge point of the boom will have a shaft diameter of 100mm and a cylindrical roller bearing will be used, with the dimensions as specified in the related chapter. The cable to hoist the boom up and down will have a diameter of 34mm.

For the requirement of the hoist and trolley, a suitable motor and transmission was chosen by calculating the required torque and desired angular velocity. And also for the hoist a suitable motor as well as a gearbox have been chosen, with according calculations. The transmission-ratio was determined to be 1.94.. this was done to avoid a hunting tooth and prolong its lifetime.

The chosen motor is the semiotics SD motor with efficiency class IE3/premium since that is what the government requires from companies to save the environment and the motor is IC411-totally-enclosed fan-cooled, because this motor satisfies the most properties that have to be taken into account. The dimensions of the parts chosen are as followed: the shaft of the motor will have a diameter of 53.58 mm and will use multiple keys in order to transfer the required torque. But the width of the keys will be 16 mm and the height will be 10 mm.

12.0.1 Evaluation and redesign

Over the years, worldwide trade has been following a trend of exponential growth resulting in a much higher work rate, and leading to increased demand in productivity. Automation technology can provide a suitable to increase productivity. STS cranes can operate with automation features to aid or possibly replace crane operators, leading to a rise in productivity and hence, efficiency. Different approaches can be implemented in such STS cranes leading to more complex crane designs.

An Automated container landing system allows for automatic loading and unloading of containers without the need of operator skills.

In addition to such an automated system, skew control can be implemented which utilizes a skew pendulum which is induced by unevenly distributed load. This system can be used as a solution counteract the deviation in hoisting landing positions during high wind speeds.

Other possible redesign ideas for our STS crane would include adjusting the hoisting system into a dual hoisting system. Such design is however, implemented in dual hoist gantry cranes and not yet in STS cranes due to its complexity. Since this must be done in such a way that the total capacity of both hoist combined falls within the crane design capacity, while also accounting for the lifted part of the boom

Currently the drum is connected to a single gear on a single side and the bending moment and torsion is really high. This results in expensive material choice and complicated design. In order to prevent this 2 gearboxes with a single motor can be places on the either sides of the drum. This will divide the bending and torsion moments by 2 reducing the stresses in the shafts allowing a cheaper material to be selected and a simpler shaft design to be drawn.
However, automation processes can lead to very complicated mechanisms. Besides, some ideas may not be welcomed by crane operators due to, in this case, inevitable decrease in labor.

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The Matlab code of the calculations of the frame and the boom

```
%% Definition of material properties
% define Elastic modulus, take for all elements the same E. E is here
% defined for steel. nu is the poisson-factor, necessary for
calculating the shear modulus.

addpath support_functions_Frame_3D

E = 200e9;
nu = 0.29;
G = E/(2*(1+nu));
rho = 7805;

L_1 = 2.400; %the distance between beams in x direction in the boom
L_2 = 4.000; %the distamce between beams in z direction in the boom
L_3 = 2.000; %the distance between beams in y direction of middle beams
in the boom
L_4 = 4.000; %the distance bewteen beams in y direction of top beams in
the boom
D_1 = 0.500; %the diameter of the large beams in the boom
T_1 = 0.050; %the thickness of the large beams in the boom
D_2 = 0.300; %the diameter of the small beams in the boom
T_2 = 0.020; %the thickness of the small beams in the boom
D_3 = 0.500; %the diameter of the beams of the frame
T_3 = 0.250; %the thickness of the beams of the frame
D_4 = 1.000; %the diameter of the cross beams of the frame
T_4 = 0.500; %the thickness of the cross beams of the frame
D_5 = 0.400; %the diameter of the bars connected to the boom and the
frame
T_5 = 0.200; %the thickness cable of the bars connected to the boom and
the frame
D_6 = 0.300; %the diameter cable connected with backside of the boom
and the frame
T_6 = 0.150; %the thickness cable connected with backside of the boom
and the frame
```

```
%%% define coordinates of the nodes [meter]
A =          [0,0,0;
              1.*L_1,0,0;
              2.*L_1,0,0;
              3.*L_1,0,0;
              4.*L_1,0,0;
              5.*L_1,0,0;
              6.*L_1,0,0;
              7.*L_1,0,0;
              8.*L_1,0,0;
              9.*L_1,0,0;
              10.*L_1,0,0;
              11.*L_1,0,0;
              12.*L_1,0,0;
              13.*L_1,0,0;
              14.*L_1,0,0;
              15.*L_1,0,0;
              16.*L_1,0,0;
              17.*L_1,0,0;
              18.*L_1,0,0;
              19.*L_1,0,0;
              20.*L_1,0,0;
              0,0,L_2;
              1.*L_1,0,L_2;
              2.*L_1,0,L_2;
              3.*L_1,0,L_2;
              4.*L_1,0,L_2;
              5.*L_1,0,L_2;
              6.*L_1,0,L_2;
              7.*L_1,0,L_2;
              8.*L_1,0,L_2;
              9.*L_1,0,L_2;
              10.*L_1,0,L_2;
              11.*L_1,0,L_2;
              12.*L_1,0,L_2;
              13.*L_1,0,L_2;
              14.*L_1,0,L_2;
              15.*L_1,0,L_2;
              16.*L_1,0,L_2;
              17.*L_1,0,L_2;
              18.*L_1,0,L_2;
              19.*L_1,0,L_2;
              20.*L_1,0,L_2;
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              0.5*L_1,L_3,0;
              1.5*L_1,L_3,0;
              2.5*L_1,L_3,0;
              3.5*L_1,L_3,0;
              4.5*L_1,L_3,0;
              5.5*L_1,L_3,0;
              6.5*L_1,L_3,0;
              7.5*L_1,L_3,0;
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```
8.5*L_1,L_3,0;
9.5*L_1,L_3,0;
10.5*L_1,L_3,0;
11.5*L_1,L_3,0;
12.5*L_1,L_3,0;
13.5*L_1,L_3,0;
14.5*L_1,L_3,0;
15.5*L_1,L_3,0;
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2.5*L_1,L_3,L_2;
3.5*L_1,L_3,L_2;
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6.5*L_1,L_3,L_2;
7.5*L_1,L_3,L_2;
8.5*L_1,L_3,L_2;
9.5*L_1,L_3,L_2;
10.5*L_1,L_3,L_2;
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12.5*L_1,L_3,L_2;
13.5*L_1,L_3,L_2;
14.5*L_1,L_3,L_2;
15.5*L_1,L_3,L_2;
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14.*L_1,L_3,0.5.*L_2;
15.*L_1,L_3,0.5.*L_2;
16.*L_1,L_3,0.5.*L_2;
17.*L_1,L_3,0.5.*L_2;
18.*L_1,L_3,0.5.*L_2;
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0.0,L_4,0.5.*L_2;
1.*L_1,L_4,0.5.*L_2;
2.*L_1,L_4,0.5.*L_2;
3.*L_1,L_4,0.5.*L_2;
4.*L_1,L_4,0.5.*L_2;
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9.*L_1,L_4,0.5.*L_2;
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-10.*L_1,0,0;
-11.*L_1,0,0;
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-14.*L_1,0,0;
-15.*L_1,0,0;
-16.*L_1,0,0;
-17.*L_1,0,0;
-18.*L_1,0,0;
-19.*L_1,0,0;
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-5.*L_1,0,L_2;
-6.*L_1,0,L_2;
-7.*L_1,0,L_2;
-8.*L_1,0,L_2;
-9.*L_1,0,L_2;
-10.*L_1,0,L_2;
-11.*L_1,0,L_2;
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-12.*L_1,0,L_2;
-13.*L_1,0,L_2;
-14.*L_1,0,L_2;
-15.*L_1,0,L_2;
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-18.*L_1,0,L_2;
-19.*L_1,0,L_2;
-20.*L_1,0,L_2;
-0.5*L_1,L_3,0;
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-1.5*L_1,L_3,L_2;
-2.5*L_1,L_3,L_2;
-3.5*L_1,L_3,L_2;
-4.5*L_1,L_3,L_2;
-5.5*L_1,L_3,L_2;
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-15.5*L_1,L_3,L_2;
-16.5*L_1,L_3,L_2;
-17.5*L_1,L_3,L_2;
-18.5*L_1,L_3,L_2;
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-1.*L_1,L_3,0.5.*L_2;
-2.*L_1,L_3,0.5.*L_2;
-3.*L_1,L_3,0.5.*L_2;
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-4.*L_1,L_3,0.5.*L_2;
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-7.*L_1,L_4,0.5.*L_2;
-8.*L_1,L_4,0.5.*L_2;
-9.*L_1,L_4,0.5.*L_2;
-10.*L_1,L_4,0.5.*L_2;
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-15.*L_1,L_4,0.5.*L_2;
-16.*L_1,L_4,0.5.*L_2;
-17.*L_1,L_4,0.5.*L_2;
-18.*L_1,L_4,0.5.*L_2;
-19.*L_1,L_4,0.5.*L_2;
0,-45,-8
0,-45,12
-28.8,-45,-8
-28.8,-45,12
0,-40,-8
0,-40,12
-28.8,-40,-8
-28.8,-40,12
0,4,-8
0,4,12
-28.8,4,-8
-28.8,4,12
0,20,2]
```

```
B = zeros(255,3)
B(:,3) = 45.*ones(255,1)
xyz_nodes = zeros(255,3)

xyz_nodes(:,1) = A(:,1)
xyz_nodes(:,2) = A(:,3)
xyz_nodes(:,3) = A(:,2) + B(:,3)
```

```
%% define which nodes are connected by elements and
elements = [1,2
            2,3
            3,4
            4,5
            5,6
            6,7
            7,8
            8,9
            9,10
            10,11
            11,12
            12,13
            13,14
            14,15
            15,16
            16,17
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            32,33
            33,34
            34,35
            35,36
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            39,40
            40,41
            41,42
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123,124
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%% define outer diameter and wall thickness of each element [meter]
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```
%% define constraints for each node
% x,y,z, rotx, roty, rotz; 0 = no constraints, 1 = constraint

xyz_constr = [0, 0, 0, 0, 0, 0
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```
%% define external forces/moments
% [node number, direction(1=x,2=y,3=z 4=moment x, 5= moment y, 6=
moment z), magnitude]

ext_forces = [20, 3, (-1000000/4)
              21, 3, (-1000000/4)
              42, 3, (-1000000/4)
              41, 3, (-1000000/4)];

%% define plot settings
% Plot 1
plot_undeformed         = true;
plot_undeformed_labels = true;
plot_undeformed_forces = true;
plot_deformed          = false;
plot_deformed_labels   = false;
plot_deformed_forces   = false;

% Plot 2
plot_undeformed_tubes  = true;

% Plot 3
plot_deformed_tubes    = true;
color_deformations     = false;
color_stress           = true;

% Plot deformation scaling: visual displacements will be multiplied
% with this factor
f = 10;

%% Calculation of model parameters and element splitting (DON'T EDIT!)
% Calculate area of each element
A = 0.25*pi*( C(:,1).^2 - (C(:,1)-2.*C(:,2)).^2);

% Calculate area moments of inertia
I = [(1/64)*pi*( C(:,1).^4 - (C(:,1)-2.*C(:,2)).^4) , (1/64)*pi*(
C(:,1).^4 - (C(:,1)-2.*C(:,2)).^4)];
J = sum(I,2);

% Automatic element split
[xyz_nodes,elements,element_split,A,I,J,C,xyz_constr] =
split_elements(xyz_nodes,elements,element_split,A,I,J,C,xyz_constr);
```

Local stresses in Pascals in different cross-sections of the elements

Elements	Sxx	Syy	Szz	Sxy	Syz	Sxz
1	-5.2684e+07	0	0	55919	0	-4.7448e+05
2	-4.031e+07	0	0	-38254	0	-1.8883e+05
3	-3.4552e+07	0	0	-1.1371e+05	0	-1.5533e+05
4	-3.0157e+07	0	0	-96553	0	-1.07e+05
5	-2.7051e+07	0	0	-61223	0	-81758
6	-2.4589e+07	0	0	-36897	0	-58242
7	-2.281e+07	0	0	-23093	0	-37889
8	-2.1671e+07	0	0	-15879	0	-18633
9	-2.1158e+07	0	0	12219	0	295.89
10	-2.1674e+07	0	0	11498	0	18290
11	-2.2758e+07	0	0	13991	0	35248
12	-2.4415e+07	0	0	21598	0	52606
13	-2.645e+07	0	0	35762	0	60697
14	-2.8661e+07	0	0	29552	0	62997
15	-3.6092e+07	0	0	-46391	0	2.9074e+05
16	-3.9976e+07	0	0	-33248	0	75507
17	-3.4884e+07	0	0	9513.6	0	-6.7393e+05
18	-1.687e+07	0	0	59177	0	-1.8278e+05
19	-1.1641e+07	0	0	51648	0	-3.8286e+05
20	-3.9308e+06	0	0	-27399	0	34121
21	-5.2684e+07	0	0	-55919	0	-4.7448e+05
22	-4.031e+07	0	0	38254	0	-1.8883e+05
23	-3.4552e+07	0	0	1.1371e+05	0	-1.5533e+05
24	-3.0157e+07	0	0	96553	0	-1.07e+05
25	-2.7051e+07	0	0	61223	0	-81758
26	-2.4589e+07	0	0	36897	0	-58242
27	-2.281e+07	0	0	23093	0	-37889
28	-2.1671e+07	0	0	15879	0	-18633

29	-2.1158e+07	0	0	-12219	0	295.89
30	-2.1674e+07	0	0	-11498	0	18290
31	-2.2758e+07	0	0	-13991	0	35248
32	-2.4415e+07	0	0	-21598	0	52606
33	-2.645e+07	0	0	-35762	0	60697
34	-2.8661e+07	0	0	-29552	0	62997
35	-3.6092e+07	0	0	46391	0	2.9074e+05
36	-3.9976e+07	0	0	33248	0	75507
37	-3.4884e+07	0	0	-9513.6	0	-6.7393e+05
38	-1.687e+07	0	0	-59177	0	-1.8278e+05
39	-1.1641e+07	0	0	-51648	0	-3.8286e+05
40	-3.9308e+06	0	0	27399	0	34121
41	-3.1659e+06	0	0	-2.6482e+05	0	10524
42	-1.9306e+07	0	0	-5.3793e+05	0	-4.5899e+05
43	-1.3517e+07	0	0	-2.0942e+05	0	-2.0935e+05
44	-1.4422e+07	0	0	-1.4532e+05	0	-1.4441e+05
45	-1.4843e+07	0	0	-87814	0	-1.2271e+05
46	-1.489e+07	0	0	-49501	0	-97487
47	-1.482e+07	0	0	-29797	0	-70248
48	-1.4641e+07	0	0	-16450	0	-41092
49	-1.4402e+07	0	0	-5280.5	0	-11646
50	-1.4562e+07	0	0	10370	0	17344
51	-1.4998e+07	0	0	23027	0	46483
52	-1.5473e+07	0	0	38057	0	75803
53	-1.5939e+07	0	0	56586	0	99053
54	-1.7354e+07	0	0	1.031e+05	0	1.5365e+05
55	-1.6457e+07	0	0	1.4179e+05	0	-38710
56	-3.6208e+07	0	0	2.8773e+05	0	1.0085e+06
57	3.8483e+07	0	0	-1.1258e+05	0	-1.2248e+06
58	1.2689e+07	0	0	-2.2862e+05	0	-1.4753e+05
59	1.0734e+07	0	0	-2.8669e+05	0	-3.818e+05

60	5.7426e+06	0	0	-1.4305e+05	0	-1.7238e+05
61	-3.1659e+06	0	0	2.6482e+05	0	10524
62	-1.9306e+07	0	0	5.3793e+05	0	-4.5899e+05
63	-1.3517e+07	0	0	2.0942e+05	0	-2.0935e+05
64	-1.4422e+07	0	0	1.4532e+05	0	-1.4441e+05
65	-1.4843e+07	0	0	87814	0	-1.2271e+05
66	-1.489e+07	0	0	49501	0	-97487
67	-1.482e+07	0	0	29797	0	-70248
68	-1.4641e+07	0	0	16450	0	-41092
69	-1.4402e+07	0	0	5280.5	0	-11646
70	-1.4562e+07	0	0	-10370	0	17344
71	-1.4998e+07	0	0	-23027	0	46483
72	-1.5473e+07	0	0	-38057	0	75803
73	-1.5939e+07	0	0	-56586	0	99053
74	-1.7354e+07	0	0	-1.031e+05	0	1.5365e+05
75	-1.6457e+07	0	0	-1.4179e+05	0	-38710
76	-3.6208e+07	0	0	-2.8773e+05	0	1.0085e+06
77	3.8483e+07	0	0	1.1258e+05	0	-1.2248e+06
78	1.2689e+07	0	0	2.2862e+05	0	-1.4753e+05
79	1.0734e+07	0	0	2.8669e+05	0	-3.818e+05
80	5.7426e+06	0	0	1.4305e+05	0	-1.7238e+05
81	-1.2505e+07	0	0	1.4433e-07	0	-1.1795e+05
82	-1.3853e+07	0	0	9.041e-08	0	-75101
83	-1.2444e+07	0	0	8.0773e-08	0	-12581
84	-1.2481e+07	0	0	1.9652e-08	0	-8100.9
85	-1.2963e+07	0	0	-6.5462e-10	0	-6813.4
86	-1.3396e+07	0	0	-4.1009e-09	0	-4937.6
87	-1.3704e+07	0	0	2.4542e-09	0	-3288.5
88	-1.3901e+07	0	0	1.2083e-08	0	-1599.2
89	-1.4017e+07	0	0	-5.3093e-08	0	66.991
90	-1.4135e+07	0	0	-9.374e-08	0	1722.5

91	-1.4223e+07	0	0	-1.018e-07	0	3403.6
92	-1.4271e+07	0	0	-5.3516e-08	0	4610
93	-1.4225e+07	0	0	9.2345e-09	0	8137.3
94	-1.3034e+07	0	0	-7.8486e-08	0	-8014.6
95	-1.4581e+07	0	0	2.0244e-07	0	1.4172e+05
96	-1.0925e+07	0	0	2.13e-07	0	16795
97	1.0432e+07	0	0	1.5249e-07	0	-1.5237e+05
98	6.079e+06	0	0	3.7356e-08	0	-17307
99	2.6294e+06	0	0	1.4363e-07	0	-10604
100	5.468e+07	0	0	1.0759e-07	0	-2.2132e+06
101	1.8077e+07	0	0	5.7211e-08	0	3.6386e+05
102	1.1749e+07	0	0	-5.8013e-08	0	-1.6122e+05
103	6.7899e+06	0	0	-2.4296e-09	0	-1.0889e+05
104	3.2115e+06	0	0	2.2506e-09	0	-92488
105	-3.02e+06	0	0	-3.6437e-09	0	-69744
106	-4.2466e+06	0	0	-4.7688e-09	0	-45461
107	-4.8087e+06	0	0	4.5847e-09	0	-20252
108	-4.8077e+06	0	0	-1.1926e-07	0	5827
109	-4.5722e+06	0	0	-1.7058e-07	0	32854
110	-3.5844e+06	0	0	-1.9812e-07	0	60686
111	1.957e+06	0	0	1.2994e-07	0	91394
112	5.9223e+06	0	0	-8.6975e-09	0	1.2455e+05
113	1.0806e+07	0	0	-1.0789e-07	0	1.4868e+05
114	2.5399e+07	0	0	-2.1085e-07	0	5.5614e+05
115	2.952e+07	0	0	3.4073e-07	0	-85807
116	2.5281e+07	0	0	2.4257e-07	0	-3.2234e+05
117	1.5763e+07	0	0	1.6071e-07	0	-2.5371e+05
118	8.6662e+06	0	0	1.1701e-07	0	-2.3106e+05
119	2.6988e+07	0	0	-4.9761e+05	0	-1.0035e+05
120	-8.7414e+06	0	0	84328	0	2.5831e+05
121	1.6598e+07	0	0	78642	0	-68016

122	-3.0066e+07	0	0	-1.7573e+05	0	7.8506e+05
123	1.998e+07	0	0	1.0308e+05	0	2.1708e+05
124	-2.7745e+07	0	0	-1.458e+05	0	6.9342e+05
125	1.5405e+07	0	0	1.2785e+05	0	1.403e+05
126	-2.2941e+07	0	0	-35969	0	6.1444e+05
127	1.1462e+07	0	0	73044	0	78174
128	-1.869e+07	0	0	1088.5	0	5.2517e+05
129	7.9497e+06	0	0	41038	0	21767
130	-1.4918e+07	0	0	3332.3	0	4.4558e+05
131	6.5979e+06	0	0	-35278	0	-55401
132	-1.142e+07	0	0	1312.1	0	3.7215e+05
133	5.57e+06	0	0	-21222	0	-1.1655e+05
134	-8.1224e+06	0	0	808.2	0	3.0369e+05
135	4.6313e+06	0	0	-10413	0	-1.7763e+05
136	-4.9916e+06	0	0	2327.4	0	2.3978e+05
137	-4.9855e+06	0	0	3715.5	0	-2.3936e+05
138	4.6915e+06	0	0	-2533.7	0	1.8048e+05
139	-7.9691e+06	0	0	-2550.8	0	-3.0178e+05
140	5.6405e+06	0	0	-3995	0	1.2663e+05
141	-1.0881e+07	0	0	-7757.3	0	-3.6437e+05
142	6.635e+06	0	0	-5551.8	0	79956
143	-1.3595e+07	0	0	-10847	0	-4.2353e+05
144	7.6503e+06	0	0	984.04	0	41384
145	-1.5982e+07	0	0	-5479.8	0	-4.8448e+05
146	9.089e+06	0	0	21986	0	37313
147	-1.7904e+07	0	0	-10351	0	-5.1665e+05
148	9.9118e+06	0	0	99111	0	-50615
149	-1.5434e+07	0	0	-76613	0	-4.8375e+05
150	2.3073e+07	0	0	-1.7743e+05	0	7.8811e+05
151	4.543e+07	0	0	88723	0	3.8481e+05
152	-5.2689e+07	0	0	-24457	0	1.0079e+06

153	4.8823e+07	0	0	39125	0	1.0868e+06
154	-4.7212e+07	0	0	35099	0	9.4541e+05
155	4.0529e+07	0	0	-32077	0	8.2011e+05
156	-3.7346e+07	0	0	-50526	0	7.7505e+05
157	3.3727e+07	0	0	-29041	0	5.4368e+05
158	-1.9481e+07	0	0	-96268	0	5.9047e+05
159	2.2858e+07	0	0	-21666	0	2.8766e+05
160	2.6988e+07	0	0	-4.9761e+05	0	1.0035e+05
161	-8.7414e+06	0	0	-84328	0	2.5831e+05
162	1.6598e+07	0	0	-78642	0	-68016
163	-3.0066e+07	0	0	1.7573e+05	0	7.8506e+05
164	1.998e+07	0	0	-1.0308e+05	0	2.1708e+05
165	-2.7745e+07	0	0	1.458e+05	0	6.9342e+05
166	1.5405e+07	0	0	-1.2785e+05	0	1.403e+05
167	-2.2941e+07	0	0	35969	0	6.1444e+05
168	1.1462e+07	0	0	-73044	0	78174
169	-1.869e+07	0	0	-1088.5	0	5.2517e+05
170	7.9497e+06	0	0	-41038	0	21767
171	-1.4918e+07	0	0	-3332.3	0	4.4558e+05
172	6.5979e+06	0	0	35278	0	-55401
173	-1.142e+07	0	0	-1312.1	0	3.7215e+05
174	5.57e+06	0	0	21222	0	-1.1655e+05
175	-8.1224e+06	0	0	-808.2	0	3.0369e+05
176	4.6313e+06	0	0	10413	0	-1.7763e+05
177	-4.9916e+06	0	0	-2327.4	0	2.3978e+05
178	-4.9855e+06	0	0	-3715.5	0	-2.3936e+05
179	4.6915e+06	0	0	2533.7	0	1.8048e+05
180	-7.9691e+06	0	0	2550.8	0	-3.0178e+05
181	5.6405e+06	0	0	3995	0	1.2663e+05
182	-1.0881e+07	0	0	7757.3	0	-3.6437e+05
183	6.635e+06	0	0	5551.8	0	79956

184	-1.3595e+07	0	0	10847	0	-4.2353e+05
185	7.6503e+06	0	0	-984.04	0	41384
186	-1.5982e+07	0	0	5479.8	0	-4.8448e+05
187	9.089e+06	0	0	-21986	0	37313
188	-1.7904e+07	0	0	10351	0	-5.1665e+05
189	9.9118e+06	0	0	-99111	0	-50615
190	-1.5434e+07	0	0	76613	0	-4.8375e+05
191	2.3073e+07	0	0	1.7743e+05	0	7.8811e+05
192	4.543e+07	0	0	-88723	0	3.8481e+05
193	-5.2689e+07	0	0	24457	0	1.0079e+06
194	4.8823e+07	0	0	-39125	0	1.0868e+06
195	-4.7212e+07	0	0	-35099	0	9.4541e+05
196	4.0529e+07	0	0	32077	0	8.2011e+05
197	-3.7346e+07	0	0	50526	0	7.7505e+05
198	3.3727e+07	0	0	29041	0	5.4368e+05
199	-1.9481e+07	0	0	96268	0	5.9047e+05
200	2.2858e+07	0	0	21666	0	2.8766e+05
201	-2.4736e+07	0	0	-9.2863e+05	0	-7.1023e+05
202	-1.3119e+07	0	0	7.3605e+05	0	-4.3104e+05
203	-1.269e+07	0	0	8.1675e+05	0	-64813
204	-4.1226e+06	0	0	-15574	0	3.9392e+05
205	-4.54e+06	0	0	4.3609e+05	0	1.2375e+05
206	3.5589e+06	0	0	-2.575e+05	0	-48793
207	-3.8387e+06	0	0	4.0515e+05	0	91856
208	3.7444e+06	0	0	-2.9088e+05	0	-38374
209	-4.6298e+06	0	0	3.8701e+05	0	71728
210	3.7709e+06	0	0	-2.9727e+05	0	-28351
211	-4.8641e+06	0	0	3.6441e+05	0	52656
212	-3.9838e+06	0	0	-17964	0	2.644e+05
213	-4.9087e+06	0	0	3.4308e+05	0	33731
214	-4.2743e+06	0	0	-32250	0	2.6253e+05

215	-4.9013e+06	0	0	3.2561e+05	0	18655
216	-4.489e+06	0	0	-39249	0	2.6392e+05
217	-4.8706e+06	0	0	3.1321e+05	0	8842.9
218	-4.6438e+06	0	0	-37795	0	2.7029e+05
219	-4.8312e+06	0	0	3.0599e+05	0	4836.3
220	-4.7516e+06	0	0	-27821	0	2.8206e+05
221	-4.797e+06	0	0	3.0395e+05	0	6941.2
222	-4.8285e+06	0	0	-9475.5	0	2.9915e+05
223	-4.7821e+06	0	0	3.0739e+05	0	15607
224	-4.9117e+06	0	0	17874	0	3.2181e+05
225	-4.7879e+06	0	0	3.1495e+05	0	29274
226	-5.1585e+06	0	0	45069	0	3.4611e+05
227	-4.6833e+06	0	0	3.3523e+05	0	56406
228	-6.1377e+06	0	0	1.1221e+05	0	4.0751e+05
229	-3.9752e+06	0	0	2.701e+05	0	2291.9
230	-6.5064e+06	0	0	-9506.9	0	3.3412e+05
231	4.4875e+06	0	0	-2.7757e+05	0	-7.2746e+05
232	-1.1417e+07	0	0	5.4077e+05	0	1.2797e+06
233	1.8748e+07	0	0	-1.5921e+06	0	2.1473e+05
234	4.6997e+06	0	0	-5.261e+05	0	-6.184e+05
235	5.8379e+06	0	0	-4.6073e+05	0	85226
236	6.3878e+06	0	0	-29577	0	1.9561e+05
237	-4.3085e+06	0	0	3.2527e+05	0	-1.7213e+05
238	4.8813e+06	0	0	59450	0	1.2478e+05
239	-6.2564e+06	0	0	1.036e+05	0	-1.0273e+05
240	-5.1362e+06	0	0	54750	0	1.6874e+05
241	-7.5998e+06	0	0	6.5822e-08	0	-2.3698e-08
242	-2.4736e+07	0	0	9.2863e+05	0	-7.1023e+05
243	-1.3119e+07	0	0	-7.3605e+05	0	-4.3104e+05
244	-1.269e+07	0	0	-8.1675e+05	0	-64813
245	-4.1226e+06	0	0	15574	0	3.9392e+05

246	-4.54e+06	0	0	-4.3609e+05	0	1.2375e+05
247	3.5589e+06	0	0	2.575e+05	0	-48793
248	-3.8387e+06	0	0	-4.0515e+05	0	91856
249	3.7444e+06	0	0	2.9088e+05	0	-38374
250	-4.6298e+06	0	0	-3.8701e+05	0	71728
251	3.7709e+06	0	0	2.9727e+05	0	-28351
252	-4.8641e+06	0	0	-3.6441e+05	0	52656
253	-3.9838e+06	0	0	17964	0	2.644e+05
254	-4.9087e+06	0	0	-3.4308e+05	0	33731
255	-4.2743e+06	0	0	32250	0	2.6253e+05
256	-4.9013e+06	0	0	-3.2561e+05	0	18655
257	-4.489e+06	0	0	39249	0	2.6392e+05
258	-4.8706e+06	0	0	-3.1321e+05	0	8842.9
259	-4.6438e+06	0	0	37795	0	2.7029e+05
260	-4.8312e+06	0	0	-3.0599e+05	0	4836.3
261	-4.7516e+06	0	0	27821	0	2.8206e+05
262	-4.797e+06	0	0	-3.0395e+05	0	6941.2
263	-4.8285e+06	0	0	9475.5	0	2.9915e+05
264	-4.7821e+06	0	0	-3.0739e+05	0	15607
265	-4.9117e+06	0	0	-17874	0	3.2181e+05
266	-4.7879e+06	0	0	-3.1495e+05	0	29274
267	-5.1585e+06	0	0	-45069	0	3.4611e+05
268	-4.6833e+06	0	0	-3.3523e+05	0	56406
269	-6.1377e+06	0	0	-1.1221e+05	0	4.0751e+05
270	-3.9752e+06	0	0	-2.701e+05	0	2291.9
271	-6.5064e+06	0	0	9506.9	0	3.3412e+05
272	4.4875e+06	0	0	2.7757e+05	0	-7.2746e+05
273	-1.1417e+07	0	0	-5.4077e+05	0	1.2797e+06
274	1.8748e+07	0	0	1.5921e+06	0	2.1473e+05
275	4.6997e+06	0	0	5.261e+05	0	-6.184e+05
276	5.8379e+06	0	0	4.6073e+05	0	85226

277	6.3878e+06	0	0	29577	0	1.9561e+05
278	-4.3085e+06	0	0	-3.2527e+05	0	-1.7213e+05
279	4.8813e+06	0	0	-59450	0	1.2478e+05
280	-6.2564e+06	0	0	-1.036e+05	0	-1.0273e+05
281	-5.1362e+06	0	0	-54750	0	1.6874e+05
282	4.0563e+07	0	0	-3.2928e+05	0	5.3547e+05
283	4.212e+07	0	0	3.4433e+05	0	-5.6483e+05
284	-1.6887e+07	0	0	-4.8831e+05	0	1.0522e+06
285	2.415e+07	0	0	5.933e+05	0	-1.7113e+05
286	-1.6751e+07	0	0	2.1933e+05	0	1.9438e+05
287	1.4165e+07	0	0	1.3081e+05	0	3.0213e+05
288	-1.49e+07	0	0	1.8644e+05	0	2.2248e+05
289	1.3139e+07	0	0	1.6142e+05	0	2.3043e+05
290	-1.3325e+07	0	0	1.5462e+05	0	2.262e+05
291	1.0919e+07	0	0	1.4659e+05	0	1.8845e+05
292	-1.1137e+07	0	0	1.239e+05	0	2.1726e+05
293	8.3177e+06	0	0	1.2504e+05	0	1.4814e+05
294	-8.5693e+06	0	0	89130	0	1.9769e+05
295	5.615e+06	0	0	1.1332e+05	0	1.0487e+05
296	-5.8263e+06	0	0	17081	0	1.535e+05
297	3.2307e+06	0	0	1.199e+05	0	23966
298	-3.0723e+06	0	0	-41297	0	1.1481e+05
299	1.7074e+06	0	0	75480	0	-83193
300	2.3729e+06	0	0	1.205e+05	0	48634
301	-4.5405e+06	0	0	-1.6735e+05	0	-534.98
302	4.6167e+06	0	0	26041	0	1.2023e+05
303	-7.6416e+06	0	0	-2.0616e+05	0	-1685.1
304	7.8679e+06	0	0	-80812	0	1.3222e+05
305	-1.1072e+07	0	0	-2.3192e+05	0	7263
306	1.1771e+07	0	0	-1.7124e+05	0	1.2712e+05
307	-1.4917e+07	0	0	-2.9348e+05	0	-2128.9

308	1.6462e+07	0	0	-2.6657e+05	0	1.2151e+05
309	-1.9246e+07	0	0	-3.6782e+05	0	9958.5
310	2.2415e+07	0	0	-3.626e+05	0	87092
311	-2.4817e+07	0	0	-4.3161e+05	0	-1.6628e+05
312	2.5091e+07	0	0	-5.5463e+05	0	6.4718e+05
313	-2.3881e+07	0	0	-1.9656e+05	0	4.9039e+05
314	-1.4712e+07	0	0	4.545e+05	0	-7.5269e+05
315	1.5343e+07	0	0	49493	0	7.3469e+05
316	-2.0847e+07	0	0	2.2751e+05	0	1.9244e+05
317	2.377e+07	0	0	3.7065e+05	0	3.3825e+05
318	-2.4219e+07	0	0	2.7615e+05	0	2.2981e+05
319	2.5048e+07	0	0	3.8486e+05	0	2.4675e+05
320	-2.1589e+07	0	0	3.6474e+05	0	1.0293e+05
321	2.1039e+07	0	0	3.3612e+05	0	1.4977e+05
322	4.0563e+07	0	0	3.2928e+05	0	5.3547e+05
323	4.212e+07	0	0	-3.4433e+05	0	-5.6483e+05
324	-1.6887e+07	0	0	4.8831e+05	0	1.0522e+06
325	2.415e+07	0	0	-5.933e+05	0	-1.7113e+05
326	-1.6751e+07	0	0	-2.1933e+05	0	1.9438e+05
327	1.4165e+07	0	0	-1.3081e+05	0	3.0213e+05
328	-1.49e+07	0	0	-1.8644e+05	0	2.2248e+05
329	1.3139e+07	0	0	-1.6142e+05	0	2.3043e+05
330	-1.3325e+07	0	0	-1.5462e+05	0	2.262e+05
331	1.0919e+07	0	0	-1.4659e+05	0	1.8845e+05
332	-1.1137e+07	0	0	-1.239e+05	0	2.1726e+05
333	8.3177e+06	0	0	-1.2504e+05	0	1.4814e+05
334	-8.5693e+06	0	0	-89130	0	1.9769e+05
335	5.615e+06	0	0	-1.1332e+05	0	1.0487e+05
336	-5.8263e+06	0	0	-17081	0	1.535e+05
337	3.2307e+06	0	0	-1.199e+05	0	23966
338	-3.0723e+06	0	0	41297	0	1.1481e+05

339	1.7074e+06	0	0	-75480	0	-83193
340	2.3729e+06	0	0	-1.205e+05	0	48634
341	-4.5405e+06	0	0	1.6735e+05	0	-534.98
342	4.6167e+06	0	0	-26041	0	1.2023e+05
343	-7.6416e+06	0	0	2.0616e+05	0	-1685.1
344	7.8679e+06	0	0	80812	0	1.3222e+05
345	-1.1072e+07	0	0	2.3192e+05	0	7263
346	1.1771e+07	0	0	1.7124e+05	0	1.2712e+05
347	-1.4917e+07	0	0	2.9348e+05	0	-2128.9
348	1.6462e+07	0	0	2.6657e+05	0	1.2151e+05
349	-1.9246e+07	0	0	3.6782e+05	0	9958.5
350	2.2415e+07	0	0	3.626e+05	0	87092
351	-2.4817e+07	0	0	4.3161e+05	0	-1.6628e+05
352	2.5091e+07	0	0	5.5463e+05	0	6.4718e+05
353	-2.3881e+07	0	0	1.9656e+05	0	4.9039e+05
354	-1.4712e+07	0	0	-4.545e+05	0	-7.5269e+05
355	1.5343e+07	0	0	-49493	0	7.3469e+05
356	-2.0847e+07	0	0	-2.2751e+05	0	1.9244e+05
357	2.377e+07	0	0	-3.7065e+05	0	3.3825e+05
358	-2.4219e+07	0	0	-2.7615e+05	0	2.2981e+05
359	2.5048e+07	0	0	-3.8486e+05	0	2.4675e+05
360	-2.1589e+07	0	0	-3.6474e+05	0	1.0293e+05
361	2.1039e+07	0	0	-3.3612e+05	0	1.4977e+05
362	-5.1967e+07	0	0	-62972	0	-6.02e+05
363	-3.5308e+07	0	0	35920	0	-3.2862e+05
364	-2.4982e+07	0	0	1.2115e+05	0	-2.8748e+05
365	-1.7529e+07	0	0	1.0128e+05	0	-2.2296e+05
366	-1.2655e+07	0	0	37785	0	-2.1648e+05
367	-7.3767e+06	0	0	24684	0	-1.0001e+05
368	-3.2505e+06	0	0	24265	0	-2087.8
369	1.9055e+06	0	0	14655	0	-15800

370	3.1074e+06	0	0	51562	0	-34419
371	3.978e+06	0	0	45684	0	-21760
372	4.1684e+06	0	0	-15717	0	12874
373	3.8123e+06	0	0	-2107.6	0	2290.7
374	5.2101e+06	0	0	25201	0	-53097
375	7.2117e+06	0	0	19630	0	-61796
376	7.9653e+06	0	0	-4915.6	0	-20470
377	8.0374e+06	0	0	-3647.3	0	5089.1
378	7.7774e+06	0	0	-18009	0	31825
379	6.6344e+06	0	0	-9232.9	0	82583
380	3.9753e+06	0	0	10187	0	1.5572e+05
381	-5.8722e+05	0	0	64.506	0	1151.3
382	-5.1967e+07	0	0	62972	0	-6.02e+05
383	-3.5308e+07	0	0	-35920	0	-3.2862e+05
384	-2.4982e+07	0	0	-1.2115e+05	0	-2.8748e+05
385	-1.7529e+07	0	0	-1.0128e+05	0	-2.2296e+05
386	-1.2655e+07	0	0	-37785	0	-2.1648e+05
387	-7.3767e+06	0	0	-24684	0	-1.0001e+05
388	-3.2505e+06	0	0	-24265	0	-2087.8
389	1.9055e+06	0	0	-14655	0	-15800
390	3.1074e+06	0	0	-51562	0	-34419
391	3.978e+06	0	0	-45684	0	-21760
392	4.1684e+06	0	0	15717	0	12874
393	3.8123e+06	0	0	2107.6	0	2290.7
394	5.2101e+06	0	0	-25201	0	-53097
395	7.2117e+06	0	0	-19630	0	-61796
396	7.9653e+06	0	0	4915.6	0	-20470
397	8.0374e+06	0	0	3647.3	0	5089.1
398	7.7774e+06	0	0	18009	0	31825
399	6.6344e+06	0	0	9232.9	0	82583
400	3.9753e+06	0	0	-10187	0	1.5572e+05

401	-5.8722e+05	0	0	-64.506	0	1151.3
402	-1.9242e+07	0	0	95427	0	-85795
403	-2.1983e+07	0	0	6.5152e+05	0	-6.3339e+05
404	-1.6172e+07	0	0	3.0769e+05	0	-3.9845e+05
405	-1.7252e+07	0	0	2.4637e+05	0	-3.4791e+05
406	-1.905e+07	0	0	1.9665e+05	0	-3.389e+05
407	-2.1336e+07	0	0	2.8684e+05	0	-3.5872e+05
408	-1.5713e+07	0	0	48058	0	-1.2038e+05
409	-1.2709e+07	0	0	-26499	0	-1.2377e+05
410	-1.1155e+07	0	0	9415.8	0	-1.1751e+05
411	-1.0106e+07	0	0	1507.6	0	-89164
412	-9.2714e+06	0	0	-7977.8	0	-60896
413	-8.1151e+06	0	0	49901	0	35696
414	-8.2746e+06	0	0	16299	0	-46766
415	-9.391e+06	0	0	1.3499e+05	0	-1.0091e+05
416	-9.2167e+06	0	0	42485	0	-48125
417	-8.9461e+06	0	0	21246	0	-19616
418	-8.3897e+06	0	0	18368	0	9196.6
419	-7.6247e+06	0	0	63699	0	39828
420	-6.1299e+06	0	0	74033	0	1.3408e+05
421	-2.8702e+06	0	0	74364	0	71494
422	-1.9242e+07	0	0	-95427	0	-85795
423	-2.1983e+07	0	0	-6.5152e+05	0	-6.3339e+05
424	-1.6172e+07	0	0	-3.0769e+05	0	-3.9845e+05
425	-1.7252e+07	0	0	-2.4637e+05	0	-3.4791e+05
426	-1.905e+07	0	0	-1.9665e+05	0	-3.389e+05
427	-2.1336e+07	0	0	-2.8684e+05	0	-3.5872e+05
428	-1.5713e+07	0	0	-48058	0	-1.2038e+05
429	-1.2709e+07	0	0	26499	0	-1.2377e+05
430	-1.1155e+07	0	0	-9415.8	0	-1.1751e+05
431	-1.0106e+07	0	0	-1507.6	0	-89164

432	-9.2714e+06	0	0	7977.8	0	-60896
433	-8.1151e+06	0	0	-49901	0	35696
434	-8.2746e+06	0	0	-16299	0	-46766
435	-9.391e+06	0	0	-1.3499e+05	0	-1.0091e+05
436	-9.2167e+06	0	0	-42485	0	-48125
437	-8.9461e+06	0	0	-21246	0	-19616
438	-8.3897e+06	0	0	-18368	0	9196.6
439	-7.6247e+06	0	0	-63699	0	39828
440	-6.1299e+06	0	0	-74033	0	1.3408e+05
441	-2.8702e+06	0	0	-74364	0	71494
442	5.7518e+07	0	0	-3.1858e-07	0	-2.5772e+06
443	8.2008e+06	0	0	3.242e-07	0	1.7313e+05
444	-1.313e+07	0	0	3.2007e-07	0	-3.8173e+05
445	-2.294e+07	0	0	2.7453e-07	0	-3.4749e+05
446	-3.1466e+07	0	0	1.2525e-07	0	-2.1637e+05
447	-5.41e+07	0	0	-3.0453e-07	0	-8.5672e+05
448	9.5584e+06	0	0	9.6853e-07	0	3.0411e+05
449	-7.4309e+06	0	0	4.9026e-07	0	-3.0912e+05
450	-1.0857e+07	0	0	3.174e-07	0	-1.1404e+05
451	-1.3606e+07	0	0	6.357e-08	0	-75341
452	-1.8112e+07	0	0	-4.9966e-07	0	-1.6855e+05
453	-2.0013e+07	0	0	2.1991e-06	0	4.3171e+05
454	-2.2477e+07	0	0	3.1618e-06	0	-5.6398e+05
455	-2.1384e+07	0	0	-1.3947e-06	0	61346
456	-2.1584e+07	0	0	6.0393e-07	0	-45739
457	-2.2333e+07	0	0	3.134e-07	0	-20085
458	-2.2458e+07	0	0	-1.5216e-07	0	700.17
459	-2.4752e+07	0	0	3.7231e-08	0	-1.0145e+05
460	-2.537e+07	0	0	6.8027e-08	0	2.2779e+05
461	-1.4942e+07	0	0	2.8051e-07	0	-2.0217e+05
462	-1.4033e+07	0	0	2.4079e-07	0	-87447

463	-1.2782e+07	0	0	2.2674e-07	0	-24663
464	-1.3231e+07	0	0	2.0651e-07	0	-20645
465	-1.4593e+07	0	0	2.4188e-07	0	-30355
466	-1.5863e+07	0	0	2.2754e-07	0	-6017.4
467	-1.2589e+07	0	0	-1.8518e-07	0	24831
468	-9.5912e+06	0	0	-1.4833e-07	0	6577.9
469	-8.9379e+06	0	0	2.1807e-07	0	-2926.3
470	-8.8141e+06	0	0	2.4092e-07	0	-2260.3
471	-8.5325e+06	0	0	-2.3214e-07	0	9274.1
472	-6.7942e+06	0	0	-2.5033e-07	0	10175
473	-6.746e+06	0	0	3.8305e-07	0	-14451
474	-8.2934e+06	0	0	3.0137e-07	0	-14336
475	-8.1146e+06	0	0	2.2964e-07	0	-2609.7
476	-7.5841e+06	0	0	-1.0801e-07	0	41.119
477	-7.095e+06	0	0	-5.675e-08	0	2683.1
478	-6.3383e+06	0	0	-1.1298e-08	0	15361
479	-3.6784e+06	0	0	1.9593e-08	0	33565
480	-3.1203e+07	0	0	14488	0	7.3928e+05
481	3.8984e+07	0	0	1.1149e+05	0	4.6968e+05
482	-5.1828e+07	0	0	2.1701e+05	0	1.2118e+06
483	4.2709e+07	0	0	-1.2789e+05	0	7.1302e+05
484	-4.8636e+07	0	0	2.0528e+05	0	1.0909e+06
485	3.7732e+07	0	0	-1.6302e+05	0	6.4798e+05
486	-4.2858e+07	0	0	91996	0	9.7263e+05
487	3.2935e+07	0	0	-1.0597e+05	0	5.7447e+05
488	-3.6925e+07	0	0	8123.1	0	8.2049e+05
489	2.6724e+07	0	0	-43677	0	4.6357e+05
490	-2.8262e+07	0	0	84746	0	5.5497e+05
491	1.5185e+07	0	0	-1.0894e+05	0	2.8175e+05
492	-1.5094e+07	0	0	48605	0	3.061e+05
493	7.4059e+06	0	0	-94505	0	1.0048e+05

494	-8.6749e+06	0	0	-34322	0	2.1061e+05
495	6.0816e+06	0	0	-1016.5	0	67119
496	-6.934e+06	0	0	-19527	0	1.679e+05
497	5.1348e+06	0	0	9168.3	0	57902
498	-5.421e+06	0	0	1538.8	0	1.2513e+05
499	3.284e+06	0	0	5255.1	0	35289
500	-3.1127e+06	0	0	33092	0	65358
501	1.6417e+06	0	0	-13707	0	4255
502	-1.8333e+06	0	0	18722	0	76847
503	4.0063e+06	0	0	19164	0	17854
504	-4.9482e+06	0	0	-7147.7	0	1.509e+05
505	7.3996e+06	0	0	36101	0	95865
506	-7.0973e+06	0	0	29692	0	1.4296e+05
507	6.0021e+06	0	0	-14527	0	1.0631e+05
508	-4.7706e+06	0	0	29997	0	83305
509	2.4618e+06	0	0	-25587	0	35503
510	-9.4901e+05	0	0	-3359.3	0	3192.1
511	-2.822e+06	0	0	-8125.8	0	-44705
512	4.5333e+06	0	0	-22475	0	-86878
513	-7.4031e+06	0	0	9086.6	0	-1.3352e+05
514	9.2514e+06	0	0	4808.6	0	-1.9142e+05
515	-1.1827e+07	0	0	2296.9	0	-2.2858e+05
516	1.2963e+07	0	0	25852	0	-2.5521e+05
517	-1.1089e+07	0	0	27514	0	-2.4294e+05
518	1.144e+07	0	0	46013	0	-1.8307e+05
519	5.2224e+06	0	0	41056	0	-2.2671e+05
520	-3.1203e+07	0	0	-14488	0	7.3928e+05
521	3.8984e+07	0	0	-1.1149e+05	0	4.6968e+05
522	-5.1828e+07	0	0	-2.1701e+05	0	1.2118e+06
523	4.2709e+07	0	0	1.2789e+05	0	7.1302e+05
524	-4.8636e+07	0	0	-2.0528e+05	0	1.0909e+06

525	3.7732e+07	0	0	1.6302e+05	0	6.4798e+05
526	-4.2858e+07	0	0	-91996	0	9.7263e+05
527	3.2935e+07	0	0	1.0597e+05	0	5.7447e+05
528	-3.6925e+07	0	0	-8123.1	0	8.2049e+05
529	2.6724e+07	0	0	43677	0	4.6357e+05
530	-2.8262e+07	0	0	-84746	0	5.5497e+05
531	1.5185e+07	0	0	1.0894e+05	0	2.8175e+05
532	-1.5094e+07	0	0	-48605	0	3.061e+05
533	7.4059e+06	0	0	94505	0	1.0048e+05
534	-8.6749e+06	0	0	34322	0	2.1061e+05
535	6.0816e+06	0	0	1016.5	0	67119
536	-6.934e+06	0	0	19527	0	1.679e+05
537	5.1348e+06	0	0	-9168.3	0	57902
538	-5.421e+06	0	0	-1538.8	0	1.2513e+05
539	3.284e+06	0	0	-5255.1	0	35289
540	-3.1127e+06	0	0	-33092	0	65358
541	1.6417e+06	0	0	13707	0	4255
542	-1.8333e+06	0	0	-18722	0	76847
543	4.0063e+06	0	0	-19164	0	17854
544	-4.9482e+06	0	0	7147.7	0	1.509e+05
545	7.3996e+06	0	0	-36101	0	95865
546	-7.0973e+06	0	0	-29692	0	1.4296e+05
547	6.0021e+06	0	0	14527	0	1.0631e+05
548	-4.7706e+06	0	0	-29997	0	83305
549	2.4618e+06	0	0	25587	0	35503
550	-9.4901e+05	0	0	3359.3	0	3192.1
551	-2.822e+06	0	0	8125.8	0	-44705
552	4.5333e+06	0	0	22475	0	-86878
553	-7.4031e+06	0	0	-9086.6	0	-1.3352e+05
554	9.2514e+06	0	0	-4808.6	0	-1.9142e+05
555	-1.1827e+07	0	0	-2296.9	0	-2.2858e+05

556	1.2963e+07	0	0	-25852	0	-2.5521e+05
557	-1.1089e+07	0	0	-27514	0	-2.4294e+05
558	1.144e+07	0	0	-46013	0	-1.8307e+05
559	5.2224e+06	0	0	-41056	0	-2.2671e+05
560	5.7153e+07	0	0	-7.8479e+05	0	-1.4824e+05
561	-4.2146e+07	0	0	-1.1463e+05	0	1.2739e+06
562	4.9785e+07	0	0	-9.8229e+05	0	-94671
563	-4.3296e+07	0	0	-6.5026e+05	0	2.658e+05
564	3.9054e+07	0	0	-5.2469e+05	0	3.7869e+05
565	-4.2782e+07	0	0	-6.812e+05	0	2.7673e+05
566	3.8833e+07	0	0	-5.4743e+05	0	2.6338e+05
567	-4.3511e+07	0	0	-7.1424e+05	0	2.6305e+05
568	3.8754e+07	0	0	-5.5321e+05	0	1.866e+05
569	-4.7567e+07	0	0	-7.5645e+05	0	4.2449e+05
570	3.9634e+07	0	0	-6.4516e+05	0	46187
571	-5.281e+07	0	0	-8.0904e+05	0	9685.6
572	3.0494e+07	0	0	-5.1994e+05	0	3.4901e+05
573	-2.8201e+07	0	0	-5.3018e+05	0	-36569
574	2.1804e+07	0	0	-2.9526e+05	0	2.4787e+05
575	-2.0407e+07	0	0	-3.3487e+05	0	1.8289e+05
576	1.6696e+07	0	0	-2.472e+05	0	19050
577	-1.5164e+07	0	0	-2.5587e+05	0	1.2678e+05
578	1.0916e+07	0	0	-1.5415e+05	0	-14711
579	-1.1037e+07	0	0	-2.0032e+05	0	89412
580	6.4096e+06	0	0	-84265	0	-36585
581	-5.9783e+06	0	0	-2.301e+05	0	-62542
582	5.2445e+06	0	0	-1.5429e+05	0	-38739
583	9.513e+06	0	0	-89177	0	2.3313e+05
584	1.5661e+07	0	0	-75887	0	-1.4947e+05
585	-1.0812e+07	0	0	-1.1908e+05	0	2.5977e+05
586	8.8249e+06	0	0	-1.6817e+05	0	-2.0147e+05

587	-8.9102e+06	0	0	-1.8707e+05	0	35697
588	4.4001e+06	0	0	16118	0	-55482
589	-6.5564e+06	0	0	-1.6475e+05	0	31313
590	3.3559e+06	0	0	64252	0	-40958
591	-4.9169e+06	0	0	-1.3917e+05	0	29847
592	2.5126e+06	0	0	87163	0	-24055
593	-4.0067e+06	0	0	-1.1527e+05	0	30380
594	-1.8493e+06	0	0	-15320	0	-72782
595	-2.7846e+06	0	0	-1.9045e+05	0	-63076
596	2.2889e+06	0	0	-94434	0	-1.2064e+05
597	8.9993e+06	0	0	1.9411e+05	0	2.8587e+05
598	1.8694e+07	0	0	-4.143e+05	0	-81639
599	5.7153e+07	0	0	7.8479e+05	0	-1.4824e+05
600	-4.2146e+07	0	0	1.1463e+05	0	1.2739e+06
601	4.9785e+07	0	0	9.8229e+05	0	-94671
602	-4.3296e+07	0	0	6.5026e+05	0	2.658e+05
603	3.9054e+07	0	0	5.2469e+05	0	3.7869e+05
604	-4.2782e+07	0	0	6.812e+05	0	2.7673e+05
605	3.8833e+07	0	0	5.4743e+05	0	2.6338e+05
606	-4.3511e+07	0	0	7.1424e+05	0	2.6305e+05
607	3.8754e+07	0	0	5.5321e+05	0	1.866e+05
608	-4.7567e+07	0	0	7.5645e+05	0	4.2449e+05
609	3.9634e+07	0	0	6.4516e+05	0	46187
610	-5.281e+07	0	0	8.0904e+05	0	9685.6
611	3.0494e+07	0	0	5.1994e+05	0	3.4901e+05
612	-2.8201e+07	0	0	5.3018e+05	0	-36569
613	2.1804e+07	0	0	2.9526e+05	0	2.4787e+05
614	-2.0407e+07	0	0	3.3487e+05	0	1.8289e+05
615	1.6696e+07	0	0	2.472e+05	0	19050
616	-1.5164e+07	0	0	2.5587e+05	0	1.2678e+05
617	1.0916e+07	0	0	1.5415e+05	0	-14711

618	-1.1037e+07	0	0	2.0032e+05	0	89412
619	6.4096e+06	0	0	84265	0	-36585
620	-5.9783e+06	0	0	2.301e+05	0	-62542
621	5.2445e+06	0	0	1.5429e+05	0	-38739
622	9.513e+06	0	0	89177	0	2.3313e+05
623	1.5661e+07	0	0	75887	0	-1.4947e+05
624	-1.0812e+07	0	0	1.1908e+05	0	2.5977e+05
625	8.8249e+06	0	0	1.6817e+05	0	-2.0147e+05
626	-8.9102e+06	0	0	1.8707e+05	0	35697
627	4.4001e+06	0	0	-16118	0	-55482
628	-6.5564e+06	0	0	1.6475e+05	0	31313
629	3.3559e+06	0	0	-64252	0	-40958
630	-4.9169e+06	0	0	1.3917e+05	0	29847
631	2.5126e+06	0	0	-87163	0	-24055
632	-4.0067e+06	0	0	1.1527e+05	0	30380
633	-1.8493e+06	0	0	15320	0	-72782
634	-2.7846e+06	0	0	1.9045e+05	0	-63076
635	2.2889e+06	0	0	94434	0	-1.2064e+05
636	8.9993e+06	0	0	-1.9411e+05	0	2.8587e+05
637	1.8694e+07	0	0	4.143e+05	0	-81639
638	-1.1334e+07	0	0	-8.4919e+05	0	-5.3375e+05
639	-1.2743e+07	0	0	-8.3729e+05	0	-1.6454e+05
640	-3.9974e+06	0	0	99972	0	1.7932e+05
641	-5.066e+06	0	0	-4.3275e+05	0	60759
642	4.1538e+06	0	0	1.5777e+05	0	1.1215e+05
643	4.4426e+06	0	0	59382	0	-3.4981e+05
644	4.4393e+06	0	0	1.4248e+05	0	1.4676e+05
645	4.6579e+06	0	0	-1958.5	0	-2.8512e+05
646	5.2019e+06	0	0	1.184e+05	0	1.9864e+05
647	6.3365e+06	0	0	-1.3267e+05	0	-2.0089e+05
648	7.9544e+06	0	0	1.4276e+05	0	2.9695e+05

649	8.2776e+06	0	0	-2.1273e+05	0	-97042
650	5.3507e+06	0	0	91946	0	2.4067e+05
651	4.6507e+06	0	0	-53348	0	-1.6022e+05
652	-5.1713e+06	0	0	1.6153e+05	0	1.1528e+05
653	-4.4432e+06	0	0	-92359	0	-1.3508e+05
654	-4.9546e+06	0	0	1.4435e+05	0	1.0887e+05
655	-4.1454e+06	0	0	-62739	0	-1.4483e+05
656	-4.3661e+06	0	0	1.6191e+05	0	94626
657	-3.8559e+06	0	0	-33473	0	-1.5845e+05
658	-4.1284e+06	0	0	1.7016e+05	0	89613
659	-4.1002e+06	0	0	-25288	0	-1.4929e+05
660	-5.3593e+06	0	0	97904	0	1.3117e+05
661	-5.6066e+06	0	0	-50343	0	-1.4238e+05
662	-5.7132e+06	0	0	73547	0	1.2904e+05
663	-5.2081e+06	0	0	-22650	0	-1.5831e+05
664	-4.1782e+06	0	0	1.8422e+05	0	59751
665	-3.6128e+06	0	0	4215.8	0	-1.7541e+05
666	-3.8556e+06	0	0	2.232e+05	0	53655
667	3.534e+06	0	0	-1.7699e+05	0	-93695
668	-3.8662e+06	0	0	2.0832e+05	0	70675
669	3.608e+06	0	0	-1.8528e+05	0	-87109
670	-3.729e+06	0	0	1.9194e+05	0	83772
671	3.7913e+06	0	0	-1.9562e+05	0	-76561
672	-3.5427e+06	0	0	1.739e+05	0	96014
673	3.2464e+06	0	0	-1.5732e+05	0	-77439
674	-4.6776e+06	0	0	60862	0	1.4551e+05
675	-3.7369e+06	0	0	28453	0	-1.1115e+05
676	-6.4453e+06	0	0	-85960	0	1.415e+05
677	-1.1334e+07	0	0	8.4919e+05	0	-5.3375e+05
678	-1.2743e+07	0	0	8.3729e+05	0	-1.6454e+05
679	-3.9974e+06	0	0	-99972	0	1.7932e+05

680	-5.066e+06	0	0	4.3275e+05	0	60759
681	4.1538e+06	0	0	-1.5777e+05	0	1.1215e+05
682	4.4426e+06	0	0	-59382	0	-3.4981e+05
683	4.4393e+06	0	0	-1.4248e+05	0	1.4676e+05
684	4.6579e+06	0	0	1958.5	0	-2.8512e+05
685	5.2019e+06	0	0	-1.184e+05	0	1.9864e+05
686	6.3365e+06	0	0	1.3267e+05	0	-2.0089e+05
687	7.9544e+06	0	0	-1.4276e+05	0	2.9695e+05
688	8.2776e+06	0	0	2.1273e+05	0	-97042
689	5.3507e+06	0	0	-91946	0	2.4067e+05
690	4.6507e+06	0	0	53348	0	-1.6022e+05
691	-5.1713e+06	0	0	-1.6153e+05	0	1.1528e+05
692	-4.4432e+06	0	0	92359	0	-1.3508e+05
693	-4.9546e+06	0	0	-1.4435e+05	0	1.0887e+05
694	-4.1454e+06	0	0	62739	0	-1.4483e+05
695	-4.3661e+06	0	0	-1.6191e+05	0	94626
696	-3.8559e+06	0	0	33473	0	-1.5845e+05
697	-4.1284e+06	0	0	-1.7016e+05	0	89613
698	-4.1002e+06	0	0	25288	0	-1.4929e+05
699	-5.3593e+06	0	0	-97904	0	1.3117e+05
700	-5.6066e+06	0	0	50343	0	-1.4238e+05
701	-5.7132e+06	0	0	-73547	0	1.2904e+05
702	-5.2081e+06	0	0	22650	0	-1.5831e+05
703	-4.1782e+06	0	0	-1.8422e+05	0	59751
704	-3.6128e+06	0	0	-4215.8	0	-1.7541e+05
705	-3.8556e+06	0	0	-2.232e+05	0	53655
706	3.534e+06	0	0	1.7699e+05	0	-93695
707	-3.8662e+06	0	0	-2.0832e+05	0	70675
708	3.608e+06	0	0	1.8528e+05	0	-87109
709	-3.729e+06	0	0	-1.9194e+05	0	83772
710	3.7913e+06	0	0	1.9562e+05	0	-76561

711	-3.5427e+06	0	0	-1.739e+05	0	96014
712	3.2464e+06	0	0	1.5732e+05	0	-77439
713	-4.6776e+06	0	0	-60862	0	1.4551e+05
714	-3.7369e+06	0	0	-28453	0	-1.1115e+05
715	-6.4453e+06	0	0	85960	0	1.415e+05
716	-5.3949e+06	0	0	1.4245e-08	0	-3.2718e-08
717	-5.2965e+05	0	0	3.8108e-08	0	-1.1851e-08
718	-8.0529e+05	0	0	2.0795e-07	0	-4.6625e-08
719	-3.7906e+07	0	0	-46490	0	13423
720	-3.7906e+07	0	0	-46490	0	-13423
721	-1.267e+07	0	0	-1.9374e-08	0	55290
722	-1.267e+07	0	0	5.2687e-08	0	-55290
723	2.4383e+05	0	0	-6.6591e-07	0	2.2717e-07
724	1.2241e+06	0	0	-71887	0	13581
725	8.6053e+05	0	0	-3.8966e-07	0	1.1635e-07
726	1.2241e+06	0	0	-70245	0	21918
727	-3.611e+07	0	0	41062	0	3904.3
728	-3.611e+07	0	0	41062	0	-3904.3
729	-1.3115e+07	0	0	61593	0	-19648
730	-1.3115e+07	0	0	61593	0	19648
731	-2.4851e+06	0	0	-37418	0	1.335e+05
732	-2.4851e+06	0	0	37418	0	1.335e+05
733	-3.7526e+07	0	0	-1.3434e+05	0	-50735
734	-3.7526e+07	0	0	-85405	0	-1.0999e+05
735	1.9703e+07	0	0	-6.4715e+05	0	9.6193e+05
736	-8.0199e+06	0	0	8.5901e+05	0	1.4293e+05
737	-8.0199e+06	0	0	-8.5901e+05	0	1.4293e+05
738	-2.1304e+07	0	0	-1.9422e+06	0	82728
739	-2.1304e+07	0	0	1.9422e+06	0	82728
740	1.9703e+07	0	0	-6.1038e+05	0	9.8828e+05
741	2.0786e+07	0	0	3280.9	0	-2.2939e+05

742	2.0786e+07	0	0	-78212	0	2.1745e+05
743	5.1603e+07	0	0	27724	0	6.6616e+05
744	5.1603e+07	0	0	-27724	0	6.6616e+05
745	2.6861e+07	0	0	-1.7401e-07	0	-3615.7
746	2.5848e+07	0	0	52163	0	10417
747	2.5848e+07	0	0	-52163	0	10417
748	2.9623e+07	0	0	-26811	0	7.7036e-09

Principal stresses in Pascals in different directions of the elements

Elements	x-direction	y-direction	z-direction
1	4332.3	-1.08e-05	-5.2688e+07
2	920.86	-1.0863e-05	-4.0311e+07
3	1072.5	-1.9085e-05	-3.4553e+07
4	688.75	-1.8017e-05	-3.0158e+07
5	385.67	7.0408e-07	-2.7051e+07
6	193.31	-2.3013e-06	-2.459e+07
7	86.319	-0.00011538	-2.281e+07
8	27.656	-0.00013481	-2.1671e+07
9	7.0611	-0.00036121	-2.1158e+07
10	21.533	-2.5736e-05	-2.1674e+07
11	63.193	9.0318e-05	-2.2758e+07
12	132.45	-4.0916e-05	-2.4415e+07
13	187.64	-5.8001e-05	-2.645e+07
14	168.94	3.7739e-05	-2.8661e+07
15	2401.5	-5.6066e-07	-3.6095e+07
16	170.27	-1.7229e-05	-3.9976e+07
17	13017	-1.0245e-07	-3.4897e+07
18	2187.7	-4.2375e-07	-1.6872e+07
19	12807	-1.0524e-07	-1.1654e+07
20	487.11	1.5926e-07	-3.9312e+06
21	4332.3	-1.0796e-05	-5.2688e+07
22	920.86	3.6675e-06	-4.0311e+07
23	1072.5	1.7559e-05	-3.4553e+07
24	688.75	1.4568e-05	-3.0158e+07
25	385.67	7.0222e-07	-2.7051e+07
26	193.31	2.3422e-05	-2.459e+07
27	86.319	3.3326e-05	-2.281e+07
28	27.656	-0.00013481	-2.1671e+07

29	7.0611	-0.00036121	-2.1158e+07
30	21.534	-0.00038457	-2.1674e+07
31	63.193	-4.4482e-05	-2.2758e+07
32	132.45	3.3101e-05	-2.4415e+07
33	187.64	3.3211e-06	-2.645e+07
34	168.94	-8.2219e-05	-2.8661e+07
35	2401.5	-5.6066e-07	-3.6095e+07
36	170.27	-1.7228e-05	-3.9976e+07
37	13017	-1.0245e-07	-3.4897e+07
38	2187.7	-4.2468e-07	-1.6872e+07
39	12807	-1.9558e-08	-1.1654e+07
40	487.11	4.2072e-07	-3.9312e+06
41	22034	-1.0245e-08	-3.188e+06
42	25867	-2.3749e-07	-1.9331e+07
43	6483.6	-1.5181e-07	-1.3524e+07
44	2909.7	4.638e-07	-1.4425e+07
45	1533.9	-5.4855e-07	-1.4844e+07
46	802.8	-2.8396e-06	-1.489e+07
47	392.89	1.1493e-06	-1.482e+07
48	133.81	-5.4054e-06	-1.4641e+07
49	11.354	0.00024811	-1.4402e+07
50	28.042	-8.8522e-06	-1.4562e+07
51	179.42	1.1928e-05	-1.4998e+07
52	464.96	-1.234e-06	-1.5473e+07
53	816.4	2.8759e-06	-1.594e+07
54	1972.7	1.3541e-06	-1.7356e+07
55	1312.5	-3.1199e-07	-1.6458e+07
56	30351	6.0908e-07	-3.6238e+07
57	3.8522e+07	-4.3586e-07	-39274
58	1.2695e+07	2.8498e-07	-5831.7
59	1.0756e+07	2.0489e-08	-21194

60	5.7513e+06	-2.794e-09	-8724.2
61	22034	3.9581e-09	-3.188e+06
62	25867	-2.3656e-07	-1.9331e+07
63	6483.6	-1.5181e-07	-1.3524e+07
64	2909.7	4.6473e-07	-1.4425e+07
65	1533.9	6.4075e-07	-1.4844e+07
66	802.8	-5.7183e-07	-1.489e+07
67	392.89	-8.0466e-06	-1.482e+07
68	133.81	-5.4054e-06	-1.4641e+07
69	11.354	-5.239e-05	-1.4402e+07
70	28.042	5.3335e-05	-1.4562e+07
71	179.42	1.6149e-06	-1.4998e+07
72	464.96	-1.2331e-06	-1.5473e+07
73	816.4	-2.2408e-06	-1.594e+07
74	1972.7	-1.1558e-06	-1.7356e+07
75	1312.5	-3.1572e-07	-1.6458e+07
76	30351	-1.0245e-07	-3.6238e+07
77	3.8522e+07	-4.3586e-07	-39274
78	1.2695e+07	5.5879e-08	-5831.7
79	1.0756e+07	1.9092e-08	-21194
80	5.7513e+06	3.3295e-08	-8724.2
81	1112.4	3.9162e-07	-1.2507e+07
82	407.14	-9.4771e-06	-1.3853e+07
83	12.721	1.4179e-06	-1.2444e+07
84	5.2582	-0.00027239	-1.2481e+07
85	3.5804	0.00070052	-1.2963e+07
86	1.8207	-0.00073639	-1.3396e+07
87	0.78558	0.0035088	-1.3704e+07
88	0.19746	-0.013489	-1.3901e+07
89	0.057007	-0.056687	-1.4017e+07
90	0.2122	-0.0022943	-1.4135e+07

91	0.81512	-0.00060896	-1.4223e+07
92	1.4892	4.557e-05	-1.4271e+07
93	4.6548	9.7185e-05	-1.4225e+07
94	4.9288	-0.00040059	-1.3034e+07
95	1377.3	2.794e-07	-1.4582e+07
96	25.818	3.702e-06	-1.0925e+07
97	1.0434e+07	-6.5146e-07	-2225
98	6.0791e+06	1.1162e-06	-49.272
99	2.6295e+06	5.0315e-07	-42.76
100	5.477e+07	7.4506e-09	-89433
101	1.8085e+07	-3.8464e-07	-7320.7
102	1.1751e+07	1.3178e-06	-2211.9
103	6.7916e+06	2.2538e-07	-1745.8
104	3.2142e+06	2.142e-08	-2661.4
105	1609.8	-1.8068e-07	-3.0216e+06
106	486.61	4.0256e-07	-4.2471e+06
107	85.289	-3.0925e-06	-4.8088e+06
108	7.0623	-1.3479e-06	-4.8077e+06
109	236.06	2.6659e-07	-4.5725e+06
110	1027.2	5.3551e-09	-3.5854e+06
111	1.9613e+06	2.3283e-10	-4258.9
112	5.9249e+06	1.0477e-08	-2618
113	1.0809e+07	6.0676e-07	-2045.1
114	2.5411e+07	2.8312e-07	-12171
115	2.9521e+07	2.254e-05	-249.42
116	2.5285e+07	-4.4331e-07	-4109.3
117	1.5767e+07	-5.9605e-08	-4082.5
118	8.6723e+06	2.8545e-07	-6156.2
119	2.6998e+07	3.7253e-08	-9544.8
120	8438.7	-9.3132e-09	-8.7498e+06
121	1.6599e+07	3.7085e-06	-651.31

122	21511	-1.844e-07	-3.0087e+07
123	1.9983e+07	-1.4789e-06	-2889.8
124	18084	-1.4715e-07	-2.7763e+07
125	1.5407e+07	-2.617e-07	-2338.6
126	16502	1.4342e-07	-2.2957e+07
127	1.1463e+07	-3.9861e-07	-998.61
128	14745	2.3562e-07	-1.8705e+07
129	7.95e+06	1.0245e-07	-271.44
130	13298	3.0734e-08	-1.4931e+07
131	6.5985e+06	-8.666e-07	-653.75
132	12114	5.3085e-08	-1.1432e+07
133	5.5725e+06	-1.1409e-08	-2518.7
134	11339	-3.6787e-08	-8.1338e+06
135	4.6381e+06	-3.0035e-08	-6826.3
136	11493	-5.8208e-09	-5.0031e+06
137	11468	2.4913e-08	-4.997e+06
138	4.6985e+06	-1.7928e-08	-6934.2
139	11413	3.7253e-09	-7.9805e+06
140	5.6434e+06	-4.028e-08	-2844.2
141	12193	2.3283e-08	-1.0894e+07
142	6.636e+06	-7.7346e-07	-968.03
143	13191	-2.8685e-07	-1.3608e+07
144	7.6506e+06	3.0473e-06	-223.98
145	14675	3.4645e-07	-1.5996e+07
146	9.0892e+06	1.2293e-07	-206.36
147	14902	-1.3039e-08	-1.7919e+07
148	9.9131e+06	-2.7195e-07	-1249.3
149	15527	2.0862e-07	-1.5449e+07
150	2.3101e+07	-1.397e-07	-28250
151	4.5433e+07	3.6657e-06	-3432.6
152	19284	-4.1351e-07	-5.2708e+07

153	4.8848e+07	3.5204e-07	-24213
154	18950	-7.4692e-07	-4.7231e+07
155	4.0545e+07	-6.8545e-07	-16614
156	16146	-4.34e-07	-3.7362e+07
157	3.3736e+07	-2.1458e-06	-8786.9
158	18355	-2.1979e-07	-1.9499e+07
159	2.2862e+07	-3.3807e-07	-3640
160	2.6998e+07	3.9116e-08	-9544.8
161	8438.7	-2.2771e-07	-8.7498e+06
162	1.6599e+07	3.7095e-06	-651.31
163	21511	-8.9407e-07	-3.0087e+07
164	1.9983e+07	-1.4799e-06	-2889.8
165	18084	-8.4192e-07	-2.7763e+07
166	1.5407e+07	-2.645e-07	-2338.6
167	16502	1.4435e-07	-2.2957e+07
168	1.1463e+07	1.7625e-06	-998.61
169	14745	-5.383e-07	-1.8705e+07
170	7.95e+06	2.0145e-06	-271.44
171	13298	-1.071e-07	-1.4931e+07
172	6.5985e+06	-3.1758e-07	-653.75
173	12114	-3.4925e-08	-1.1432e+07
174	5.5725e+06	-2.0815e-07	-2518.7
175	11339	9.3132e-10	-8.1338e+06
176	4.6381e+06	2.4214e-08	-6826.3
177	11493	1.5832e-08	-5.0031e+06
178	11468	-1.0943e-08	-4.997e+06
179	4.6985e+06	4.0513e-08	-6934.2
180	11413	5.5879e-09	-7.9805e+06
181	5.6434e+06	-1.2433e-07	-2844.2
182	12193	1.844e-07	-1.0894e+07
183	6.636e+06	-2.5146e-08	-968.03

184	13191	6.2399e-08	-1.3608e+07
185	7.6506e+06	9.0152e-07	-223.98
186	14675	1.9837e-07	-1.5996e+07
187	9.0892e+06	-9.7519e-06	-206.36
188	14902	-1.0245e-08	-1.7919e+07
189	9.9131e+06	-2.7427e-07	-1249.3
190	15527	-1.4994e-07	-1.5449e+07
191	2.3101e+07	-1.6112e-07	-28250
192	4.5433e+07	-1.274e-06	-3432.6
193	19284	-1.5683e-06	-5.2708e+07
194	4.8848e+07	-4.5449e-07	-24213
195	18950	2.1607e-06	-4.7231e+07
196	4.0545e+07	9.2573e-07	-16614
197	16146	-4.3586e-07	-3.7362e+07
198	3.3736e+07	2.0992e-06	-8786.9
199	18355	1.3318e-07	-1.9499e+07
200	2.2862e+07	-3.3807e-07	-3640
201	55131	-9.3132e-09	-2.4791e+07
202	55226	-2.4214e-08	-1.3174e+07
203	52682	-3.6322e-08	-1.2742e+07
204	37359	-3.4925e-09	-4.16e+06
205	44820	-6.2864e-09	-4.5848e+06
206	3.5781e+06	-6.2864e-09	-19196
207	44445	2.3283e-10	-3.8832e+06
208	3.7672e+06	-4.6566e-10	-22850
209	33224	-3.7253e-09	-4.663e+06
210	3.7944e+06	-3.2596e-09	-23501
211	27712	-1.071e-08	-4.8918e+06
212	17552	1.8626e-09	-4.0013e+06
213	24092	6.0536e-09	-4.9328e+06
214	16306	2.3516e-08	-4.2906e+06

215	21606	1.071e-08	-4.9229e+06
216	15804	-5.1223e-09	-4.5048e+06
217	20075	-5.3551e-09	-4.8906e+06
218	15985	-1.56e-08	-4.6598e+06
219	19308	1.3039e-08	-4.8505e+06
220	16847	1.8626e-09	-4.7684e+06
221	19193	-9.5461e-09	-4.8162e+06
222	18481	1.6997e-08	-4.8469e+06
223	19728	-3.2596e-09	-4.8018e+06
224	21060	-8.6147e-09	-4.9328e+06
225	20806	8.1491e-09	-4.8087e+06
226	23509	-1.8161e-08	-5.1821e+06
227	24547	-1.4668e-08	-4.7079e+06
228	28971	-3.0268e-08	-6.1666e+06
229	18269	9.3132e-10	-3.9935e+06
230	17127	-1.1642e-08	-6.5235e+06
231	4.6187e+06	-3.9581e-09	-1.3126e+05
232	1.6663e+05	-9.3132e-10	-1.1584e+07
233	1.8885e+07	-4.6566e-09	-1.3667e+05
234	4.836e+06	-1.6298e-09	-1.3631e+05
235	5.8753e+06	1.1642e-08	-37366
236	6.3939e+06	8.8476e-08	-6121.2
237	31208	2.5611e-09	-4.3397e+06
238	4.8852e+06	2.8173e-08	-3910.7
239	3400.6	-7.2643e-08	-6.2598e+06
240	6120.2	-3.702e-08	-5.1423e+06
241	0	-3.7253e-09	-7.5998e+06
242	55131	1.6205e-07	-2.4791e+07
243	55226	-4.6566e-09	-1.3174e+07
244	52682	2.142e-08	-1.2742e+07
245	37359	4.4238e-09	-4.16e+06

246	44820	4.191e-09	-4.5848e+06
247	3.5781e+06	-3.0268e-09	-19196
248	44445	5.1223e-09	-3.8832e+06
249	3.7672e+06	-2.3283e-09	-22850
250	33224	-1.8859e-08	-4.663e+06
251	3.7944e+06	-5.5879e-09	-23501
252	27712	8.1491e-09	-4.8918e+06
253	17552	1.6298e-09	-4.0013e+06
254	24092	1.1409e-08	-4.9328e+06
255	16306	-2.5611e-08	-4.2906e+06
256	21606	1.7695e-08	-4.9229e+06
257	15804	-1.397e-08	-4.5048e+06
258	20075	1.3504e-08	-4.8906e+06
259	15985	-4.4238e-09	-4.6598e+06
260	19308	1.2107e-08	-4.8505e+06
261	16847	-8.6147e-09	-4.7684e+06
262	19193	-2.3516e-08	-4.8162e+06
263	18481	2.0489e-08	-4.8469e+06
264	19728	-1.9092e-08	-4.8018e+06
265	21060	-1.6298e-09	-4.9328e+06
266	20806	-9.3132e-09	-4.8087e+06
267	23509	-5.1223e-09	-5.1821e+06
268	24547	-1.397e-09	-4.7079e+06
269	28971	1.6531e-08	-6.1666e+06
270	18269	6.9849e-10	-3.9935e+06
271	17127	9.3132e-10	-6.5235e+06
272	4.6187e+06	-2.794e-09	-1.3126e+05
273	1.6663e+05	-9.7789e-09	-1.1584e+07
274	1.8885e+07	-7.4506e-09	-1.3667e+05
275	4.836e+06	-3.2596e-09	-1.3631e+05
276	5.8753e+06	-2.794e-09	-37366

277	6.3939e+06	-2.794e-08	-6121.2
278	31208	-1.1642e-09	-4.3397e+06
279	4.8852e+06	2.5379e-08	-3910.7
280	3400.6	1.56e-08	-6.2598e+06
281	6120.2	-1.2806e-08	-5.1423e+06
282	4.0573e+07	1.4901e-08	-9739.4
283	4.2131e+07	7.5251e-07	-10387
284	79302	-4.936e-08	-1.6967e+07
285	2.4166e+07	-5.7369e-07	-15778
286	5125.7	4.6007e-07	-1.6757e+07
287	1.4173e+07	4.4983e-07	-7647.8
288	5652.7	3.5111e-07	-1.4906e+07
289	1.3145e+07	-2.5146e-08	-6021.4
290	5631.4	3.2037e-07	-1.3331e+07
291	1.0924e+07	2.4727e-07	-5218.1
292	5614	-6.9384e-08	-1.1142e+07
293	8.3222e+06	-9.4995e-08	-4515.6
294	5484.2	2.1653e-07	-8.5748e+06
295	5.6193e+06	4.6566e-10	-4242.5
296	4091.3	-7.4739e-08	-5.8304e+06
297	3.2354e+06	1.2107e-08	-4621.3
298	4838.2	-5.4715e-09	-3.0771e+06
299	1.7148e+06	3.1432e-09	-7358.6
300	2.38e+06	2.2119e-09	-7094.9
301	6159.7	-1.071e-08	-4.5467e+06
302	4.6199e+06	-1.7928e-08	-3275.6
303	5558.1	-9.3132e-09	-7.6471e+06
304	7.871e+06	2.1886e-08	-3050.9
305	4860.6	8.1025e-08	-1.1077e+07
306	1.1774e+07	-2.3842e-07	-3862.9
307	5772.2	4.2561e-07	-1.4922e+07

308	1.6467e+07	-3.7067e-07	-5211.9
309	7032.1	-1.397e-07	-1.9253e+07
310	2.2421e+07	1.2685e-06	-6202.3
311	8617.5	1.1511e-06	-2.4825e+07
312	2.512e+07	-2.7847e-07	-28920
313	11682	-1.1083e-07	-2.3893e+07
314	52362	-2.6077e-08	-1.4765e+07
315	1.5379e+07	1.8626e-08	-35258
316	4258.4	-1.1725e-06	-2.0851e+07
317	2.378e+07	8.0653e-07	-10588
318	5328.3	-5.234e-07	-2.4224e+07
319	2.5057e+07	2.142e-08	-8341.2
320	6651	8.3353e-07	-2.1595e+07
321	2.1045e+07	1.5367e-07	-6434.4
322	4.0573e+07	-1.3746e-06	-9739.4
323	4.2131e+07	-6.4634e-07	-10387
324	79302	-5.5879e-09	-1.6967e+07
325	2.4166e+07	6.4261e-07	-15778
326	5125.7	4.61e-07	-1.6757e+07
327	1.4173e+07	2.3376e-07	-7647.8
328	5652.7	2.8871e-08	-1.4906e+07
329	1.3145e+07	2.1048e-07	-6021.4
330	5631.4	-2.0023e-07	-1.3331e+07
331	1.0924e+07	5.6811e-08	-5218.1
332	5614	-6.8918e-08	-1.1142e+07
333	8.3222e+06	2.5611e-08	-4515.6
334	5484.2	3.2457e-07	-8.5748e+06
335	5.6193e+06	-4.6566e-10	-4242.5
336	4091.3	-7.9628e-08	-5.8304e+06
337	3.2354e+06	3.1898e-08	-4621.3
338	4838.2	5.8208e-08	-3.0771e+06

339	1.7148e+06	-1.2806e-09	-7358.6
340	2.38e+06	-1.3155e-08	-7094.9
341	6159.7	-1.7462e-08	-4.5467e+06
342	4.6199e+06	-2.1653e-08	-3275.6
343	5558.1	-1.1642e-08	-7.6471e+06
344	7.871e+06	1.8999e-07	-3050.9
345	4860.6	4.9453e-07	-1.1077e+07
346	1.1774e+07	-2.3982e-07	-3862.9
347	5772.2	1.1455e-07	-1.4922e+07
348	1.6467e+07	5.7742e-08	-5211.9
349	7032.1	-1.3504e-07	-1.9253e+07
350	2.2421e+07	-1.383e-06	-6202.3
351	8617.5	-3.1665e-08	-2.4825e+07
352	2.512e+07	6.2771e-07	-28920
353	11682	-5.0198e-07	-2.3893e+07
354	52362	-6.5193e-08	-1.4765e+07
355	1.5379e+07	-3.6322e-08	-35258
356	4258.4	-3.39e-07	-2.0851e+07
357	2.378e+07	-5.1316e-07	-10588
358	5328.3	-5.2247e-07	-2.4224e+07
359	2.5057e+07	1.2564e-06	-8341.2
360	6651	-3.1851e-07	-2.1595e+07
361	2.1045e+07	-4.0699e-07	-6434.4
362	7049	-3.2224e-06	-5.1974e+07
363	3094.7	-8.015e-06	-3.5311e+07
364	3895.2	-2.115e-06	-2.4986e+07
365	3420.6	6.3516e-07	-1.7532e+07
366	3814.7	-3.6135e-07	-1.2659e+07
367	1438.1	-6.631e-07	-7.3782e+06
368	182.47	-1.3271e-08	-3.2507e+06
369	1.9058e+06	6.9384e-08	-243.69

370	3.1086e+06	1.9092e-08	-1236.3
371	3.9786e+06	-2.184e-07	-643.56
372	4.1685e+06	6.0466e-07	-99.017
373	3.8123e+06	7.1765e-06	-2.5415
374	5.2107e+06	-2.007e-07	-662.93
375	7.2123e+06	2.0256e-07	-582.91
376	7.9654e+06	-5.9814e-06	-55.638
377	8.0374e+06	-5.9776e-05	-4.8773
378	7.7775e+06	-6.5411e-06	-171.93
379	6.6355e+06	5.2899e-07	-1040.6
380	3.9814e+06	1.2107e-08	-6116.8
381	2.2642	5.4244e-07	-5.8722e+05
382	7049	-6.3926e-06	-5.1974e+07
383	3094.7	-1.3914e-06	-3.5311e+07
384	3895.2	1.8245e-06	-2.4986e+07
385	3420.6	-8.5123e-07	-1.7532e+07
386	3814.7	-1.8626e-08	-1.2659e+07
387	1438.1	-6.659e-07	-7.3782e+06
388	182.47	4.5775e-07	-3.2507e+06
389	1.9058e+06	-5.9139e-08	-243.69
390	3.1086e+06	6.9267e-08	-1236.3
391	3.9786e+06	-4.3004e-07	-643.56
392	4.1685e+06	6.021e-07	-99.017
393	3.8123e+06	7.1763e-06	-2.5415
394	5.2107e+06	-2.0536e-07	-662.93
395	7.2123e+06	2.007e-07	-582.91
396	7.9654e+06	3.397e-06	-55.638
397	8.0374e+06	-5.9776e-05	-4.8773
398	7.7775e+06	-3.6503e-06	-171.93
399	6.6355e+06	-1.6857e-07	-1040.6
400	3.9814e+06	-9.0804e-09	-6116.8

401	2.2642	5.4252e-07	-5.8722e+05
402	855.73	-2.5146e-06	-1.9243e+07
403	37495	-5.0291e-08	-2.202e+07
404	15656	2.0489e-08	-1.6188e+07
405	10528	9.7789e-08	-1.7263e+07
406	8055.7	5.1036e-07	-1.9058e+07
407	9883	2.4494e-07	-2.1346e+07
408	1069.1	1.0487e-06	-1.5714e+07
409	1260.5	-1.1455e-07	-1.271e+07
410	1245.8	5.2759e-07	-1.1156e+07
411	786.87	-2.3656e-07	-1.0106e+07
412	406.82	3.404e-07	-9.2719e+06
413	463.84	8.2422e-08	-8.1156e+06
414	296.41	1.8664e-06	-8.2749e+06
415	3023.7	-2.0722e-07	-9.394e+06
416	447.11	2.3795e-06	-9.2171e+06
417	93.468	-8.9202e-06	-8.9461e+06
418	50.294	-2.0028e-05	-8.3898e+06
419	740.13	1.4435e-07	-7.6254e+06
420	3824.6	6.4261e-08	-6.1337e+06
421	3702.7	5.5879e-09	-2.8739e+06
422	855.73	-2.5164e-06	-1.9243e+07
423	37495	1.4249e-07	-2.202e+07
424	15656	5.5879e-09	-1.6188e+07
425	10528	9.3132e-08	-1.7263e+07
426	8055.7	-5.9884e-07	-1.9058e+07
427	9883	2.4121e-07	-2.1346e+07
428	1069.1	1.0477e-06	-1.5714e+07
429	1260.5	-1.1083e-07	-1.271e+07
430	1245.8	5.2853e-07	-1.1156e+07
431	786.87	-2.3423e-07	-1.0106e+07

432	406.82	3.8194e-06	-9.2719e+06
433	463.84	-1.0789e-06	-8.1156e+06
434	296.41	1.865e-06	-8.2749e+06
435	3023.7	-2.1188e-07	-9.394e+06
436	447.11	2.3781e-06	-9.2171e+06
437	93.468	-8.9211e-06	-8.9461e+06
438	50.293	2.9937e-06	-8.3898e+06
439	740.13	-1.1497e-06	-7.6254e+06
440	3824.6	-1.397e-08	-6.1337e+06
441	3702.7	-3.248e-08	-2.8739e+06
442	5.7633e+07	2.3097e-07	-1.1525e+05
443	8.2045e+06	3.8184e-08	-3653.2
444	11088	-3.9116e-08	-1.3141e+07
445	5262.5	6.9477e-07	-2.2946e+07
446	1487.7	-5.9959e-06	-3.1468e+07
447	13564	-7.0781e-07	-5.4113e+07
448	9.568e+06	-8.1491e-08	-9666
449	12837	-2.6543e-08	-7.4438e+06
450	1197.6	2.1104e-06	-1.0858e+07
451	417.18	9.303e-06	-1.3606e+07
452	1568.3	-2.2165e-06	-1.8114e+07
453	9308.4	4.6566e-08	-2.0022e+07
454	14142	5.4948e-08	-2.2491e+07
455	175.99	-3.8738e-05	-2.1384e+07
456	96.927	0.00010054	-2.1584e+07
457	18.063	5.3015e-05	-2.2334e+07
458	0.010915	0.010915	-2.2458e+07
459	415.82	1.3127e-05	-2.4752e+07
460	2045.1	-3.8613e-06	-2.5372e+07
461	2734.9	-2.4214e-07	-1.4945e+07
462	544.91	9.9558e-07	-1.4033e+07

463	47.588	-9.7314e-06	-1.2782e+07
464	32.212	-0.00010629	-1.3231e+07
465	63.14	2.8891e-05	-1.4593e+07
466	2.284	-0.0014746	-1.5863e+07
467	48.978	-5.574e-05	-1.2589e+07
468	4.5115	-0.00027263	-9.5912e+06
469	0.95652	0.0015958	-8.9379e+06
470	0.58131	-0.0016903	-8.8141e+06
471	10.08	5.1002e-05	-8.5325e+06
472	15.239	-1.6624e-05	-6.7942e+06
473	30.955	-1.4371e-05	-6.746e+06
474	24.781	1.2504e-05	-8.2934e+06
475	0.83979	-0.00052653	-8.1146e+06
476	0.00011147	0.00011147	-7.5841e+06
477	1.0144	0.00030302	-7.095e+06
478	37.229	1.4548e-05	-6.3383e+06
479	306.25	3.0943e-07	-3.6787e+06
480	17513	1.8626e-07	-3.1221e+07
481	3.899e+07	-3.4831e-07	-5976.8
482	29226	1.5274e-07	-5.1857e+07
483	4.2722e+07	3.0715e-06	-12283
484	25321	-3.9116e-08	-4.8661e+07
485	3.7744e+07	5.9232e-07	-11828
486	22259	1.0487e-06	-4.288e+07
487	3.2946e+07	-3.2969e-07	-10358
488	18225	3.9302e-07	-3.6943e+07
489	2.6732e+07	-8.4192e-07	-8110.3
490	11147	9.8348e-07	-2.8273e+07
491	1.5191e+07	4.3865e-07	-6006.8
492	6361.6	-3.6042e-07	-1.51e+07
493	7.4084e+06	1.8487e-07	-2568.5

494	5245.7	-1.4855e-07	-8.6801e+06
495	6.0823e+06	5.6205e-07	-740.84
496	4118	-5.4017e-08	-6.9381e+06
497	5.1355e+06	3.4249e-07	-669.2
498	2887.4	3.539e-08	-5.4239e+06
499	3.2844e+06	3.1735e-07	-387.56
500	1723.2	1.234e-07	-3.1145e+06
501	1.6418e+06	2.2002e-08	-125.47
502	3406.1	4.3074e-09	-1.8367e+06
503	4.0065e+06	-1.2666e-06	-171.22
504	4608.1	-5.4017e-08	-4.9528e+06
505	7.401e+06	-2.2212e-07	-1417.8
506	3002.5	3.7998e-07	-7.1003e+06
507	6.004e+06	3.0268e-07	-1917.4
508	1642.8	-1.4668e-08	-4.7722e+06
509	2.4625e+06	-5.5879e-08	-777.72
510	22.628	-2.6479e-07	-9.4903e+05
511	731.4	4.1095e-08	-2.8227e+06
512	4.535e+06	1.2619e-07	-1775.7
513	2418.6	1.2247e-07	-7.4055e+06
514	9.2554e+06	-1.2154e-07	-3961.5
515	4416.4	1.9092e-07	-1.1832e+07
516	1.2968e+07	2.8964e-07	-5074.4
517	5387.9	1.5832e-08	-1.1095e+07
518	1.1443e+07	-1.6484e-07	-3114
519	5.2326e+06	4.6566e-08	-10145
520	17513	-7.2643e-07	-3.1221e+07
521	3.899e+07	-2.4457e-06	-5976.8
522	29226	1.5274e-07	-5.1857e+07
523	4.2722e+07	6.2026e-07	-12283
524	25321	-3.9116e-08	-4.8661e+07

525	3.7744e+07	-2.3674e-06	-11828
526	22259	1.0449e-06	-4.288e+07
527	3.2946e+07	5.3644e-07	-10358
528	18225	3.9116e-07	-3.6943e+07
529	2.6732e+07	6.1281e-07	-8110.3
530	11147	-1.8813e-07	-2.8273e+07
531	1.5191e+07	4.3865e-07	-6006.8
532	6361.6	-6.8918e-08	-1.51e+07
533	7.4084e+06	1.8766e-07	-2568.5
534	5245.7	8.6147e-08	-8.6801e+06
535	6.0823e+06	1.5507e-07	-740.84
536	4118	4.3306e-08	-6.9381e+06
537	5.1355e+06	-3.0408e-07	-669.2
538	2887.4	2.9569e-08	-5.4239e+06
539	3.2844e+06	8.9174e-08	-387.56
540	1723.2	7.1013e-08	-3.1145e+06
541	1.6418e+06	2.3632e-08	-125.47
542	3406.1	5.0059e-09	-1.8367e+06
543	4.0065e+06	2.7451e-07	-171.22
544	4608.1	-1.0477e-08	-4.9528e+06
545	7.401e+06	4.1025e-07	-1417.8
546	3002.5	-3.865e-08	-7.1003e+06
547	6.004e+06	-5.1223e-09	-1917.4
548	1642.8	-1.6065e-08	-4.7722e+06
549	2.4625e+06	1.2689e-08	-777.72
550	22.628	3.8935e-07	-9.4903e+05
551	731.4	3.993e-08	-2.8227e+06
552	4.535e+06	-6.2864e-08	-1775.7
553	2418.6	-2.4866e-07	-7.4055e+06
554	9.2554e+06	5.4948e-08	-3961.5
555	4416.4	1.9092e-07	-1.1832e+07

556	1.2968e+07	-2.5891e-07	-5074.4
557	5387.9	1.7695e-08	-1.1095e+07
558	1.1443e+07	-1.6624e-07	-3114
559	5.2326e+06	-2.0955e-08	-10145
560	5.7164e+07	-2.3991e-06	-11159
561	38779	3.8743e-07	-4.2184e+07
562	4.9805e+07	-1.0431e-07	-19554
563	11395	2.3656e-07	-4.3308e+07
564	3.9065e+07	5.5507e-07	-10718
565	12633	8.7544e-08	-4.2794e+07
566	3.8843e+07	8.6427e-07	-9501.1
567	13311	-1.7509e-07	-4.3525e+07
568	3.8763e+07	8.6427e-07	-8793.4
569	15813	-9.3132e-09	-4.7582e+07
570	3.9644e+07	-7.3947e-07	-10553
571	12393	2.5406e-06	-5.2823e+07
572	3.0507e+07	-7.7859e-07	-12854
573	10012	1.2852e-07	-2.8211e+07
574	2.1811e+07	-7.2364e-07	-6814
575	7131.6	1.5367e-07	-2.0414e+07
576	1.67e+07	-3.7905e-07	-3681.1
577	5375.5	-1.5832e-08	-1.5169e+07
578	1.0918e+07	3.865e-08	-2196.4
579	4358.3	-1.1967e-07	-1.1041e+07
580	6.4109e+06	1.071e-07	-1316.4
581	9495.6	6.2399e-08	-5.9878e+06
582	5.2493e+06	6.7521e-09	-4820.8
583	9.5195e+06	1.8207e-07	-6544.5
584	1.5663e+07	8.9407e-07	-1794.1
585	7547.6	6.007e-08	-1.0819e+07
586	8.8327e+06	1.5786e-07	-7797.5

587	4068.8	2.4727e-07	-8.9142e+06
588	4.4009e+06	-3.0966e-08	-758.51
589	4286.8	-1.8626e-09	-6.5607e+06
590	3.3576e+06	6.9384e-08	-1729.1
591	4116.6	2.6776e-08	-4.921e+06
592	2.5158e+06	6.7521e-09	-3249.9
593	3543.7	2.1188e-08	-4.0103e+06
594	2986.5	-1.397e-09	-1.8523e+06
595	14380	2.4447e-09	-2.799e+06
596	2.2991e+06	-1.1642e-10	-10209
597	9.0125e+06	-2.3283e-09	-13248
598	1.8704e+07	-1.2107e-08	-9533.4
599	5.7164e+07	-2.4028e-06	-11159
600	38779	-1.8626e-08	-4.2184e+07
601	4.9805e+07	1.9912e-06	-19554
602	11395	2.3656e-07	-4.3308e+07
603	3.9065e+07	-2.9709e-06	-10718
604	12633	-2.2855e-06	-4.2794e+07
605	3.8843e+07	-1.7472e-06	-9501.1
606	13311	-1.7509e-07	-4.3525e+07
607	3.8763e+07	8.6613e-07	-8793.4
608	15813	-1.1176e-08	-4.7582e+07
609	3.9644e+07	1.7006e-06	-10553
610	12393	-3.01e-06	-5.2823e+07
611	3.0507e+07	-1.8626e-07	-12854
612	10012	-1.1679e-06	-2.8211e+07
613	2.1811e+07	-7.2364e-07	-6814
614	7131.6	6.3516e-07	-2.0414e+07
615	1.67e+07	-3.7905e-07	-3681.1
616	5375.5	3.3528e-07	-1.5169e+07
617	1.0918e+07	3.9116e-08	-2196.4

618	4358.3	-3.4831e-07	-1.1041e+07
619	6.4109e+06	-1.4901e-07	-1316.4
620	9495.6	5.5181e-08	-5.9878e+06
621	5.2493e+06	-3.0035e-08	-4820.8
622	9.5195e+06	-1.7835e-07	-6544.5
623	1.5663e+07	8.8476e-07	-1794.1
624	7547.6	-8.7079e-08	-1.0819e+07
625	8.8327e+06	7.6368e-08	-7797.5
626	4068.8	2.5053e-07	-8.9142e+06
627	4.4009e+06	5.9884e-07	-758.51
628	4286.8	-8.1491e-08	-6.5607e+06
629	3.3576e+06	7.1479e-08	-1729.1
630	4116.6	2.8638e-08	-4.921e+06
631	2.5158e+06	1.0477e-08	-3249.9
632	3543.7	5.7742e-08	-4.0103e+06
633	2986.5	-2.794e-09	-1.8523e+06
634	14380	-8.1491e-10	-2.799e+06
635	2.2991e+06	3.8417e-09	-10209
636	9.0125e+06	-1.8626e-09	-13248
637	1.8704e+07	-1.1176e-08	-9533.4
638	88075	-2.3283e-09	-1.1422e+07
639	56886	1.7695e-08	-1.28e+07
640	10517	-1.6531e-08	-4.008e+06
641	37419	3.9581e-09	-5.1034e+06
642	4.1628e+06	5.1223e-09	-9000.7
643	4.4708e+06	3.7253e-09	-28159
644	4.4487e+06	1.5134e-08	-9405
645	4.6753e+06	-1.4203e-08	-17388
646	5.2122e+06	-2.8638e-08	-10260
647	6.3456e+06	3.4459e-08	-9133.3
648	7.968e+06	7.0781e-08	-13625

649	8.2842e+06	-4.1444e-08	-6599.4
650	5.3631e+06	6.0536e-09	-12377
651	4.6568e+06	2.142e-08	-6123.4
652	7604	5.1688e-08	-5.1789e+06
653	6018	1.397e-08	-4.4493e+06
654	6589	7.2177e-09	-4.9612e+06
655	6001.1	1.1409e-08	-4.1514e+06
656	8039.8	-3.4692e-08	-4.3742e+06
657	6789.6	-1.071e-08	-3.8627e+06
658	8939	1.0012e-08	-4.1373e+06
659	5584	6.9849e-09	-4.1058e+06
660	4994.1	1.2992e-07	-5.3643e+06
661	4064.6	-1.2433e-07	-5.6107e+06
662	3858.6	-5.4948e-08	-5.7171e+06
663	4906.1	1.6531e-08	-5.213e+06
664	8957.9	-2.5611e-09	-4.1872e+06
665	8501.6	-1.3504e-08	-3.6213e+06
666	13619	-1.8626e-09	-3.8692e+06
667	3.5453e+06	1.0477e-08	-11312
668	12476	7.4506e-09	-3.8787e+06
669	3.6195e+06	-3.9581e-09	-11581
670	11724	1.9791e-08	-3.7407e+06
671	3.8029e+06	3.0268e-09	-11604
672	11103	-6.9849e-09	-3.5538e+06
673	3.2559e+06	2.142e-08	-9443.4
674	5312.3	-3.3528e-08	-4.6829e+06
675	3519.1	5.2154e-08	-3.7404e+06
676	4250.3	-3.0268e-08	-6.4496e+06
677	88075	-3.7253e-09	-1.1422e+07
678	56886	3.7253e-08	-1.28e+07
679	10517	-8.6147e-09	-4.008e+06

680	37419	3.0268e-09	-5.1034e+06
681	4.1628e+06	-8.6147e-09	-9000.7
682	4.4708e+06	-1.8394e-08	-28159
683	4.4487e+06	1.6298e-08	-9405
684	4.6753e+06	5.8208e-09	-17388
685	5.2122e+06	1.4203e-08	-10260
686	6.3456e+06	-4.0978e-08	-9133.3
687	7.968e+06	2.9802e-08	-13625
688	8.2842e+06	1.248e-07	-6599.4
689	5.3631e+06	2.0955e-09	-12377
690	4.6568e+06	2.6077e-08	-6123.4
691	7604	2.5611e-08	-5.1789e+06
692	6018	-4.2608e-08	-4.4493e+06
693	6589	-2.1886e-08	-4.9612e+06
694	6001.1	-3.4925e-08	-4.1514e+06
695	8039.8	4.6566e-09	-4.3742e+06
696	6789.6	-2.2119e-08	-3.8627e+06
697	8939	2.2352e-08	-4.1373e+06
698	5584	1.6531e-08	-4.1058e+06
699	4994.1	3.6787e-08	-5.3643e+06
700	4064.6	5.3551e-09	-5.6107e+06
701	3858.6	8.475e-08	-5.7171e+06
702	4906.1	2.142e-08	-5.213e+06
703	8957.9	2.794e-08	-4.1872e+06
704	8501.6	6.0536e-09	-3.6213e+06
705	13619	4.191e-09	-3.8692e+06
706	3.5453e+06	2.0955e-09	-11312
707	12476	-5.8208e-09	-3.8787e+06
708	3.6195e+06	6.0536e-09	-11581
709	11724	7.9162e-09	-3.7407e+06
710	3.8029e+06	-4.6566e-09	-11604

711	11103	4.6566e-09	-3.5538e+06
712	3.2559e+06	-1.1874e-08	-9443.4
713	5312.3	-1.0338e-07	-4.6829e+06
714	3519.1	-4.5635e-08	-3.7404e+06
715	4250.3	-1.1316e-07	-6.4496e+06
716	2.3283e-10	-2.5611e-09	-5.3949e+06
717	0.002148	-0.002148	-5.2965e+05
718	5.8208e-11	-3.4925e-10	-8.0529e+05
719	61.771	2.7303e-05	-3.7906e+07
720	61.771	2.7301e-05	-3.7906e+07
721	241.27	9.7277e-06	-1.267e+07
722	241.27	1.5205e-05	-1.267e+07
723	2.4383e+05	2.9104e-11	-7.276e-11
724	1.2284e+06	2.0373e-09	-4356.9
725	8.6053e+05	1.1642e-10	-2.3283e-10
726	1.2285e+06	-1.1642e-10	-4407.7
727	47.116	-5.8552e-05	-3.611e+07
728	47.116	-5.8552e-05	-3.611e+07
729	318.68	-7.9982e-06	-1.3116e+07
730	318.68	8.7917e-07	-1.3116e+07
731	7710.5	-2.794e-09	-2.4929e+06
732	7710.5	7.567e-09	-2.4929e+06
733	549.5	-3.0126e-05	-3.7527e+07
734	516.76	3.2904e-05	-3.7527e+07
735	1.9771e+07	1.4901e-08	-67986
736	93467	-7.9162e-09	-8.1134e+06
737	93467	-5.5879e-09	-8.1134e+06
738	1.7592e+05	3.6322e-08	-2.148e+07
739	1.7592e+05	-2.142e-08	-2.148e+07
740	1.9771e+07	-3.4459e-08	-68245
741	2.0788e+07	-6.333e-08	-2531.7

742	2.0788e+07	-9.5926e-07	-2568.9
743	5.1612e+07	-6.5565e-07	-8613
744	5.1612e+07	9.4995e-06	-8613
745	2.6861e+07	0.00024193	-0.48694
746	2.5849e+07	4.367e-05	-109.46
747	2.5849e+07	-5.6725e-05	-109.46
748	2.9623e+07	-1.8699e-05	-24.266

Displacements in meters and rotations in newton meter in different directions of the nodes

Nodes	x-direction	y-direction	z-direction	x-rotation	y-rotation	z-rotation
1	0.010316	0.00010606	-0.014303	-2.2268e-05	0.00014348	-2.3606e-06
2	0.0098532	4.6382e-05	-0.015249	-1.0402e-05	0.00055715	-3.9969e-05
3	0.0094361	-4.681e-05	-0.01682	-1.1967e-05	0.00071702	-3.2891e-05
4	0.0090668	-0.00010587	-0.018693	-2.6187e-05	0.00081638	-1.6442e-05
5	0.0087359	-0.00013301	-0.020756	-3.879e-05	0.00088527	-7.0612e-06
6	0.0084354	-0.00014485	-0.022961	-4.6672e-05	0.00093752	-3.2426e-06
7	0.008158	-0.00015075	-0.02527	-5.133e-05	0.00097575	-1.8057e-06
8	0.0078967	-0.00015433	-0.027655	-5.4198e-05	0.0010042	-1.1927e-06
9	0.0076449	-0.00015679	-0.030096	-5.6152e-05	0.001027	-8.382e-07
10	0.0073962	-0.00015851	-0.032586	-5.7682e-05	0.0010479	-5.6669e-07
11	0.0071445	-0.00015961	-0.035125	-5.9121e-05	0.001071	-3.2269e-07
12	0.0068835	-0.00016021	-0.037722	-6.0842e-05	0.0010998	-2.0224e-07
13	0.0066077	-0.00016116	-0.040396	-6.3418e-05	0.0011389	-7.3978e-07
14	0.0063119	-0.00016567	-0.043177	-6.7578e-05	0.00119	-3.4238e-06
15	0.0059921	-0.00018056	-0.04609	-7.1288e-05	0.00125	-8.9182e-06
16	0.005645	-0.00020311	-0.049241	-6.7339e-05	0.00143	-7.1574e-06
17	0.0052823	-0.00019782	-0.053165	-6.3825e-05	0.0018543	1.2485e-05
18	0.0050271	-0.00015365	-0.058096	-6.4367e-05	0.0021291	2.1723e-05
19	0.0048682	-0.00010035	-0.063333	-5.746e-05	0.0022002	2.2058e-05
20	0.0047878	-4.7592e-05	-0.068673	-5.1337e-05	0.0021783	2.1489e-05
21	0.00476	3.631e-07	-0.073824	-4.7866e-05	0.0021207	1.8358e-05
22	0.010316	-0.00010606	-0.014303	2.2268e-05	0.00014348	2.3606e-06
23	0.0098532	-4.6382e-05	-0.015249	1.0402e-05	0.00055715	3.9969e-05
24	0.0094361	4.681e-05	-0.01682	1.1967e-05	0.00071702	3.2891e-05
25	0.0090668	0.00010587	-0.018693	2.6187e-05	0.00081638	1.6442e-05
26	0.0087359	0.00013301	-0.020756	3.879e-05	0.00088527	7.0612e-06
27	0.0084354	0.00014485	-0.022961	4.6672e-05	0.00093752	3.2426e-06
28	0.008158	0.00015075	-0.02527	5.133e-05	0.00097575	1.8057e-06

29	0.0078967	0.00015433	-0.027655	5.4198e-05	0.0010042	1.1927e-06
30	0.0076449	0.00015679	-0.030096	5.6152e-05	0.001027	8.382e-07
31	0.0073962	0.00015851	-0.032586	5.7682e-05	0.0010479	5.6669e-07
32	0.0071445	0.00015961	-0.035125	5.9121e-05	0.001071	3.2269e-07
33	0.0068835	0.00016021	-0.037722	6.0842e-05	0.0010998	2.0224e-07
34	0.0066077	0.00016116	-0.040396	6.3418e-05	0.0011389	7.3978e-07
35	0.0063119	0.00016567	-0.043177	6.7578e-05	0.00119	3.4238e-06
36	0.0059921	0.00018056	-0.04609	7.1288e-05	0.00125	8.9182e-06
37	0.005645	0.00020311	-0.049241	6.7339e-05	0.00143	7.1574e-06
38	0.0052823	0.00019782	-0.053165	6.3825e-05	0.0018543	-1.2485e-05
39	0.0050271	0.00015365	-0.058096	6.4367e-05	0.0021291	-2.1723e-05
40	0.0048682	0.00010035	-0.063333	5.746e-05	0.0022002	-2.2058e-05
41	0.0047878	4.7592e-05	-0.068673	5.1337e-05	0.0021783	-2.1489e-05
42	0.00476	-3.631e-07	-0.073824	4.7866e-05	0.0021207	-1.8358e-05
43	0.010707	0.00017264	-0.014118	3.819e-05	0.00034107	-7.2798e-05
44	0.010707	9.4575e-05	-0.014549	3.5046e-05	0.00037461	-4.3995e-05
45	0.010619	-2.0989e-05	-0.015905	-1.1264e-05	0.00066107	-2.1059e-05
46	0.01051	-4.1929e-05	-0.017662	-3.674e-05	0.00076773	4.5236e-06
47	0.01038	-3.9322e-05	-0.019638	-4.9955e-05	0.00084933	5.0404e-06
48	0.010236	-3.9916e-05	-0.021779	-5.519e-05	0.00091081	3.1588e-06
49	0.010083	-4.1223e-05	-0.024042	-5.6976e-05	0.00095605	2.3774e-06
50	0.0099243	-4.2245e-05	-0.026393	-5.7533e-05	0.00098964	1.5266e-06
51	0.0097611	-4.2881e-05	-0.028808	-5.777e-05	0.0010155	6.7334e-07
52	0.0095955	-4.3085e-05	-0.031275	-5.7997e-05	0.0010375	-1.9643e-07
53	0.0094289	-4.2837e-05	-0.033788	-5.8303e-05	0.0010598	-1.082e-06
54	0.0092624	-4.2061e-05	-0.036352	-5.8741e-05	0.0010861	-1.9388e-06
55	0.0090968	-4.0536e-05	-0.038982	-5.9478e-05	0.0011203	-2.8365e-06
56	0.0089316	-3.7142e-05	-0.041701	-6.1147e-05	0.0011644	-2.4784e-06
57	0.0087648	-2.824e-05	-0.044543	-6.4944e-05	0.0012339	-3.8644e-06
58	0.0085907	-3.4171e-05	-0.047537	-7.2201e-05	0.0012644	-2.3096e-05
59	0.0083943	-7.274e-05	-0.050809	-0.0001062	0.0016507	-1.1515e-05

60	0.0085752	-2.7196e-05	-0.055572	-7.833e-05	0.0020929	2.8579e-05
61	0.0086829	2.7931e-06	-0.060701	-6.1167e-05	0.0021434	1.5365e-05
62	0.0087437	1.9476e-05	-0.065973	-4.0451e-05	0.0021716	2.1765e-05
63	0.0087722	6.9261e-05	-0.071177	-3.0823e-05	0.0021281	3.266e-05
64	0.010707	-0.00017264	-0.014118	-3.819e-05	0.00034107	7.2798e-05
65	0.010707	-9.4575e-05	-0.014549	-3.5046e-05	0.00037461	4.3995e-05
66	0.010619	2.0989e-05	-0.015905	1.1264e-05	0.00066107	2.1059e-05
67	0.01051	4.1929e-05	-0.017662	3.674e-05	0.00076773	-4.5236e-06
68	0.01038	3.9322e-05	-0.019638	4.9955e-05	0.00084933	-5.0404e-06
69	0.010236	3.9916e-05	-0.021779	5.519e-05	0.00091081	-3.1588e-06
70	0.010083	4.1223e-05	-0.024042	5.6976e-05	0.00095605	-2.3774e-06
71	0.0099243	4.2245e-05	-0.026393	5.7533e-05	0.00098964	-1.5266e-06
72	0.0097611	4.2881e-05	-0.028808	5.777e-05	0.0010155	-6.7334e-07
73	0.0095955	4.3085e-05	-0.031275	5.7997e-05	0.0010375	1.9643e-07
74	0.0094289	4.2837e-05	-0.033788	5.8303e-05	0.0010598	1.082e-06
75	0.0092624	4.2061e-05	-0.036352	5.8741e-05	0.0010861	1.9388e-06
76	0.0090968	4.0536e-05	-0.038982	5.9478e-05	0.0011203	2.8365e-06
77	0.0089316	3.7142e-05	-0.041701	6.1147e-05	0.0011644	2.4784e-06
78	0.0087648	2.824e-05	-0.044543	6.4944e-05	0.0012339	3.8644e-06
79	0.0085907	3.4171e-05	-0.047537	7.2201e-05	0.0012644	2.3096e-05
80	0.0083943	7.274e-05	-0.050809	0.0001062	0.0016507	1.1515e-05
81	0.0085752	2.7196e-05	-0.055572	7.833e-05	0.0020929	-2.8579e-05
82	0.0086829	-2.7931e-06	-0.060701	6.1167e-05	0.0021434	-1.5365e-05
83	0.0087437	-1.9476e-05	-0.065973	4.0451e-05	0.0021716	-2.1765e-05
84	0.0087722	-6.9261e-05	-0.071177	3.0823e-05	0.0021281	-3.266e-05
85	0.01076	1.8307e-14	-0.014227	1.1114e-17	0.00016459	2.7375e-16
86	0.010699	1.8999e-14	-0.015196	3.6315e-17	0.00058507	2.9157e-16
87	0.010573	1.9741e-14	-0.01684	4.5995e-17	0.00074809	3.0582e-16
88	0.010439	2.051e-14	-0.018741	5.4427e-17	0.00082991	3.1533e-16
89	0.010301	2.129e-14	-0.020815	5.3556e-17	0.00089489	3.2353e-16
90	0.010154	2.2089e-14	-0.023026	5.0149e-17	0.0009439	3.3435e-16

91	0.0099997	2.2916e-14	-0.025337	4.5787e-17	0.00097995	3.4627e-16
92	0.00984	2.3769e-14	-0.027723	4.2907e-17	0.0010067	3.5724e-16
93	0.0096767	2.4647e-14	-0.030165	4.2246e-17	0.0010277	3.6688e-16
94	0.0095114	2.5552e-14	-0.032655	5.7781e-17	0.0010471	3.7627e-16
95	0.0093454	2.6484e-14	-0.035193	8.4375e-17	0.0010686	3.8334e-16
96	0.0091796	2.7434e-14	-0.037788	1.1459e-16	0.0010961	3.8611e-16
97	0.0090149	2.8379e-14	-0.040461	1.3303e-16	0.0011332	3.8403e-16
98	0.0088539	2.9311e-14	-0.043239	1.3601e-16	0.0011857	3.812e-16
99	0.0087071	3.0228e-14	-0.046152	1.1758e-16	0.0012379	3.7797e-16
100	0.0085876	3.1133e-14	-0.049236	7.716e-17	0.0014011	3.7289e-16
101	0.0085423	3.2023e-14	-0.053245	3.1796e-17	0.0019484	3.7237e-16
102	0.0086047	3.2918e-14	-0.058246	-3.636e-19	0.0021441	3.7467e-16
103	0.0086677	3.3811e-14	-0.063451	-9.5209e-18	0.0021855	3.732e-16
104	0.0086944	3.4694e-14	-0.068683	-4.4089e-17	0.0021689	3.7364e-16
105	0.011342	1.8255e-14	-0.013406	1.1977e-17	0.0001708	1.9665e-16
106	0.011528	1.8928e-14	-0.015081	3.2929e-17	0.00081044	3.1201e-16
107	0.011666	1.9662e-14	-0.016812	4.4108e-17	0.00069969	3.0539e-16
108	0.011756	2.041e-14	-0.018661	5.1153e-17	0.00081105	3.1842e-16
109	0.011805	2.1188e-14	-0.020716	5.2817e-17	0.00088159	3.2798e-16
110	0.011817	2.1987e-14	-0.022917	5.2279e-17	0.00093483	3.3854e-16
111	0.0118	2.2818e-14	-0.025223	5.1675e-17	0.00097391	3.5362e-16
112	0.011763	2.3683e-14	-0.027606	4.8512e-17	0.0010032	3.6312e-16
113	0.011714	2.4558e-14	-0.030046	4.8687e-17	0.0010268	3.6509e-16
114	0.011663	2.5434e-14	-0.032536	6.1953e-17	0.0010486	3.6797e-16
115	0.011618	2.6321e-14	-0.035074	8.2627e-17	0.0010726	3.7186e-16
116	0.011591	2.7219e-14	-0.03767	1.0454e-16	0.0011023	3.8036e-16
117	0.011592	2.8141e-14	-0.040342	1.1797e-16	0.0011416	3.8368e-16
118	0.011633	2.9063e-14	-0.043116	1.1959e-16	0.0011934	3.8845e-16
119	0.011727	3.0016e-14	-0.046017	1.0386e-16	0.0012523	4.0225e-16
120	0.01189	3.0993e-14	-0.049201	7.2748e-17	0.0015047	4.0438e-16
121	0.012133	3.1963e-14	-0.05331	3.4909e-17	0.0019033	3.9756e-16

122	0.012341	3.2912e-14	-0.05819	6.8576e-18	0.0021028	3.8984e-16
123	0.012482	3.3841e-14	-0.063355	-1.2216e-17	0.0021545	3.8375e-16
124	0.012546	3.4765e-14	-0.068541	-2.7775e-17	0.0021238	3.8775e-16
125	0.010756	5.1869e-05	-0.014569	-9.3244e-06	-0.00025415	3.9816e-05
126	0.011104	-4.4918e-05	-0.015396	-1.0354e-05	-0.00037307	3.5667e-05
127	0.011357	-0.00011288	-0.016387	-2.544e-05	-0.00040123	2.1019e-05
128	0.011528	-0.00015331	-0.017363	-3.8368e-05	-0.00036962	1.3241e-05
129	0.011626	-0.00017705	-0.018191	-4.2291e-05	-0.0002792	5.3921e-06
130	0.011668	-0.00017296	-0.018728	-4.5413e-05	-0.00014953	-8.7131e-06
131	0.011681	-0.00014389	-0.018962	-4.9748e-05	-4.4791e-05	-1.3499e-05
132	0.011678	-0.00011616	-0.018988	-4.7524e-05	2.5809e-05	-9.0051e-06
133	0.011661	-9.8874e-05	-0.018855	-4.1487e-05	9.1338e-05	-5.9261e-06
134	0.011635	-8.3579e-05	-0.018554	-3.6052e-05	0.00016321	-7.1576e-06
135	0.011602	-6.4741e-05	-0.018084	-3.4714e-05	0.00022639	-7.6182e-06
136	0.011568	-5.4026e-05	-0.017488	-3.5077e-05	0.00026946	-3.6879e-07
137	0.011525	-6.3049e-05	-0.016796	-3.2548e-05	0.00031742	6.9856e-06
138	0.011467	-8e-05	-0.015953	-3.0823e-05	0.00039621	6.0722e-06
139	0.011399	-9.0086e-05	-0.014889	-3.1502e-05	0.00049502	2.2267e-06
140	0.011328	-9.0868e-05	-0.013577	-3.0976e-05	0.00059666	-1.6861e-06
141	0.011264	-8.0396e-05	-0.01202	-2.8555e-05	0.0006948	-7.3265e-06
142	0.011216	-5.4943e-05	-0.010241	-2.7796e-05	0.00077245	-1.3301e-05
143	0.011192	-2.2597e-05	-0.0083405	-2.9843e-05	0.00078212	-1.2468e-05
144	0.011193	6.2785e-07	-0.0064941	-3.0217e-05	0.0007563	-7.4596e-06
145	0.010756	-5.1869e-05	-0.014569	9.3244e-06	-0.00025415	-3.9816e-05
146	0.011104	4.4918e-05	-0.015396	1.0354e-05	-0.00037307	-3.5667e-05
147	0.011357	0.00011288	-0.016387	2.544e-05	-0.00040123	-2.1019e-05
148	0.011528	0.00015331	-0.017363	3.8368e-05	-0.00036962	-1.3241e-05
149	0.011626	0.00017705	-0.018191	4.2291e-05	-0.0002792	-5.3921e-06
150	0.011668	0.00017296	-0.018728	4.5413e-05	-0.00014953	8.7131e-06
151	0.011681	0.00014389	-0.018962	4.9748e-05	-4.4791e-05	1.3499e-05
152	0.011678	0.00011616	-0.018988	4.7524e-05	2.5809e-05	9.0051e-06

153	0.011661	9.8874e-05	-0.018855	4.1487e-05	9.1338e-05	5.9261e-06
154	0.011635	8.3579e-05	-0.018554	3.6052e-05	0.00016321	7.1576e-06
155	0.011602	6.4741e-05	-0.018084	3.4714e-05	0.00022639	7.6182e-06
156	0.011568	5.4026e-05	-0.017488	3.5077e-05	0.00026946	3.6879e-07
157	0.011525	6.3049e-05	-0.016796	3.2548e-05	0.00031742	-6.9856e-06
158	0.011467	8e-05	-0.015953	3.0823e-05	0.00039621	-6.0722e-06
159	0.011399	9.0086e-05	-0.014889	3.1502e-05	0.00049502	-2.2267e-06
160	0.011328	9.0868e-05	-0.013577	3.0976e-05	0.00059666	1.6861e-06
161	0.011264	8.0396e-05	-0.01202	2.8555e-05	0.0006948	7.3265e-06
162	0.011216	5.4943e-05	-0.010241	2.7796e-05	0.00077245	1.3301e-05
163	0.011192	2.2597e-05	-0.0083405	2.9843e-05	0.00078212	1.2468e-05
164	0.011193	-6.2785e-07	-0.0064941	3.0217e-05	0.0007563	7.4596e-06
165	0.010808	9.0564e-05	-0.014214	3.8417e-05	-8.1137e-05	2.4544e-05
166	0.010903	-2.2822e-05	-0.014875	-7.47e-06	-0.00033514	1.5474e-05
167	0.011025	-4.8857e-05	-0.015835	-3.3766e-05	-0.00038592	-1.1814e-05
168	0.011174	-4.8776e-05	-0.016842	-4.9079e-05	-0.00038127	-1.2401e-05
169	0.011338	-6.0954e-05	-0.017774	-5.7672e-05	-0.00032903	-1.6629e-06
170	0.011502	-9.0939e-05	-0.018503	-6.5538e-05	-0.00020604	-1.6118e-05
171	0.011639	-4.7396e-05	-0.018864	-6.5807e-05	-7.2164e-05	-2.877e-05
172	0.011759	-1.6794e-05	-0.018974	-5.2533e-05	-6.7998e-07	-1.1427e-05
173	0.011862	-1.5116e-05	-0.018925	-4.4583e-05	6.0439e-05	-3.3383e-06
174	0.011955	-1.9316e-05	-0.018716	-3.8642e-05	0.00012833	-2.1975e-06
175	0.01204	-1.5247e-05	-0.01833	-3.2508e-05	0.0002021	-8.6199e-06
176	0.01212	1.0623e-05	-0.017775	-2.3219e-05	0.00025652	-8.5058e-06
177	0.012205	1.0838e-05	-0.017134	-2.2735e-05	0.00028657	4.5413e-06
178	0.012284	-1.632e-05	-0.016396	-3.1198e-05	0.00035082	5.0926e-06
179	0.012363	-2.2503e-05	-0.015451	-3.5638e-05	0.00044601	-1.2049e-06
180	0.012443	-2.1952e-05	-0.014265	-3.7376e-05	0.00054625	-6.0622e-07
181	0.012517	-2.3321e-05	-0.012832	-3.5849e-05	0.00064614	6.1426e-07
182	0.012579	-2.0203e-05	-0.011159	-3.0095e-05	0.00074001	-6.4442e-06
183	0.012622	1.1578e-05	-0.009287	-1.7372e-05	0.00079885	-1.5008e-05

184	0.012644	5.0933e-05	-0.0073569	-8.4285e-06	0.0007948	-1.8253e-05
185	0.010808	-9.0564e-05	-0.014214	-3.8417e-05	-8.1137e-05	-2.4544e-05
186	0.010903	2.2822e-05	-0.014875	7.47e-06	-0.00033514	-1.5474e-05
187	0.011025	4.8857e-05	-0.015835	3.3766e-05	-0.00038592	1.1814e-05
188	0.011174	4.8776e-05	-0.016842	4.9079e-05	-0.00038127	1.2401e-05
189	0.011338	6.0954e-05	-0.017774	5.7672e-05	-0.00032903	1.6629e-06
190	0.011502	9.0939e-05	-0.018503	6.5538e-05	-0.00020604	1.6118e-05
191	0.011639	4.7396e-05	-0.018864	6.5807e-05	-7.2164e-05	2.877e-05
192	0.011759	1.6794e-05	-0.018974	5.2533e-05	-6.7998e-07	1.1427e-05
193	0.011862	1.5116e-05	-0.018925	4.4583e-05	6.0439e-05	3.3383e-06
194	0.011955	1.9316e-05	-0.018716	3.8642e-05	0.00012833	2.1975e-06
195	0.01204	1.5247e-05	-0.01833	3.2508e-05	0.0002021	8.6199e-06
196	0.01212	-1.0623e-05	-0.017775	2.3219e-05	0.00025652	8.5058e-06
197	0.012205	-1.0838e-05	-0.017134	2.2735e-05	0.00028657	-4.5413e-06
198	0.012284	1.632e-05	-0.016396	3.1198e-05	0.00035082	-5.0926e-06
199	0.012363	2.2503e-05	-0.015451	3.5638e-05	0.00044601	1.2049e-06
200	0.012443	2.1952e-05	-0.014265	3.7376e-05	0.00054625	6.0622e-07
201	0.012517	2.3321e-05	-0.012832	3.5849e-05	0.00064614	-6.1426e-07
202	0.012579	2.0203e-05	-0.011159	3.0095e-05	0.00074001	6.4442e-06
203	0.012622	-1.1578e-05	-0.009287	1.7372e-05	0.00079885	1.5008e-05
204	0.012644	-5.0933e-05	-0.0073569	8.4285e-06	0.0007948	1.8253e-05
205	0.010825	1.7675e-14	-0.01451	-3.4416e-17	-0.00030179	2.2377e-16
206	0.010957	1.71e-14	-0.015424	-7.7214e-17	-0.00041738	2.3922e-16
207	0.011103	1.6541e-14	-0.016453	-1.2604e-16	-0.00042787	2.3162e-16
208	0.011252	1.6008e-14	-0.017451	-1.7009e-16	-0.0003937	2.1584e-16
209	0.011407	1.5486e-14	-0.018306	-2.1857e-16	-0.00030413	2.1537e-16
210	0.011573	1.496e-14	-0.018857	-2.6268e-16	-0.00015218	2.1667e-16
211	0.011702	1.4425e-14	-0.019074	-3.0555e-16	-4.0781e-05	2.18e-16
212	0.011806	1.3882e-14	-0.01909	-3.4363e-16	2.4467e-05	2.1717e-16
213	0.011903	1.3344e-14	-0.018955	-3.8191e-16	8.9692e-05	2.146e-16
214	0.011997	1.2814e-14	-0.018652	-4.2465e-16	0.00016402	2.1111e-16

215	0.012087	1.229e-14	-0.018169	-4.8055e-16	0.0002336	2.0659e-16
216	0.012161	1.1774e-14	-0.017562	-5.4213e-16	0.00026719	2.002e-16
217	0.012233	1.1279e-14	-0.016884	-6.1203e-16	0.00030534	1.9022e-16
218	0.012317	1.0813e-14	-0.016057	-6.6707e-16	0.00039091	1.8132e-16
219	0.012398	1.0375e-14	-0.014997	-7.0995e-16	0.00049339	1.7339e-16
220	0.012474	9.9613e-15	-0.013687	-7.3438e-16	0.00059794	1.66e-16
221	0.012543	9.5671e-15	-0.012128	-7.4602e-16	0.00070042	1.6268e-16
222	0.012603	9.1814e-15	-0.010335	-7.4843e-16	0.00078624	1.5853e-16
223	0.012636	8.8057e-15	-0.0083984	-7.4352e-16	0.00081098	1.5658e-16
224	0.011185	1.7756e-14	-0.014394	-3.0262e-17	-0.00051101	2.1561e-16
225	0.011151	1.7259e-14	-0.015385	-7.3959e-17	-0.00034727	2.0368e-16
226	0.011245	1.6794e-14	-0.016353	-1.176e-16	-0.00038817	1.8989e-16
227	0.011463	1.6355e-14	-0.017322	-1.5647e-16	-0.00035395	1.8353e-16
228	0.011806	1.5939e-14	-0.018201	-1.7724e-16	-0.00033809	1.7082e-16
229	0.012278	1.5516e-14	-0.018933	-1.4267e-16	-0.00011116	1.8672e-16
230	0.012244	1.5049e-14	-0.01895	-2.5978e-16	3.9576e-05	1.9826e-16
231	0.012287	1.4584e-14	-0.01894	-3.2165e-16	2.6371e-05	1.9048e-16
232	0.012384	1.4134e-14	-0.018821	-3.6274e-16	9.4297e-05	1.8757e-16
233	0.01252	1.3692e-14	-0.018531	-3.7076e-16	0.00016197	1.8072e-16
234	0.01268	1.3279e-14	-0.018022	-3.1037e-16	0.00029366	1.6574e-16
235	0.012855	1.2886e-14	-0.017241	-2.645e-17	0.00027577	1.7903e-16
236	0.01304	1.2516e-14	-0.016734	-4.3167e-16	0.00025246	1.5028e-16
237	0.013251	1.2155e-14	-0.015936	-6.0203e-16	0.00040169	1.5382e-16
238	0.01348	1.1791e-14	-0.014868	-6.7964e-16	0.00049632	1.5406e-16
239	0.01372	1.1424e-14	-0.013561	-7.1978e-16	0.00059707	1.5409e-16
240	0.013966	1.1054e-14	-0.012015	-7.3691e-16	0.00069105	1.5681e-16
241	0.014214	1.0672e-14	-0.010215	-7.4106e-16	0.00082761	1.6026e-16
242	0.014466	1.0289e-14	-0.0080788	-7.3393e-16	0.00091005	1.5758e-16
243	0	0	0	0	0	0
244	0	0	0	0	0	0
245	-0.00077571	0	0	-7.2918e-05	0.00018105	-4.8813e-05

246	-0.00077571	0	0	7.2918e-05	0.00018105	4.8813e-05
247	0.00013	-1.849e-06	-0.0009067	3.9388e-05	5.2001e-05	1.2649e-05
248	0.00013	1.849e-06	-0.0009067	-3.9388e-05	5.2001e-05	-1.2649e-05
249	0.00012954	-4.0087e-06	-0.00020617	0.00014824	0.00018105	-4.8813e-05
250	0.00012954	4.0087e-06	-0.00020617	-0.00014824	0.00018105	4.8813e-05
251	0.012125	-0.00019637	-0.008061	-0.00077117	0.00016101	0.00010218
252	0.012125	0.00019637	-0.008061	0.00077117	0.00016101	-0.00010218
253	0.013551	-4.0868e-05	-0.00075249	-0.0024103	0.00027856	8.7817e-05
254	0.013551	4.0868e-05	-0.00075249	0.0024103	0.00027856	-8.7817e-05
255	0.021881	1.8157e-14	-0.01146	1.2949e-17	0.00057455	2.04e-16

```
clear,clc

%% values
L_1_1 = 0.5; %the height of the two I-beams at the bottom
L_1_2 = 0.15; %the distance to the web at both sides the two I-beams at
the bottom
L_1_3 = 0.5; %the width of the flange of the two I-beams at the bottom
L_1_4 = 0.3; %the distance between the two flanges of the two I-beams
at the bottom

L_2_1 = 0.3; %the diameter of the beams which connect the two middle I-
beams
L_2_2 = 3.5; %the distance between the two middle I-beams

L_3_1 = 1.5; %the distance between the middle I-beams and the two I-
beams at the bottom
L_3_2 = 0.3; %the diameter of the beams which connect the middle I-
beams and the two I-beams at the bottom

L_4_1 = 0.5; %the diameter of the beam at the top of the boom
L_4_2 = 2.0; %the height between the top beam and the two middle I-
beams

L_5_1 = 0.3; %the diameter of the beams which connect the top beams
with the two middle I-beams

L_6_1 = 0.5; %the height of the two I-beams at the middle
L_6_2 = 0.15; %the distance to the web at both sides the two I-beams at
the middle
L_6_3 = 0.5; %the width of the flange of the two I-beams at the middle
L_6_4 = 0.3; %the distance between the two flanges of the two I-beams
at the middle

factor = 0.1; %the factor for the areas which change during different
sections

%% A1
L_y_1 = 0.5.*L_1_3;

A_1 = L_1_1.*L_1_3-2*(L_1_2.*L_1_4).*2

%% A2
L_y_2 = -0.5.*L_2_1+2.*L_1_3+L_3_1;

A_2 = (L_2_1.*L_2_2).*factor;

%% A3
L_y_3 = 0.5.*L_3_1+L_1_3;

A_3 = (L_3_1.*L_3_2).*factor;

%% A4
```

```
L_y_4 = 2.*L_1_3+L_3_1+L_4_2+0.5.*L_4_1;

A_4 = ((L_4_1./2).^2).*pi

%% A5
L_y_5 = 2.*L_1_3+L_3_1+0.5.*L_4_2;

A_5 = (sqrt((0.5.*L_2_2).^2+(L_4_2).^2).*L_5_1).*factor.*2;

%% A6
L_y_6 = L_1_3+L_3_1+0.5.*L_6_3;

A_6 = L_6_1.*L_6_3-2*(L_6_2.*L_6_4).*2

%% centre of mass
Centre_y =
(A_1.*L_y_1+A_2.*L_y_2+A_3.*L_y_3+A_4.*L_y_4+A_5.*L_y_5+A_6.*L_y_6)./(A
_1+A_2+A_3+A_4+A_5+A_6)

%% Area moment of inertia
Area_moment_of_inertia = A_1.*(abs(Center_y-
L_y_1)).^2+A_2.*(abs(Center_y-L_y_2)).^2+A_3.*(abs(Center_y-
L_y_3)).^2+A_4.*(abs(Center_y-L_y_4)).^2+A_5.*(abs(Center_y-
L_y_5)).^2+A_6.*(abs(Center_y-L_y_6)).^2
```