

**DESIGN IMPROVISATION AND FINITE ELEMENT
ANALYSIS OF LIFT FOR PEOPLE WITH DISABILITY
USING HYDRAULIC POWERED MOVEMENT SYSTEMS**

FINAL PROJECT REPORT

**Submitted as Partial Fulfillment of the Requirements for
Bachelor Degree in Mechanical Engineering at
Universitas Islam Indonesia**



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YOGYAKARTA
2017**

DECLARATION LETTER

I hereby declare that the project work entitled " DESIGN IMPROVISATION AND FINITE ELEMENT ANALYSIS OF LIFT FOR PEOPLE WITH DISABILITY USING HYDRAULIC POWERED MOVEMENT SYSTEMS" submitted to Department of Mechanical Engineering, Faculty of Industrial Technology in Partial Fulfillment of the requirement for the Bachelor Degree of Mechanical Engineering at Islamic University of Indonesia, is a final project done by me under the guidance of my advisor, Dr. Eng. Risdiyono, S.T., M.Eng. after the completion of three months' work at T.M.C. Industrial Public Co., Ltd. and Rajamangala University of Technology Tawan-ok (RMUTTO), Thailand.

If someday this project is proven as a plagiarism, Universitas Islam Indonesia has right to revoke its confession.

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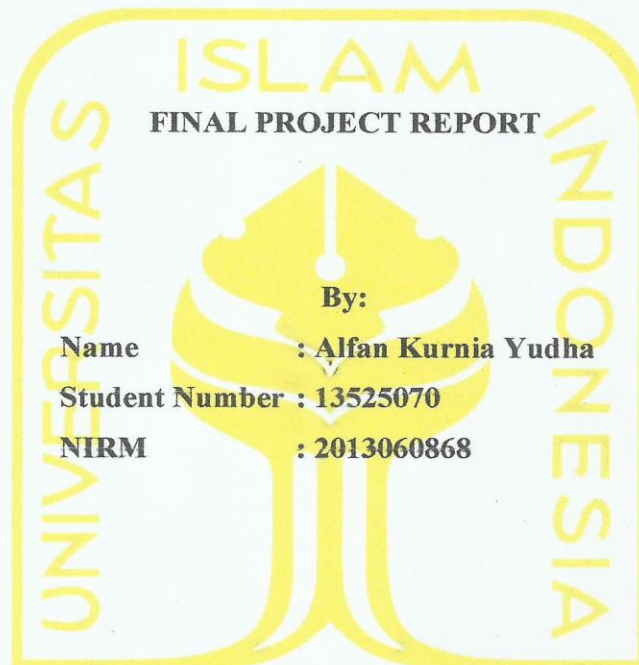



Alfan Kurnia Yudha

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ADVISOR VALIDATION PAGE

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ANALYSIS OF LIFT FOR PEOPLE WITH DISABILITY
USING HYDRAULIC POWERED MOVEMENT SYSTEMS**



Chonburi, May 2017

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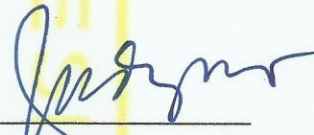
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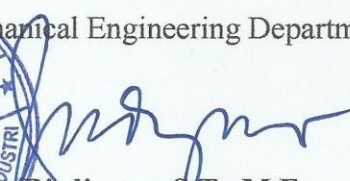
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DEDICATION PAGE

This bachelor thesis is dedicated to my parents. My beloved mother Dewi Susanti who is an absolute wonder woman in every way. My father Drs. Ari Parikesit. My dearest siblings, my twin brother Alfin Kurnia Bahari, and my beautiful little sister Natasya Sekar Larasati.

Also to all members of my big family that always supported me, The coolest uncle in the world, uncle Gerri Primacitra. My grandmother and grandfather and to Nenek arum, who is no longer in this world. But always supported me in the early years of my study in this university.

And i also dedicated to all my friends and all the people who helps, supports and prays for my bachelor thesis

MOTTO

*“Failure is only the opportunity to begin again. Only this time more wisely.” -
(Uncle Iroh)*

*“We all must suffer one of two things : The pain of Discipline or the pain of
regret.” - (Dwayne “The Rock” Johnson)*

*“Knowing is not enough, We must Apply. Willing is not enough, We must do.” -
(Bruce Lee)*

*“There is nothing outside of yourself that can ever enable you to get stronger,
better, richer, quicker, or smarter. Everything is within. Everything exists. Seek
nothing outside of Yourself.” - (Miyamoto Musashi)*

*“What is better, To be born good or overcome your evil nature with great
effort?” - (Paarthurnax)*

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Thailand, May 2017

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ABSTRACT

A lift is really helpful for disabled people but sometimes there not enough room for a wheelchair. The needs for public access for this facility is crucial. To ease the availability of lift for the disabled especially in a wheelchair comes the lift with hydraulic powered movement systems. The research activity is conducted at T.M.C Industrial Public Co., Ltd. As one of the leading Industry in Thailand and ASEAN, T.M.C is suppliers and manufacturers of hydraulic based technology and other types of machinery. This research is focused on the hydraulic systems development for the lift. A suitable design for the structure and the systems is essential to the development of this research. The goal of this research is creating the design aspect for the lift that suits the specifications so that the outcome is a design with the improvement that can be manufactured in T.M.C. Finally, Finite Element Analysis is used to determine whether the design is within the safety factor boundaries for the structure and in the critical parts of the lift assembly.

Keywords: Lift, disabled people, design, hydraulic, Finite element analysis

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CHAPTER 1

INTRODUCTION

1.1 Background

Elevator or lift by definition is a type of vertical transportation system that efficiently moves people, goods or anything between the floor of a building. The people, goods and the item shall not exceed the maximum contract load that the lift or elevator can carry. The general construction of a lift consists of a car that can be moved with a lifting machine. The car runs on a rail with a fixed guideline. The purpose is for the lift so it doesn't shake or become unstable while it moves.

In choosing a lift it usually depends on the size of the building that serves the user. It purposes so that it can serve the user and ease the travel from place to place in a stories facility. The movement systems in a lift are also varied depends on the usage requirements, the travel speed, and also the maximum height of travel. One of the movement systems that exist is Hydraulic powered movement system. The basic work principle is that the car of the lift is lifted with a hydraulic ram, which is a piston that moved with a fluid inside of a cylinder that is connected to a fluid pumping system.

As one of the assisting tools that ease the travel movement in public or private places, the elevator should be available for everybody including the people with disability. But in reality, most of the facility that existed today isn't enough and doesn't give any privileges to people with disability. To ease the availability of lift for the disabled especially in a wheelchair comes the lift with hydraulic powered movement systems. The usage of this lift can be one of the alternatives for transportation in public places or in private buildings. From the manufacturing cost, systems, maintenance and the benefits of the hydraulic lift can be the solutions to this problem.

The final project activity is conducted at T.M.C Industrial Public Co., Ltd. T.M.C. As one of the leading Industry in Thailand and ASEAN, T.M.C is suppliers and manufacturers of hydraulic and other types of machinery along with precise control systems and punctual production systems. Their product line in this area

consists of over a hundred different types of machines, ranging from press machines, cranes, also hydraulic and pneumatic lift. So, this research is focused on the hydraulic systems development for the lift.

It requires a plan and a design that suitable for this kind of lift. From the existing product needs a design improvement especially in safety of the structure, the movement system, also from the ergonomically aspects. So later on, this lift can be more comfortable and safe to use for the people with disability.

1.2 Formulation of the Problem

Based on the background of the research above, the formulation that can be taken is how to design and or remodel a design of a lift with hydraulic powered movement system so that the design can be improved and suits the aspects of safety and ergonomics for the people with disability.

1.3 Scope of the Problem

For the research of this design can be focused, the scope of the problem in this research are:

1. The design and the Analysis only done digitally without making the prototype. The design is done with CAD Software, *Autodesk Inventor*.
2. The change of the designs is done especially so that it suits to accommodate people with disability, especially in a wheelchair.
3. The movement system of this lift is powered by Hydraulic systems.
4. The dimensions and specification of the lift are based on the task that is given by the handler of this project at T.M.C Industrial Public Co., Ltd.

1.4 Objective

Based on the formulation of the problem, the objectives of this research are:

- Capable of making a design of the structure for a lift that specially built for people with disability. The design is intended so that the lift can be used in public facility such as company/office, factory, overpass, or maybe in private buildings so that it can help the people with disability.

- Capable of knowing the performance of lift with hydraulic powered movement system and can design the right hydraulic system that matches with the specification and standard from T.M.C.
- Capable of analyzing the structure of the elevator with Finite Element Method with the help of CAD/CAM/CAE Software.

1.5 Benefits of the Research or Design

The benefits that are expected with the availability of this research are:

- Can increase the availability of lift for people with disability with design and system improvement from existing products should the design manufactured into a real product.
- Can be made for a design reference for one of the products that can be manufactured or installed in T.M.C Industrial Public Co., Ltd.
- Can be made into a reference for making a lift with an efficient system and low-cost production in the manufacturing process.

1.6 Organization of Report

The remainder of this project is organized as follows:

Chapter 1	INTRODUCTION	Discusses the introduction and the outline of this research.
Chapter 2	LITERATURE REVIEWS	Discusses the literature review and then explain the theory that is used in this research and design aspect from the Lift.
Chapter 3	RESEARCH METHODOLOGY	Discusses design and the mathematical equation for the design that suits the specifications of the design process.
Chapter 4	RESULTS AND ANALYSIS	Discusses the design results, the improvement of the design, and the Finite Element Analysis of the structure and the critical parts of the lift.
Chapter 5	CONCLUSIONS	

Finally, this chapter present conclusion and the recommendation for this project.

CHAPTER 2

LITERATURE REVIEWS

2.1 Literature Review

Design is a process that has been around a long time and maybe as old as the existence of human in the earth. The definition of design itself can be based on the perspective and or the context of itself. Design is a process of problem-solving with a clear target or objective. [1] A good design isn't just what is based on a paper, but an actual activity that can contain the elements of the economy, social, technology and culture on it dynamic. A good design that is just on paper will only just be a concept without actual realization.

A design always needs an improvement for itself to continue existing. The improvement can be an innovation of the actual design without having to lose the actual purpose of the products. Innovation is an idea, a plan, a practice, or an object that realized and accepted as something new for a people or a group to be adopted. Innovation always has a connection with the design because the design is a realization of an innovation.

The design of a lift may vary based on the purpose of the lift, the traffic management, the size of the multi-storied building, etc. From hydraulics lift to traction lift, the technology of lift and elevator is evolving from time to time. Because of wheelchair access laws, elevators/lifts are often a legal requirement in new multi-story buildings, especially where wheelchair ramps would be impractical. Therefore, there should be a design that has ergonomic aspect and serve the purpose for people with disability.

The accessibility of public places for people with disability is actually stated by the regulations. It is stated in Undang-Undang Dasar 1945, UU RI No.4 Tahun 1997 about Disabled people, and UU RI No. 39 Tahun 1999 about Human Rights, Surat Edaran Menteri Negara Perencanaan Pembangunan Nasional RI No. 3064/M.PPN/05/2006 about construction planning that gives access for people with disability. But in reality, the facility that existed right now in Indonesia only a few and people with disability rarely have the privileges to use a public access

like this. That's why a facility that accommodates things like this should exist but with the right purpose and the right systems

2.2 Elevator

An elevator (or lift in the Commonwealth excluding Canada) is a type of vertical transport equipment that efficiently moves people or goods between floors (levels, decks) of a building, vessel or other structures. Elevators are generally powered by electric motors that either drive traction cables or counterweight systems like a hoist or pump hydraulic fluid to raise a cylindrical piston like a jack.

There are three types of conveying methods in buildings, Elevators & Escalators & Ramps, and they have different dimensions and uses according to building type & number of users in it. There are also many kinds of the elevator based on the systems, size, and function. Elevator types:

- According to hoist mechanism.
- According to building height.
- According to building type.
- According to elevator Location.
- According to Special uses.

2.2.1 Hydraulic Elevator

According to hoist mechanism, elevators will be classified according to 4 main types as follows:

- Hydraulic Elevators
- Traction Elevators
- Climbing elevator
- Pneumatic Elevators

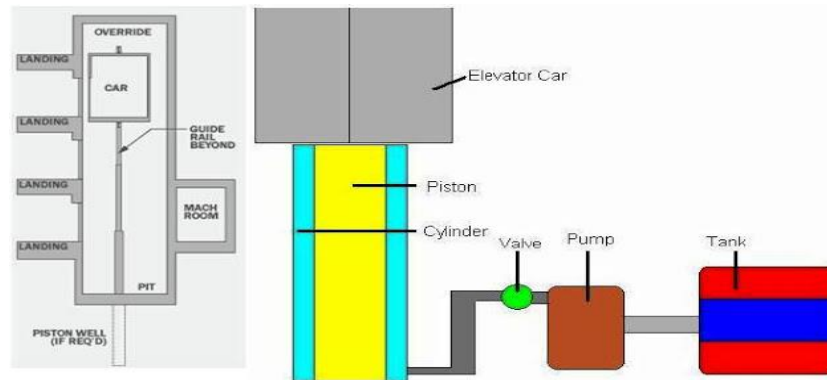


Figure 2.1 Mechanism of Hydraulic Elevator

Because in this research the mechanism that is used is based on the hydraulic elevator, therefore the literature studies will only about the hydraulic elevator. Hydraulic elevators operate on a simple principle. They lift a car by using a hydraulic ram, which is a fluid-driven piston inside a cylinder. The cylinder is connected to a system that pumps fluid, typically oil. The hydraulic elevator system consists of a tank, or fluid reservoir; a pump that is powered by an electric motor; and a valve located between the cylinder and the reservoir. They are used for low-rise applications of 2-8 stories and travel at a maximum speed of 200 feet per minute. The machine room for hydraulic elevators is located at the lowest level adjacent to the elevator shaft.

Based on the classifications, the hydraulic lift can be divided into 2 types. Such as:

2.2.1.1 Direct Acting Hydraulic Lift

Construction Details, Components of direct acting hydraulic lift:

- Fixed cylinder: It is fixed with the wall of the floor, where the sliding ram reciprocate when we apply the pressure.
- Cage: It is fitted on the top of the sliding ram where the load is placed (i.e. lifted load).
- Sliding ram: It is fitted in the fixed cylinder which is reciprocated (upward or downward direction) when we applied the pressure (i.e. reaches the floor wise.)

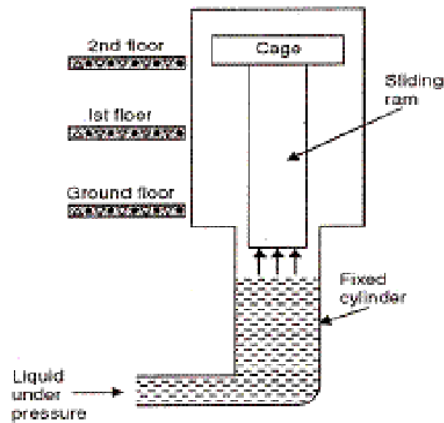


Figure 2.2 Working of Direct Acting Hydraulic Lift

When fluid under pressure is forced into the cylinder, the ram gets a push upward. The platform carries loads or passengers and moves between the guides. At the required height, it can be made to stay in level on each floor so that the goods or passengers can be transferred.

In the direct acting hydraulic lift, a stroke of the ram is equal to the lift of the cage.

2.2.1.2 Suspended Hydraulic Lift

Construction Details:

- **Cage:** It is fitted on the top of the sliding ram where the load is placed (i.e. lifted load).
- **Wire rope:** It connects the cage to the pulley.
- **Sliding ram:** It is fitted in the fixed cylinder which is reciprocated (upward or downward direction) when we applied the pressure (i.e. reaches the floor wise)
- **Pulleys:** pulleys are connected to the sliding ram and fixed cylinder; where one pulley is fixed and another pulley is movable.
- **Hydraulic jigger:** It consists of a moving ram which slides inside a fixed hydraulic cylinder.
- **Fixed cylinder:** It is fixed with the wall of the floor, where the sliding ram reciprocate when we apply the pressure.

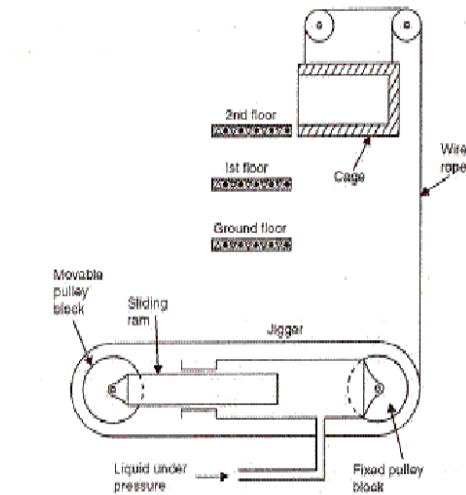


Figure 2.3Working of Suspended Hydraulic Lift

When fluid under pressure is forced into the cylinder, the ram gets reciprocate to the movable pulleys. With the help of arrangement of hydraulic jigger; pulley can rotate; with the help of wire rope, the cage is maintained their pressure force with the floor. At the required height, it can be made to stay in level on each floor so that the good or passengers can be transferred.

Working period of the lift is the ratio of the height of lift to the velocity of lift. Idle period of lift is the difference between the total time for one operation and the working period of the lift. [2]

2.2.2 Elevator According to Special Uses

2.2.2.1 Handicap Elevators



Figure 2.4 Handicap Elevators

In reality, any type of elevator that can assist a handicapped person in going up and down various levels of the building could be considered a handicap elevator. However, specific types of elevators are manufactured with handicapped persons in mind. A good example of this would be a wheelchair lift that gets a handicapped person in and out of vans. The lift comes out the sliding doors and descends in order to allow the wheelchair on the platform. Then the lift is raised up and backs into the vehicle. Most city buses have this type of handicap elevators installed on them, but they are also manufactured for privately owned vehicles as well. Most handicap elevators within a home are electric elevators, but some are pneumatic vacuum models as well and operated by air pressure. Stairway lifts are also considered to be a type of handicap elevator and this type can either be installed on a straight stairway or a curved staircase.

2.2.2.2 Limited use / Limited application (LU/LA)

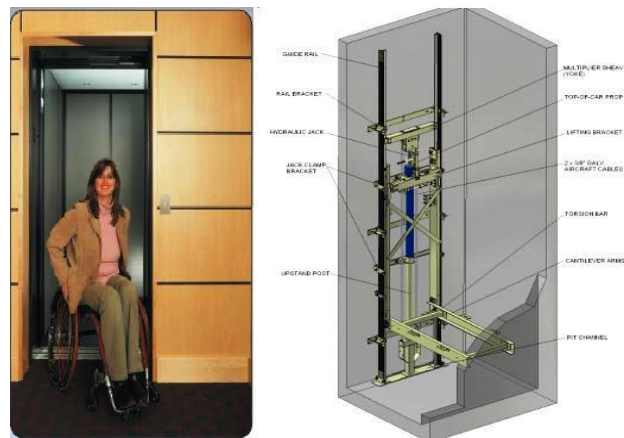


Figure 2.5 Limited use / limited application (LU/LA)

The limited-use, limited-application (LU/LA) elevator is a special purpose passenger elevator used infrequently, and which is exempt from many commercial regulations and accommodations. For example, an LU/LA is primarily meant to be handicapped accessible, and there might only be room for a single wheelchair and a standing passenger. [3]

2.3 Elevator Components

Elevators consist of complex structural, mechanical, and electrical components Janovsky's monograph (1993) gives a description of the engineering detail of elevator systems. [4] The main components of a typical traction elevator are shown in **Figure 2.6**.

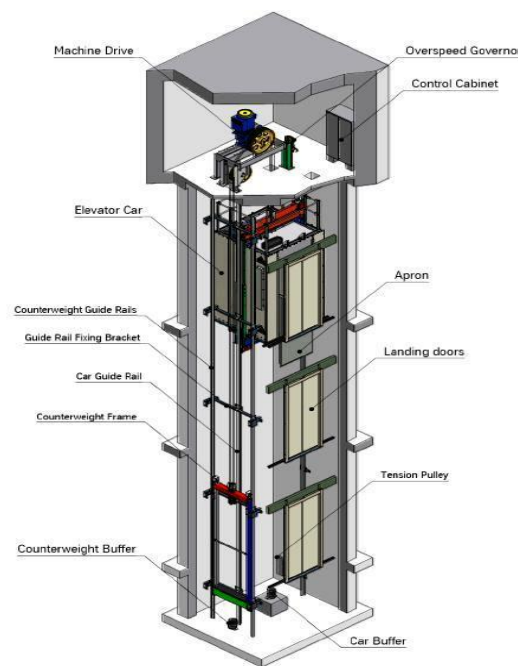


Figure 2.6 Elevator Components

The standard elevators will include the following basic components:

- Car.
- Hoistway.
- Machine/drive system.
- Control system.
- Safety system.

Below will be explained only the theory that relevant to the research and the design component such as the car and the hoist way. The drive system is already explained above because the lift uses the power of hydraulic ram to lift the car. But later in the report, it will be explained in the detail of the hydraulic systems and the components that are relevant to the design.

2.3.1 Car

Elevator Car is the vehicle that travels between the different elevator stops carrying passengers and/or goods, it is usually A heavy steel frame surrounding a cage of metal and wood panels.

Standard elevator car/cabin can be classified according to the number of entrances and their locations as follows:

1. Normal Cabin
2. Open Through Cabin
3. Diagonal Cabin

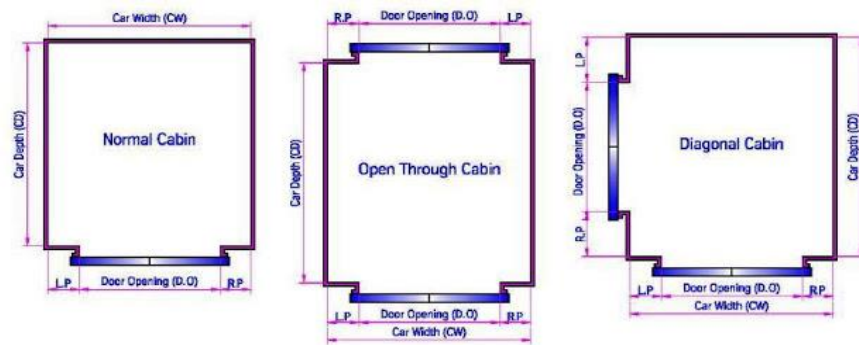


Figure 2.7 Elevator Car Types

Elevator Car Components:

Elevator Car is composed of the following components:

1. Car Sling, a metal framework connected to the means of suspension,
2. The elevator cabin,
3. Mechanical accessories which are:
 - Guide shoes.
 - Etc. (other accessories may vary depending on the design)

2.3.1.1 Car Sling

Car Sling is load carrier element in the elevator car as well as its function of isolating vibrations due to running.

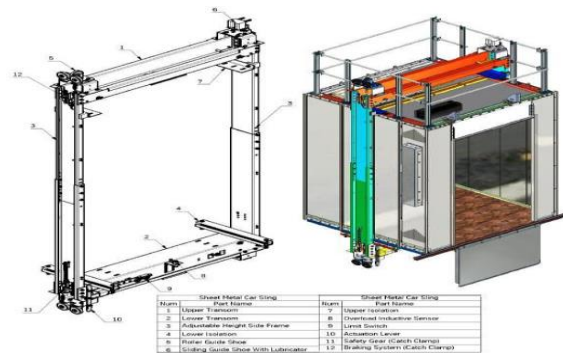


Figure 2.8 Car Sling

2.3.1.2 Elevator Cabin

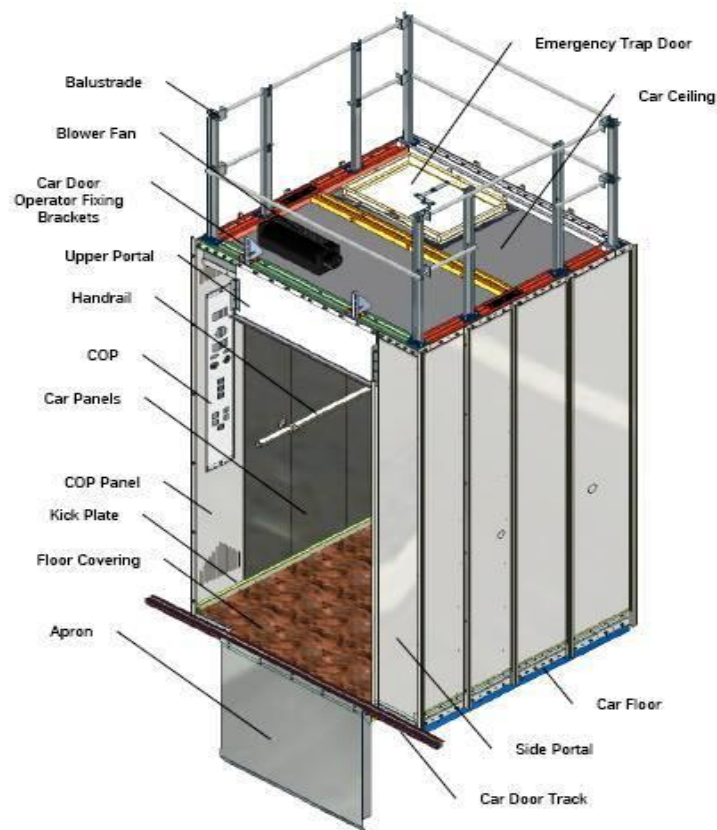


Figure 2.9 Elevator Cabin

Elevator cabinets shall be completely enclosed by walls, floors, and ceiling, the only permissible opening being is the car door, emergency trap door, and ventilation apertures.

2.3.1.3 Mechanical Accessories

- **Guide shoes:**

There are two types of guiding shoes as follows:

- 1- **Roller Guides:** Guide shoes which use rollers that rotate on guide rails (A set of three wheels that roll against the guide rails) rather than sliding on the rails.



Figure 2.10 Roller Guides

- 2- **Sliding Guides:** guide shoes which simply slide along the faces of the rails; the sliding insert or gib may be metal, requiring the guide rails to be lubricated, or may be a plastic material which is self-lubricating.

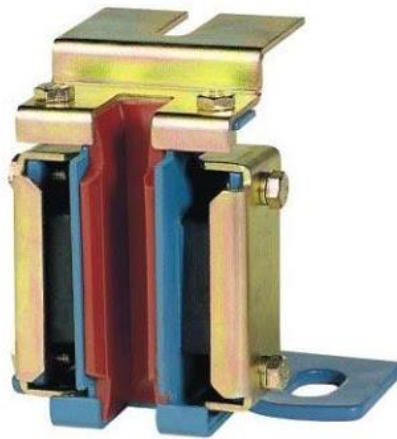


Figure 2.11 Sliding Guides

2.3.2 Hoist

way



Figure 2.12 Hoist way

A simple definition for the hoistway is the shaft that encompasses the elevator car.

Note: Generally the Hoistway serving all floors of the building but in high-rise buildings, hoistways may be banked with specific hoistways serving only the lower floors and others serving only middle or upper floors while traveling in a blind hoistway until reaching the floors that it serves. A blind hoistway has no doors on the floors that it does not serve. Hoist way is equipped with the following components:

1. Guide rails for both the car and counterweight.
2. Counterweight.
3. Suspension (Hoisting) Ropes (Cables).
4. Landing (Hoist way) doors.
5. Buffers in the pit

The design component that is used in this research only included the guide rails as the components of the hoist way. The guide rails are in form of C Beam structure.



Figure 2.13 Guide Rails

Guide Rails are Steel Tracks that run the length of the hoist way, round, or formed sections with guiding surfaces to guide and direct the course of travel of an elevator car and elevator counterweights and Usually mounted to the sides of the hoist way.

Car Guide rails are fixed to the hoist way by means of steel brackets. Which consists as shown in the below image

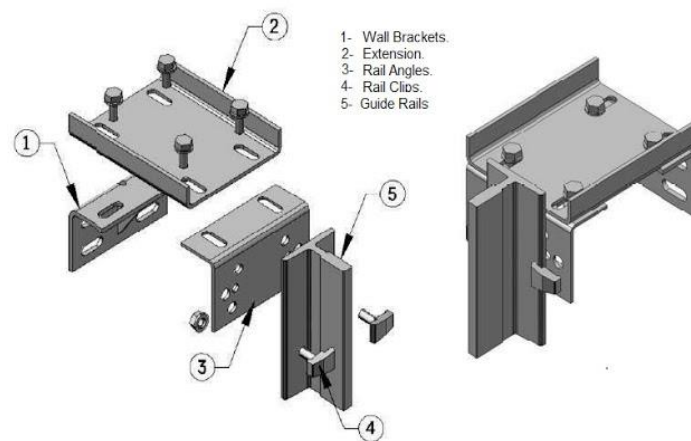


Figure 2.14 Car steel brackets

2.4 Hydraulic Systems

The word hydraulics is a derivative of the Greek words hydro (meaning water) and aulis (meaning tube or pipe). Originally, the science of hydraulics covered the physical behavior of water at rest and in motion. Pascal discovered the fundamental law underlying the entire science of hydraulics in the 17th century. Pascal's theorem was as follows:

If a vessel full of water, and closed on all sides, has two openings, one a hundred times as large as each other, and if each is supplied with a piston that fits exactly, then a man pushing the small piston will exert a force that will equal that of one hundred men pushing the large piston and will overcome that of ninety-nine men.

For Pascal's law, illustrated in **Figure 2.15**, to be made effective for practical applications, it was necessary to have a piston fit exactly.

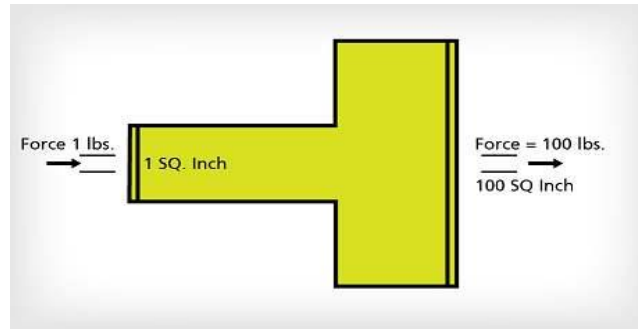


Figure 2.16 Illustration of Pascal Law

The foundations of modern hydraulics were established when Pascal discovered that pressure set up in a fluid acts equally in all directions. To understand how Pascals Law is applied to fluid power, a distinction must be made between the terms force and pressure. *Force* may be defined as "a push or pull." It is the push or pull exerted against the total area of a particular surface and is expressed in pounds. As stated earlier, the *pressure* is the amount of force on a unit area of the surface acted upon. Therefore, the pressure is the amount of force acting upon one square inch of area.

$$P = \frac{F}{A} \quad (2.1)$$

P shows Pressure, F is Force that applied in the face of the area, and A is total Area.

The hydraulic systems consists a number of parts for its proper functioning. These include a storage tank, filter, hydraulic pump, pressure regulator, control valve, hydraulic cylinder, piston, and leak proof fluid flow pipelines. The schematic of a simple hydraulic system is shown in **Figure 2.17**. It consists of:

- A movable piston connected to the output shaft in an enclosed cylinder
- Storage tank
- Filter
- Electric pump
- Relief Valve/pressure regulator
- Control valve
- Leak proof closed loop piping.

The output shaft transfers the motion or force, however, all other parts help to control the system. The storage/fluid tank is a reservoir for the liquid used as a transmission media. The liquid used is generally high-density incompressible oil.

It is filtered to remove dust or any other unwanted particles and then pumped by the hydraulic pump. The capacity of the pump depends on the hydraulic system design. These pumps generally deliver constant volume in each revolution of the pump shaft. Therefore, the fluid pressure can increase indefinitely at the dead end of the piston until the system fails. The pressure regulator is used to avoid such circumstances which redirect the excess fluid back to the storage tank. The movement of the piston is controlled by changing liquid flow from port A and port B. The cylinder movement is controlled by using control valve which directs the fluid flow. The fluid pressure line is connected to the port B to raise the piston and it is connected to port A to lower down the piston. The valve can also stop the fluid flow in any of the port. The leak proof piping is also important due to safety, environmental hazards and economical aspects. Some accessories such as flow control system, travel limit control, electric motor starter and overload protection may also be used in the hydraulic systems. [5]

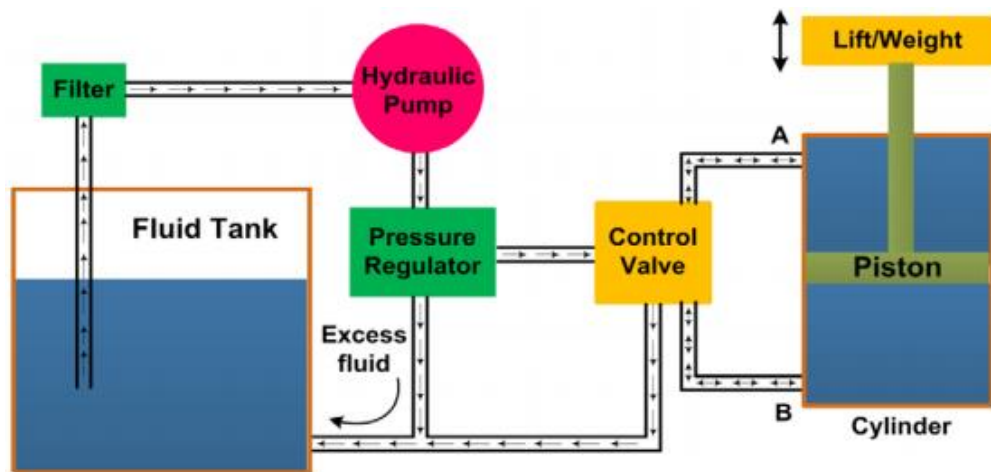


Figure 2.17 Schematic of Hydraulic System

2.5 Bearing & Retaining Ring

2.5.1 Bearing

When in operation, a shaft is subjected to axial and radial forces which tend to push it away from its axis center. Bearings are positioned to resist to these forces and maintain the shaft in proper equilibrium. [6]

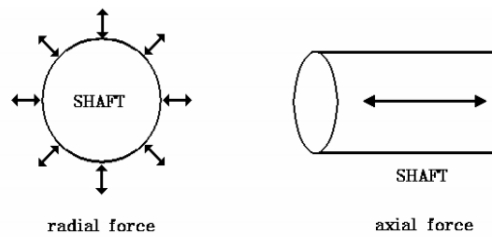


Figure 2.18 Force Illustration on Shaft

Manufacturers have grouped bearings under two headings, on the basis of the forces being encountered: radial bearings and axial bearings.

Radial Bearings

Radial bearings are made with balls or rollers, depending on the how the bearings are used. They are designed to withstand forces that are perpendicular to the axis of the shaft.



Figure 2.19 Radial Bearings

Axial bearings

Axial bearings, also known as thrust bearings, have either balls or rollers, but both are designed to withstand axial forces, which push or pull along the axis.^[5]

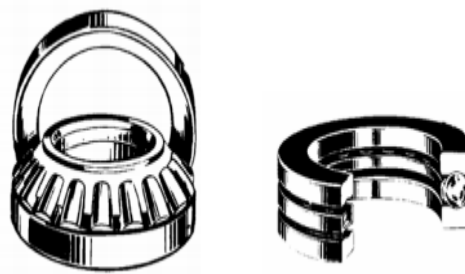


Figure 2.20 Axial Bearings

In this research, there are structures that used bearing on their shaft. The bearings that are used for this research are Radial bearing, to be precise the type is Deep Groove Ball Bearings.

2.5.2 Retaining Ring

A retaining ring is a fastener that holds components or assemblies onto a shaft or in a housing/bore when installed in a groove. Once installed, the exposed portion acts as a shoulder which retains the specific component or assembly. Circlips are a type of retaining ring. Self-locking retaining rings may be installed in applications where there is no groove.



Figure 2.21 Retaining Ring

Retaining rings are typically made from carbon steel, stainless steel or beryllium copper and may feature a variety of finishes for corrosion protection depending on the type of environment in which they are used.

2.6 C-Beam

The structural channel, also known as a C-beam, is a type of (usually structural steel) beam, used primarily in building construction and civil engineering. Its cross section consists of a wide "web", usually but not always oriented vertically, and two "flanges" at the top and bottom of the web, only sticking out on one side of the web. It is distinguished from I-beam or H-beam or W-beam type steel cross sections in that those have flanges on both sides of the web. [7]

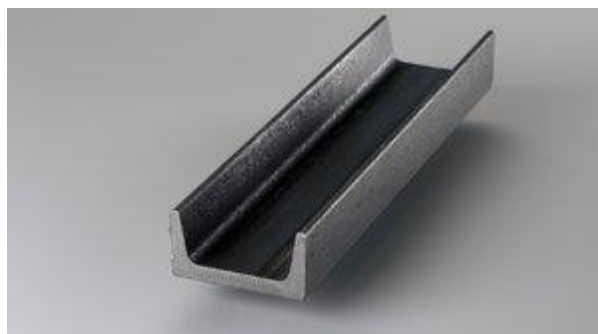
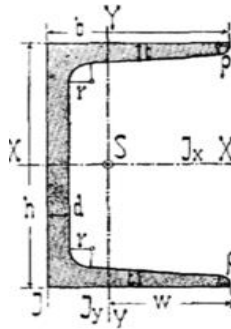


Figure 2.22 C-Beam

Channels or C-beams are often used where the flat, back side of the web can be mounted to another flat surface for maximum contact area. They are also sometimes welded together back-to-back to form a non-standard I-beam.



In this research, the c-beam is used as the guide rails for the elevator car so that it can move vertically smoothly.

Factors of safety (FoS), also known as (and used interchangeably with) safety factor (SF), is a term describing the load carrying capacity of a system beyond the expected or actual loads. Essentially, the factor of safety is how much stronger the system is than it usually needs to be for an intended load. Safety factors are often calculated using detailed analysis because comprehensive testing is impractical on many projects, such as bridges and buildings, but the structure's ability to carry load must be determined to a reasonable accuracy. The formula of the safety factor is:

$$Sf = \frac{YS}{D.S}$$

21

2.8 FEA

The finite element method (FEM) is a numerical method for solving problems of engineering and mathematical physics. It is also referred to as finite element analysis (FEA). Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

Finite element analysis helps predict the behavior of products affected by many physical effects, including:

- Mechanical stress
- Mechanical vibration
- Fatigue
- Motion
- Heat transfer
- Fluid flow

A variety of specializations under the umbrella of the mechanical engineering discipline (such as aeronautical, biomechanical, and automotive industries) commonly use integrated FEM in design and development of their products. In a structural simulation, FEM helps tremendously in producing stiffness and strength visualizations and also in minimizing weight, materials, and costs. [9]

FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of both modeling and analysis of a system. FEM allows entire designs to be constructed, refined, and optimized before the design is manufactured.

In this research the main analysis that is used are *von Misses stress*, *1st principal stress*, and *3rd Principal stress*. The *von Mises yield*

criterion [10] suggests that the yielding of materials begins when the second deviatoric stress invariant J_2 reaches a critical value. It is part of a plasticity theory that applies best to ductile materials, such as metals.

The 1st principal stress gives the value of stress that is normal to the plane in which the shear stress is zero. The 1st principal stress helps to understand the maximum tensile stress induced in the part due to the loading conditions. The 3rd principal stress acts normal to the plane in which shear stress is zero. It helps to understand the maximum compressive stress induced in the part due to the loading condition.

CHAPTER 3

RESEARCH METHOD

3.1 Schematics of the Research

The research of this final project consists of many steps that will be done as follows, as seen in **Figure 3.1**.

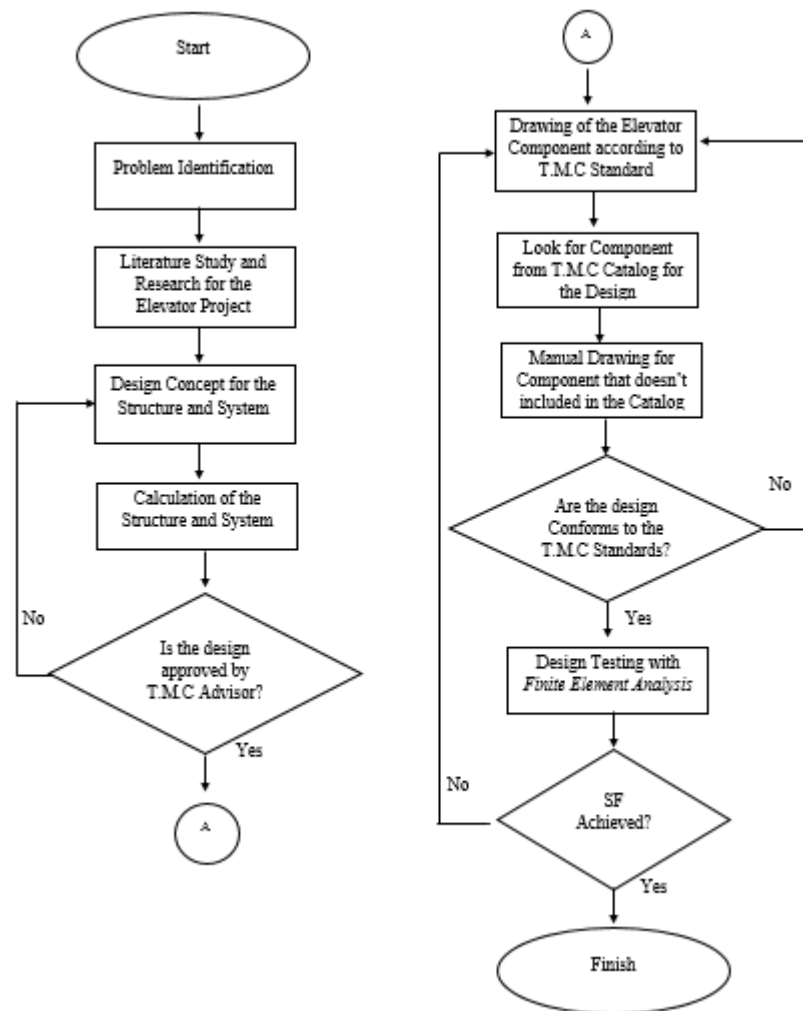


Figure 3.1 Flowchart of the Research

3.2 Problem Identification

On this research, the first step that must be done is determining the concept design of the machine and the system that is going to be designed. There are 2 steps that are done, which is identification and description criteria of the modification.

Identification that is done is based on the dimension specification of the car, and the structure of the building also the system that is used to move the lift. What is the maximum height of the lift travel? What is the dimension of the car? This all is specified by the handler of this project from T.M.C. The identification on the mechanical concept conforms with the component specification for the machine and structure.

The modification that is done is based on the problem that the design T.M.C already have. Additional modification may occur based on the ergonomic modification, so that the design may be suitable for the user of the lift. The modification of the design is done but with the supervision of the handler from T.M.C so that the design still within T.M.C standard of design.

The Description for the modification criteria of the elevator that must be achieved in the design are:

- The Elevator system is based on Hydraulic. Therefore, the travel height is equal to the stroke of the cylinder. To reduce the stroke there are changes to the design that are made in the cylinder assembly.
- The shape of the guides for the frame and the car that is used before are roller shape. The problem that T.M.C have didn't fit the frame so the elevator is unstable and unable to move vertically straight. Therefore, there should be a modification to guiding rails.
- Additional Design may be added for the ergonomic aspect of the wheelchair. The design is unlimited, as long as it can be installed within the elevator and within the Safety Factor criteria of the whole structure.
- The elevator maximum load/capacity are 500 kg. The cylinder must be able to lift this load + the weight of the car structure.
- The design should be within the safety factor and the maximum load that is specified by T.M.C.

3.3 Design Process

For the designing process of this lift project, there are 2 steps to realizing the design criteria that are given by T.M.C. The first step is determining the design concept and making the calculation that is needed for the design. After the

calculation completed the result numbers are transformed into drawing to make the design. If there are some errors along the way, that means the calculation is wrong so the calculation for the error part must be redone.

The design of some of the component may conform to the catalog that T.M.C have. An example of that is sprocket, gear, bearing, cylinder barrel, cylinder components. All of that and some other component must follow the catalog that T.M.C have, other than the part that doesn't include in the catalog, the component must be design within the safety factor criteria. After the design is completed the advisor from T.M.C will check if the design is within the boundary standard of T.M.C also if the design is within the Safety Factor that is given before.

3.3.1 Design Concept and Formula

Realizing the design concept for making a machine is crucial, the concept that can be used for a design are the one that follows the condition and the criteria from the customer. Other than that, the designer must make sure that the system that will be installed is the right system for the machine. With that in mind only then the machine will come out well in the design.

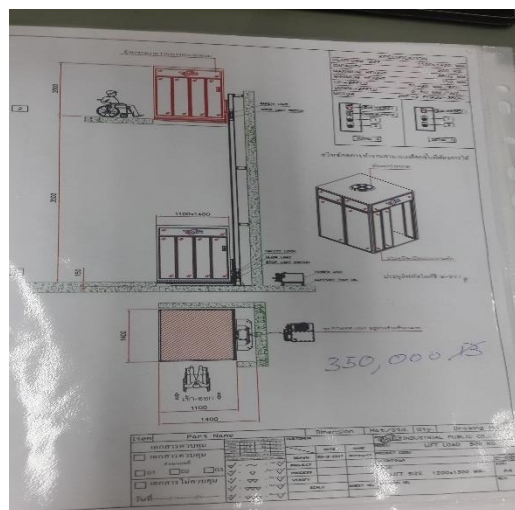


Figure 3.2 Example of lift that T.M.C Manufactured (Pneumatic)

The lift for this project is set within some boundaries condition. To ensure that the design will come out well and not too complex for the design process. The boundaries that set are as shown in **Table 3.1**

Hydraulic Lift Specification

Specification	Unit
Max. Capacity	500 kg
Platform Size	1600 mm x 1400 mm
Travel Height	6300 mm
Travel Speed	20 mm/s

Table 3-1 Boundaries Condition for Lift Project

After getting the design for the criteria, the next step is determining the movement system to lift the car. The movement system that is used for this project is hydraulic systems. In hydraulic systems consist of many aspects, for the design process, the component for this system that must be determined is a Hydraulic barrel, Hydraulic Cylinder, Hydraulic Piston, Cylinder stroke, and the movement system that attached the car lift and the cylinder. All of this can be found in the catalog and by doing the calculation to determine the dimension that is needed.

The first calculation is determining the total load for the structure to lift up.

$$F_{Total} = F_{load} + F_{car} \quad (3.1)$$

With F_{Total} shows total load in [kg], F_{load} is the load capacity in [kg], F_{car} is the load of the car structure in [kg].

After determining the total load, the next step is determining the load that needed to be lifted up.

$$F_{Lift} = F_{Total} \times SF \quad (3.2)$$

With F_{Lift} shows the load that needed to be lift up by the hydraulic in kg. and SF are safety factor coefficient. The SF coefficient that used is 2.

After the load is determined, the next step is designing the cylinder that fits the specification. The cylinder parameter is designed with a guideline to ISO 3320. The dimension of the cylinder is already set by the standards of ISO 3320, so the next step is determining the Pressure and the Flow rate of the cylinder to calculate the motor specification for the hydraulic pump.

Hydraulic Cylinder Parameter according to ISO 3320:

$$\begin{aligned} D_{Piston} &= 8 \text{ cm} \\ D_{Rod} &= 6.3 \text{ cm} \\ D_{Barrel} &= 140 \text{ cm} \end{aligned} \quad (3.3)$$

Calculation of the pressure:

$$P = \frac{F}{A}$$

$$P = \frac{F}{\frac{\pi \times (D_{Piston})^2}{4}}$$
(3.4)

P shows Pressure in [kg/cm²], F is a load that applied in the face of the area in [kg], and A is total Area in [cm²].

For flow rate the calculations are:

$$Q = A \times v_{lift}$$

$$Q = \frac{\pi \times D^2}{4} \times v_{lift} \quad [\text{cc/min}]$$

$$Q = \frac{A \times V_{lift}}{1450 \text{ rpm}}$$

$$Q = \frac{\frac{\pi \times D^2}{4} \times V_{lift}}{1450 \text{ rpm}} \quad [\text{cc/rev}]$$
(3.5)

With Q shows flowrate in [cc/rev], and v_{lift} in [m/s], later on will be converted to [cm/min].

And for the Hydraulic pump, the specification for the hydraulic motor can be looked on in the catalog. But the motor capacity that needed to lift up the load must be calculated first. The calculations are:

$$HP = \frac{Q \times \left(\frac{1450}{1000}\right) \times P}{0.746 \times 0.85 \times 600}$$
(3.6)

With HP shows motor capacity in [HP].

After that, the calculation for the system is already completed. The next thing to do is determining the oil capacity needed and the dimension of the oil tank for the reservoir.

For the oil capacity calculation:

$$V_{oil} = A \times S$$
(3.7)

With V_{oil} shows the oil capacity in [cc], and A is the effective area of the piston, and S is cylinder stroke in [cm].

For the oil tank calculation is connected with the volume capacity of the oil that needed. So, the dimension of the reservoir must capable of storing oil with that capacity.

The dimensions for the oil tank needed length, width, and height with the shape of cube oil reservoir.

$$V_{Res} = L \times W \times H \quad (3.8)$$

With V_{Res} shows the volume capacity that the reservoir can holds in $[cm^3]$, L is length, W shows width and H the height of reservoir all in $[cm]$.

After all the parameter that needed is done in the calculation. The next step is trying to configure whether the calculation is fit to be designed. The calculation checked by the advisor from T.M.C, after passing the standard, the calculation is compared with the specification in the standard catalog that T.M.C used. Such as the catalog for motor capacity, gear, and sprocket.

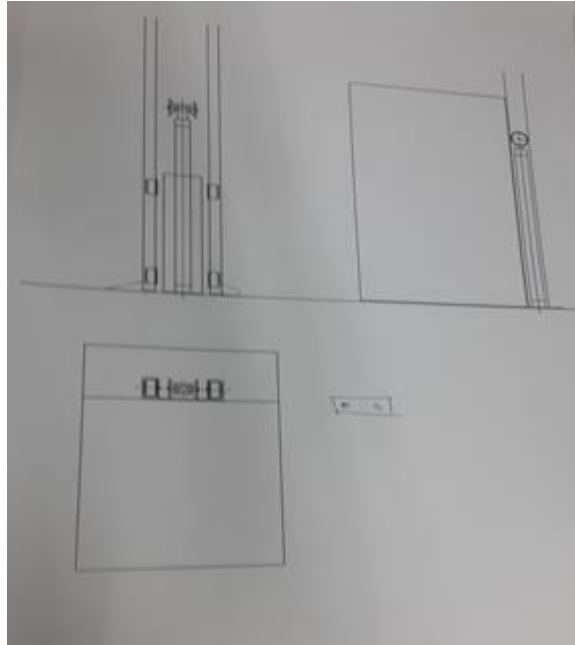


Figure 3.3 Sketch example of general drawing for Lift Project

3.3.2 Lifting system

With the maximum travel height of 6300 mm, it will be hard if the length of cylinder stroke is also 6300 mm. Therefore, needs the right adjustment for the lifting system of the car lift. From the design that already existed, it is suggested that for the lifting system uses the sprocket and gear mechanism that acts like a pulley to lift the car. The working principle of it is, the sprocket and gear are attached to the cylinder rod and the other end of the chain are fixed to the bottom of the car so that it can lift the car up and down. **Figure 3.4** and **3.5** shows the existing product for the movement system assembly for the cylinder and the car.



Figure 3.4 Example Assembly sprocket and chain



Figure 3.5 Example Assembly movement system to car

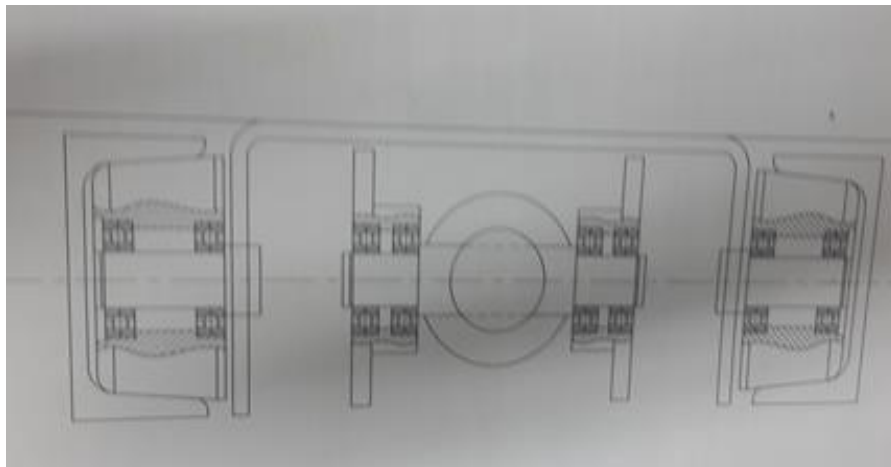


Figure 3.6 Sketch Example for the Sprocket Gear Assembly

After figuring the right movement system, choosing the sprocket and gear for the right conditions are crucial. Determining that can be done with the information that given from the calculations. For the material and type of the roller

chains and gear sprocket, the advisor from T.M.C suggested that it's better if the design uses roller chains and sprocket gear from *Tsubaki* catalog [11]. The type is for RS-60 and RS-80. For determining which is better, needed the calculation to determine the load of the structure. It can be found by using **Formula-3.2**.

It is noted that for the dimension of the sprocket gear the pitch diameter shouldn't exceed the length of the C-beam structure. So that the assembly of the movement system doesn't collide with the guide rail beam and car assembly.

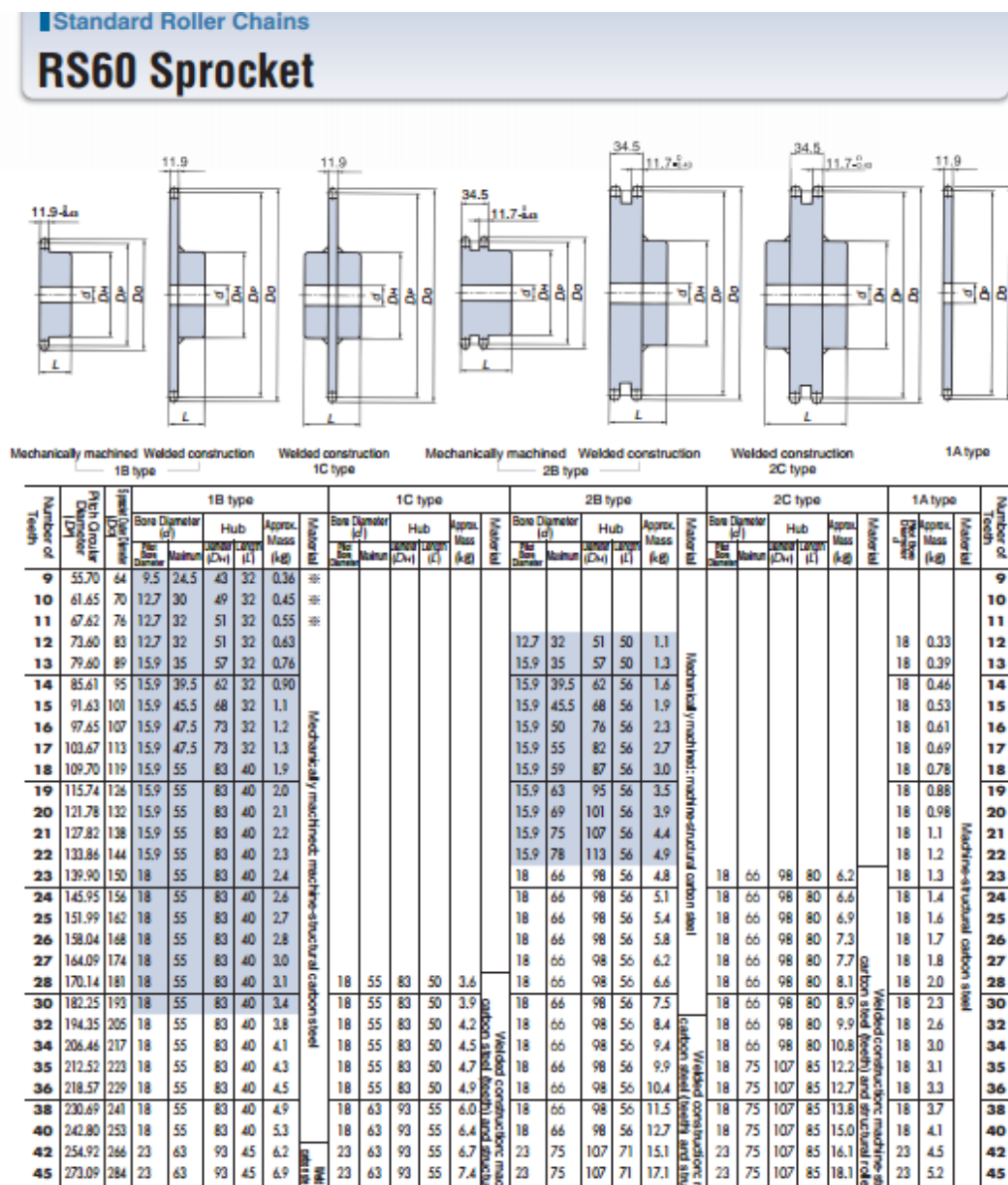


Figure 3.7 Catalog for sprocket RS-60

Standard Roller Chains RS Roller Chain

RS60

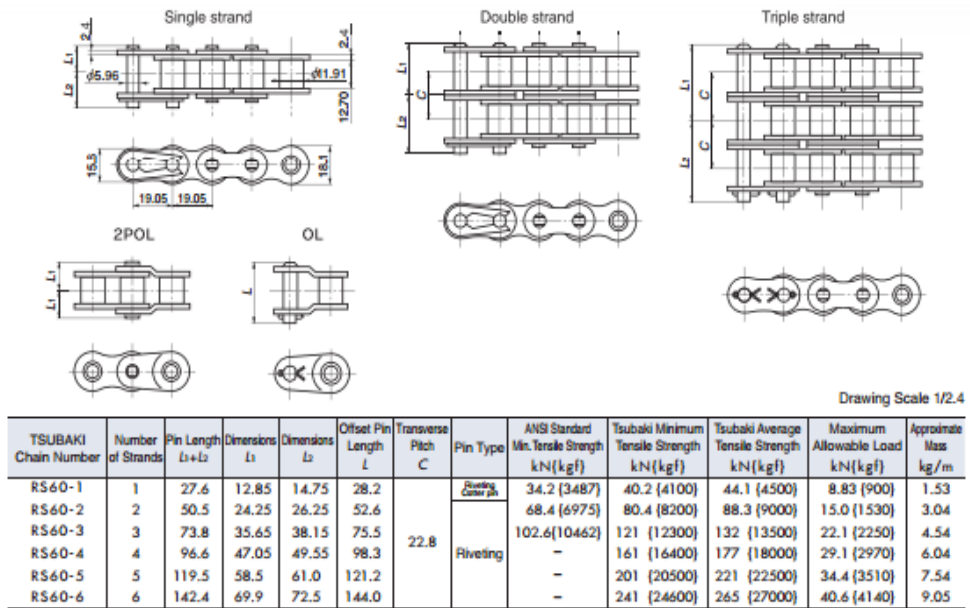
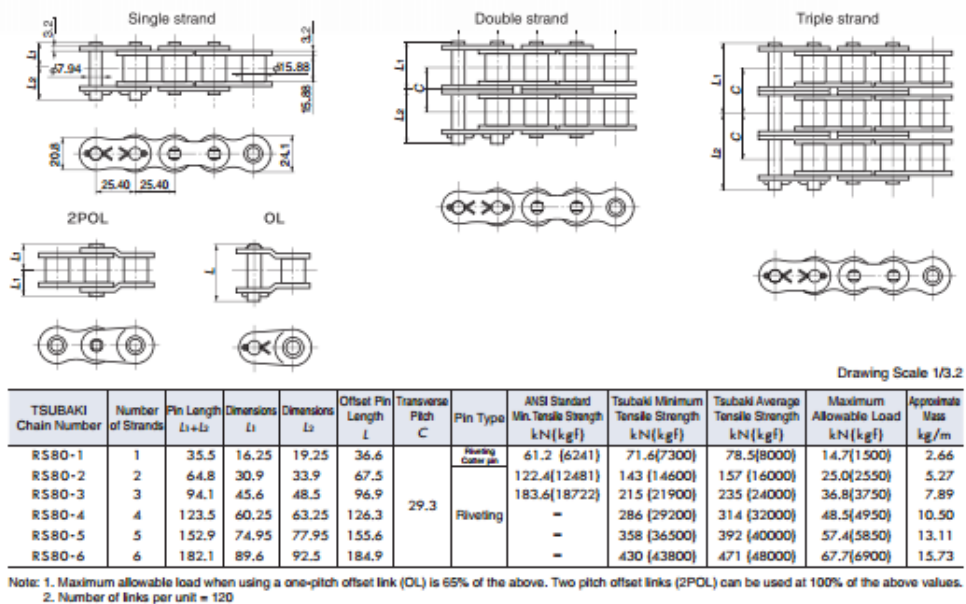


Figure 3.8 Catalog for Roller chain RS-60

Standard Roller Chains RS Roller Chain

RS80



Note: 1. Maximum allowable load when using a one-pitch offset link (OL) is 65% of the above. Two pitch offset links (2POL) can be used at 100% of the above values.
2. Number of links per unit = 120

Figure 3.9 Catalog for sprocket RS-80

RS80 Sprocket

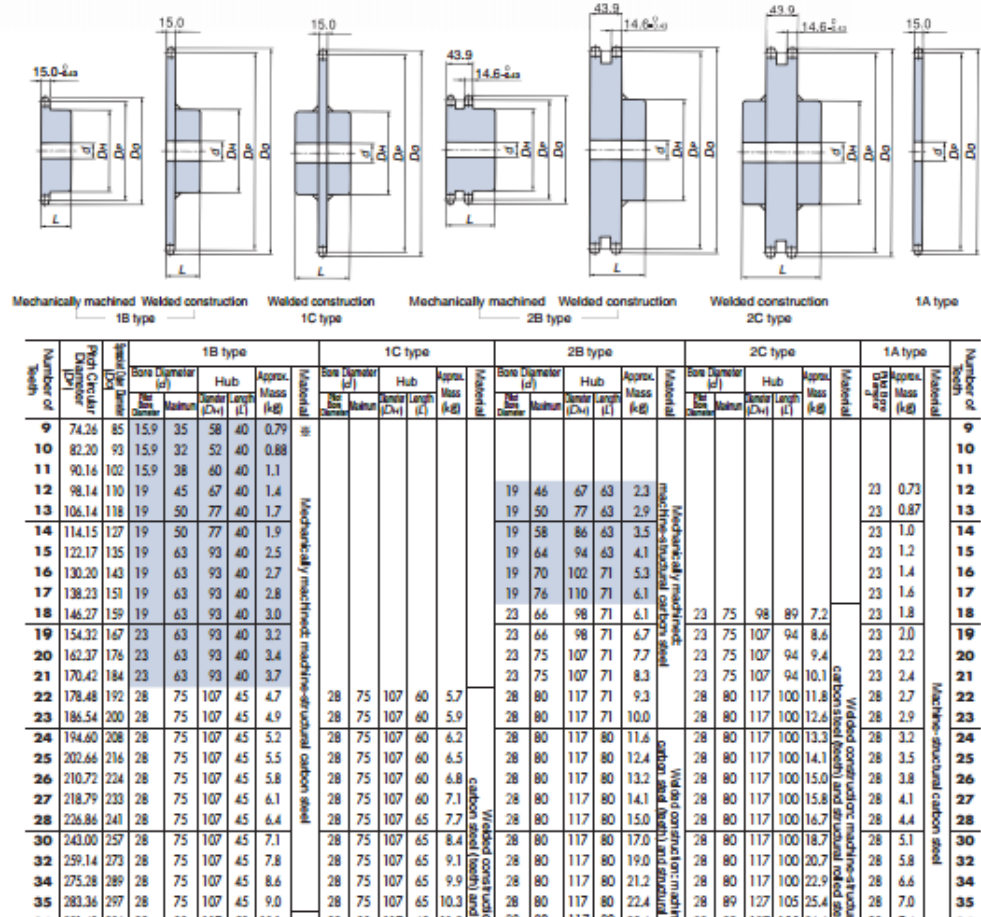


Figure 3.10 Catalog for Roller chain RS-80

And for the length of chain links for the roller chain is adjusted with the height from the top holder assembly to the bottom of the car. Figure 3.7-3.10 shows the catalog for the Tsubaki RS-60&RS-80 type. The catalog will also be included at the end of the report in the attachment.

After determining the movement system, the stroke of the cylinder will be calculated. To adjust the change of height because using the pulley systems. The calculations are as follows:

$$S = \left[\frac{H_s}{2} \right] + 100 \quad (3.9)$$

With S shows stroke of the cylinder in [mm], H_s shows the Height of the structure in [mm].

CHAPTER 4

DESIGN RESULT AND ANALYSIS

4.1 Design and Calculation

The calculations will be divided into 6 parts to determine the parameter that is needed to make the design. The formula can be found in chapter 3. The parameters that needed to be calculated are:

- Load
- Pressure
- Flowrate
- Motor Capacity
- Stroke of the Cylinder
- Oil Capacity & Oil tank Dimensions

The first parameter that needed to be calculated are the loads. The loads can be divided into 2 calculations. From **Formula-3.1**, the load for the structure can be calculated. After the structure load is calculated proceed to **Formula-3.2** to calculate the load that needed to be lifted up by the cylinder. The results of the calculations are as follows:

From the inventor feature iProperties after done designing the car, the weight of the car structure can be obtained. And the results are as shown in the **Figure-4.1**. with the mass of the lift car obtained, the load for the calculation can be calculated.

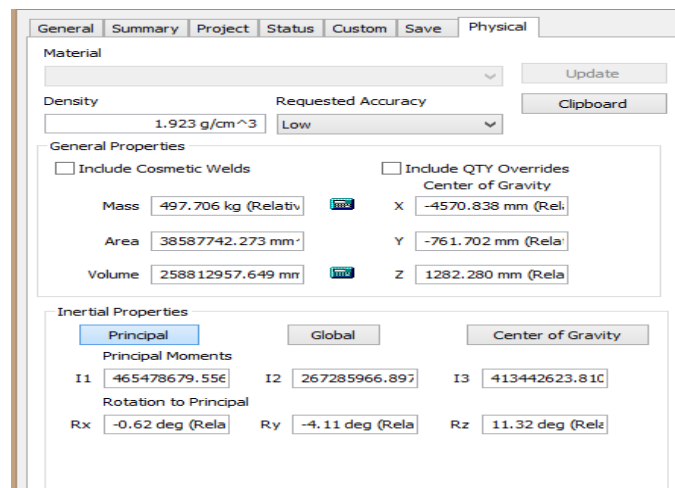


Figure 4.1 Weight of the Car structure according to Inventor iProperties

Given :

$$F_{load} = 500 \text{ kg}$$

$$F_{car} = 500 \text{ kg} \text{ rounds up from } 497.706 \text{ kg}$$

Formula :

$$F_{Total} = F_{load} + F_{car}$$

$$F_{Lift} = F_{Tot} \times SF$$

Calculation :

- $F_{Total} = 500 \text{ kg} + 500 \text{ kg}$

$$F_{Total} = 1000 \text{ kg}$$

- $F_{Lift} = 1000 \text{ kg} \times 2$

$$F_{Lift} = 2000 \text{ kg}$$

After the load parameter completed the next parameter is the pressure for the Hydraulic pump. The pressure is needed to determine the flow rate of the fluid to the cylinder. This all connected to the speed travel and the motor capacity for the hydraulic pump. For the pressure, can be calculated by using **Formula-3.4**.

Pressure:

$$P = \frac{F}{A}$$

$$P = \frac{F}{\frac{\pi \times (D_{piston})^2}{4}} [\text{kg/cm}^2]$$

Calculation :

$$P = \frac{2000 \text{ kg}}{\frac{\pi \times (8 \text{ cm})^2}{4}} = \frac{8000 \text{ kg}}{\pi \times 64 \text{ cm}^2}$$

$$P = 39.78 \text{ kg/cm}^2$$

The next parameter is the flow rate. The formula for flow rate can be found on **Formula-3.5**

Flowrate :

$$Q = A \times V_{lift} \quad [\text{cc/min}]$$

$$Q = \frac{\pi \times D^2}{4} \times V_{lift} \quad [\text{cc/min}]$$

$$Q = \frac{A \times V_{lift}}{1450 \text{ rpm}} \quad [\text{cc/rev}]$$

$$Q = \frac{\frac{\pi \times D^2}{4} \times V_{lift}}{1450 \text{ rpm}} \quad [\text{cc/rev}]$$

Calculation :

$$Q = \frac{\pi \times (8 \text{ cm})^2}{4} \times 0.2 \text{ m/s}$$

$$Q = \frac{\pi \times (8 \text{ cm})^2}{4} \times 0.2 \times (100 \text{ cm}) \times 60$$

$$Q = 60318.58 \text{ cc/min}$$

$$Q = \frac{60318.58 \text{ cc/min}}{1450 \text{ rpm}}$$

$$Q = 41.6 \text{ cc/rev}$$

After getting the pressure and the flow rate, the motor capacity for the hydraulic pump can be determined. First, the value of the motor capacity needed to be calculated with **Formula-3.6**. After that cross check with the table for the motor capacity that T.M.C use. The table for the motor capacity is listed in the **Table-4.1**.

Motor Capacity

Formula :

$$HP = \frac{Q \times \left(\frac{1450}{1000}\right) \times P}{0.746 \times 0.85 \times 600} \quad [\text{HP}]$$

Calculation :

$$HP = \frac{41.6 \times \left(\frac{1450}{1000}\right) \times 39.78}{0.746 \times 0.85 \times 600}$$

$$HP = 6.31 \text{ HP}$$

Motor 3 Phase 380 V (AC3)		Current Load (A)
kW	HP	
0.75	1	2
2.2	3	5.1
3	4	6.8
4	5.5	8.7
5.5	7.5	11.8
7.5	10	16
11	15	22

Table 4-1 Electric motor specification from Mitsubishi Electric

Conforms to the table, the closest value is $7\frac{1}{2}$ HP. And the drawing for the motor can be seen in figure

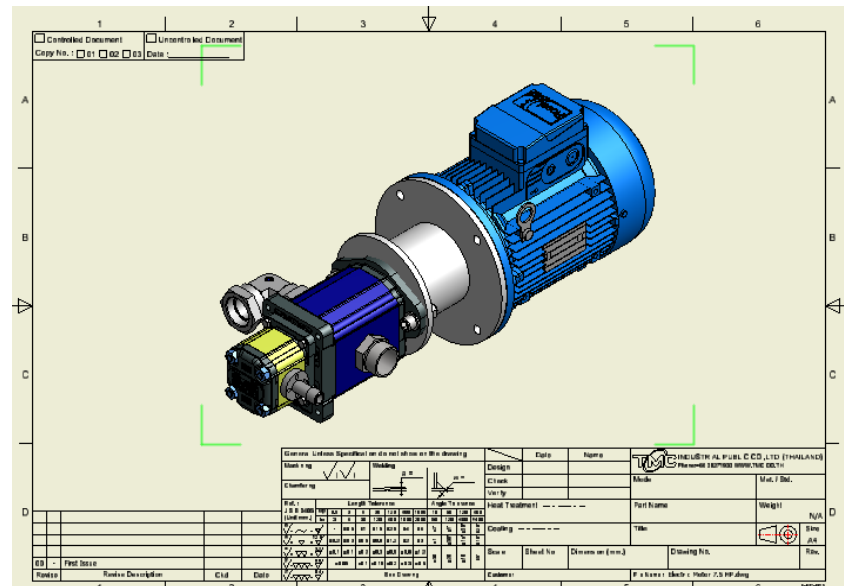


Figure 4.2 Design of Electric Motor 7.5 HP

Before continuing to calculate the oil capacity that needed to move the lift, the next step is calculating the stroke of the cylinder. Stroke is the travel height of the cylinder piston inside the cylinder barrel. To calculate the stroke the formula that is used are from **Formula-3.9**.

Formula:

$$S = \left\lceil \frac{H_s}{2} \right\rceil + 100$$

Calculation:

$$S = \left\lceil \frac{6300}{2} \right\rceil + 100$$

$$S = 3250 \text{ mm}$$

For the cylinder stroke for it to meet the design parameter the value should be 3250 mm. Therefore, inside the cylinder barrel, the piston should be able to move 3250 mm inside the chamber. The design for the cylinder that can accommodate this stroke can be seen in **Figure-4.3** & **Figure-4.4**.



Figure 4.3 3D Design of Cylinder Barrel

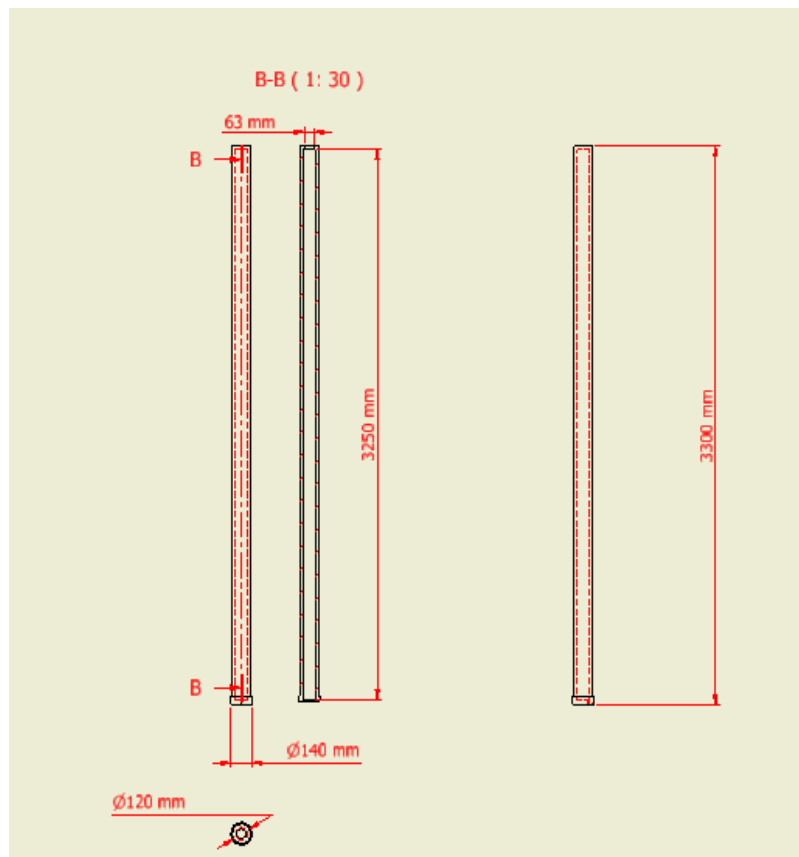


Figure 4.4 Drawing view of Cylinder Barrel

The last parameter after getting the value of the stroke is to calculate the oil capacity needed and the oil tank dimension. These 2 will connect with each other because, without the oil capacity, the dimension for the oil tank can't be found. For calculating the oil capacity, the formula that is used is from **Formula-3.7**.

Formula:

$$V_{oil} = A \times S$$

Calculation:

$$V_{oil} = \frac{\pi \times (8 \text{ cm})^2}{4} \times 325 \text{ cm}$$

$$V_{oil} = 16336.28 \text{ cm}^3$$

$$V_{oil} = 16.336 \text{ L}$$

So, the oil that is needed to move the piston along the stroke is 16.336 L. After that the calculation of the oil tank can be done. Because of T.M.C standard to prevent leakage and to ease the maintenance the size of the oil tank must be larger 4 times than the oil capacity. Therefore, the dimension for the oil tank volume is approximate $16 \times 4 = 64 \text{ L}$. And for calculating the dimension for the oil tank, the assumption can be made as long as it fits the room for the whole elevator assembly. From **Formula-3.8** the calculation for oil tank size are:

$$V_{Res} = L \times W \times H$$

And for this project the dimension of the assumption is:

$$64 = L \times W \times H$$

$$63.6025 \text{ L} = 10.3 \times 0.95 \times 0.65$$

Therefore, the dimension for the oil tank are $10.3 \times 0.95 \times 0.65 \text{ [dm]}$ or $1030 \times 950 \times 650 \text{ [mm]}$.

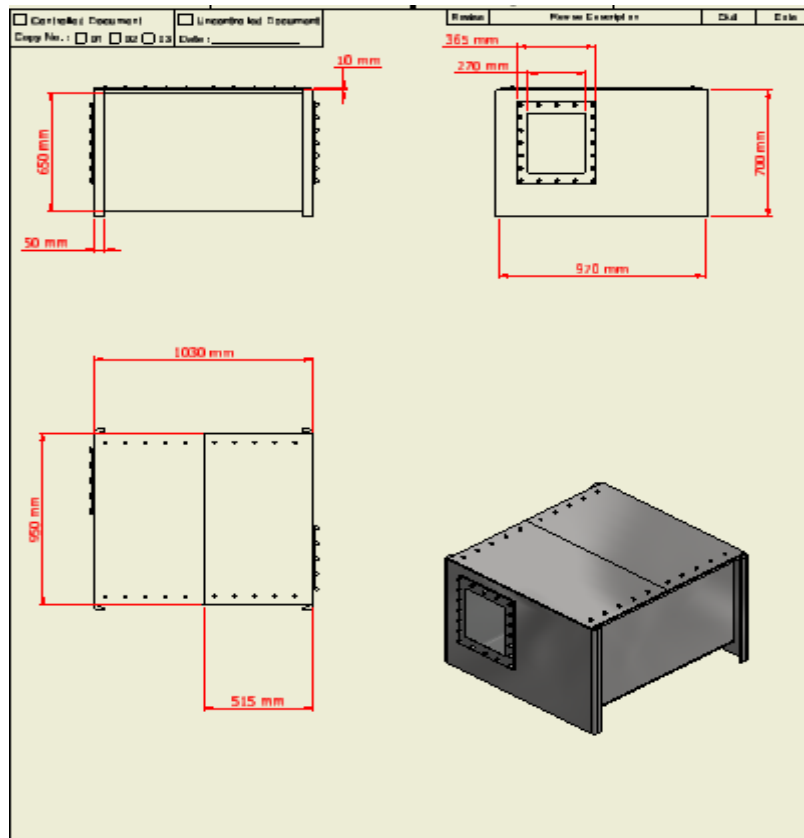


Figure 4.5 Drawing for Oil Tank

For the drawing of the movement systems, above the value of the load are already known. So, for choosing the right sprocket and gear can be done. Based on

the value of the load to lift up the car $F_{lift} = 2000$ kg, the Sprocket gear and chain for the RS-60 and RS-80 type can be compared. The comparison must be done with many aspects in mind, such as the strength of the component, dimension, shape, machining of the part, and the weight of the part.

With that in mind after looking at the catalog as seen in **Figure-3.7-Figure3.10**, for the roller chain the type that suits with the criteria are RS-80-1 with 1 strands with maximum allowable load 14.7 kN (1500 kgf). And the appropriate Sprocket gear is the RS-80-1B-19T with mechanically machine manufactured. And for the design, because the load that needed to be lifted up are $F_{lift} = 2000$ kg, and 1 strand of the RS-80-1 Roller chain only have a maximum allowable load, so for the design, the assembly of the movement system needs 2 roller chains and 2 sprockets. The illustration in **Figure-4.6** Show the design of the movement system assembly.

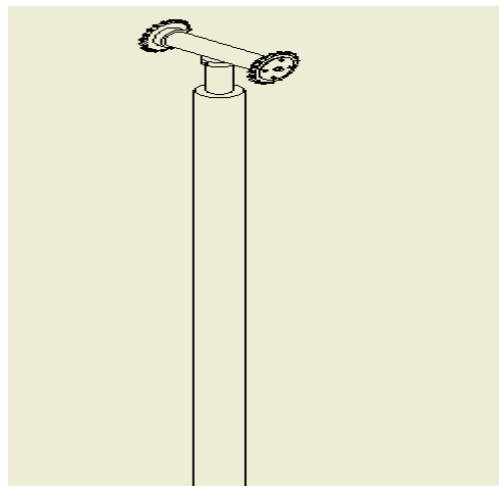


Figure 4.6 Assembly of the movement System



Figure 4.7 Roller chain RS-80 assembly pin & link

4.2 Final Design

The basic elements of the design are already completed and conform to the calculation that is made. The rest of the component like the car, car structure, C-Beam are made manually with the connection to the design that is already been made. For the Final design, this section will divide the drawing into 4 categories. Such as:

- Car Structure
- Guiding Rails (in form of sliding guide)
- Movement system explode view
- Chock for wheelchair

The chock for a wheelchair is the design improvisation for the lift project. Basically, chock is a holder for the wheel of the wheelchair so that the wheelchair doesn't experience any shaking and can be more comfortable inside the lift. Additional design for ergonomic aspect may be added as accessories as long as it's within the boundaries and safety factor of the structure.

4.2.1 Car Structure

The car structure is essential for a lift. Because it holds the cabinet that the passenger used for traveling upwards and downwards. The car structure must be strong so that it can hold the load of the passenger. The main part of the structure usually consists of platform, ceiling, door, and frame that holds the platform.

With the maximum capacity of passenger load are 500 kg, the material of the frame must be something strong that can hold the load of the passenger. The material for the frame uses standard steel with mill finish. Other accessories may be added inside the cabinet as long as it's within the safety standard. **Figure-4.8** shows the general design assembly of the car structure

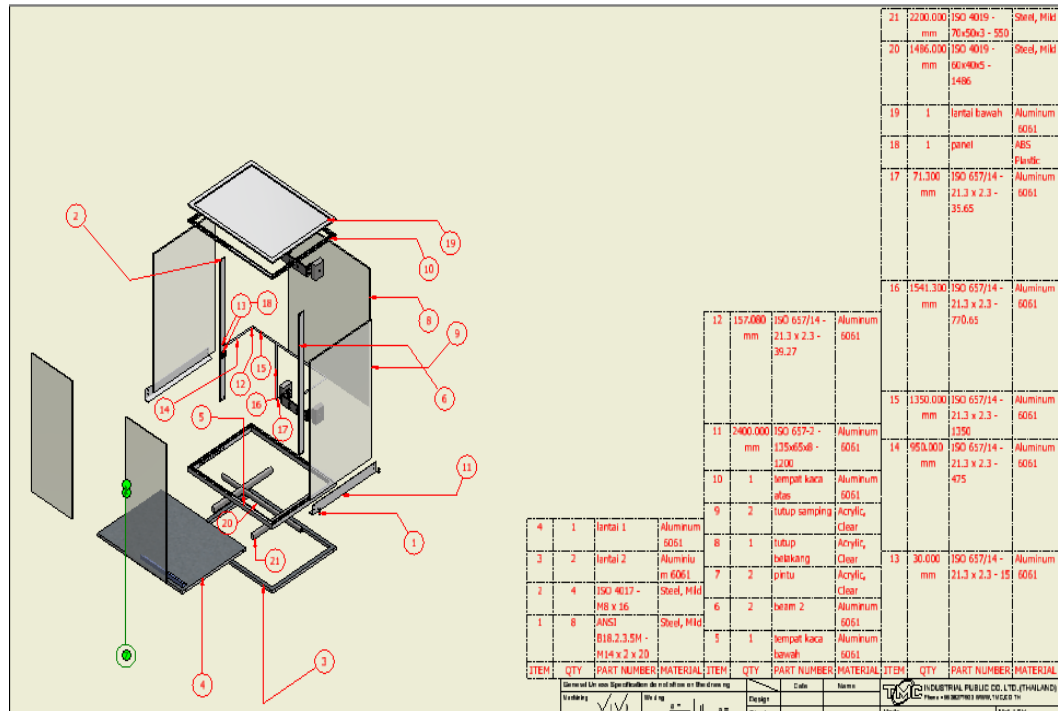


Figure 4.8 Car Structure general assembly

Additional accessories such as sound system, hand bar or other things can be installed inside the cabinet. The enclosed cabinet used clear acrylic as the material for the side panel and the door so that the user can be seen through from the outside. After the car structure complete, for the car to travel up a C-beam is installed as the guide rail for the car. The guide rails are installed to ensure that the car moves up and down vertically without slanted and doesn't have turbulence while it travels.

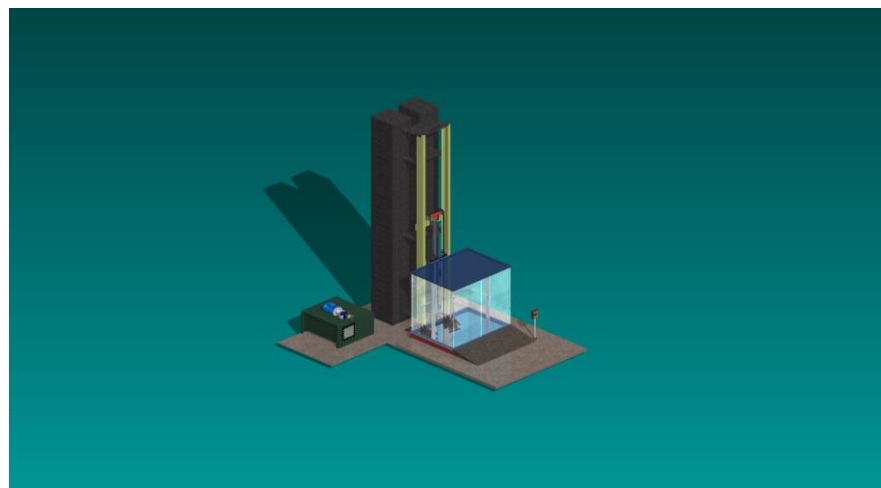


Figure 4.9 Final Design of the lift structure

4.2.2 Guiding Rails

The guiding rails that are used in this project are in shape of sliding guides. The sliding guides are uniform in dimension with the guideway of the c-beam. This ensures that the sliding guides fit perfectly and touches the faces of the C-Beam. The usage of the sliding guides is the answer to the problem for the previous design. The previous design used the roller as the guide for the rails, and it doesn't fit perfectly with the c-beam and cause the elevator car to slanted while it moves up.

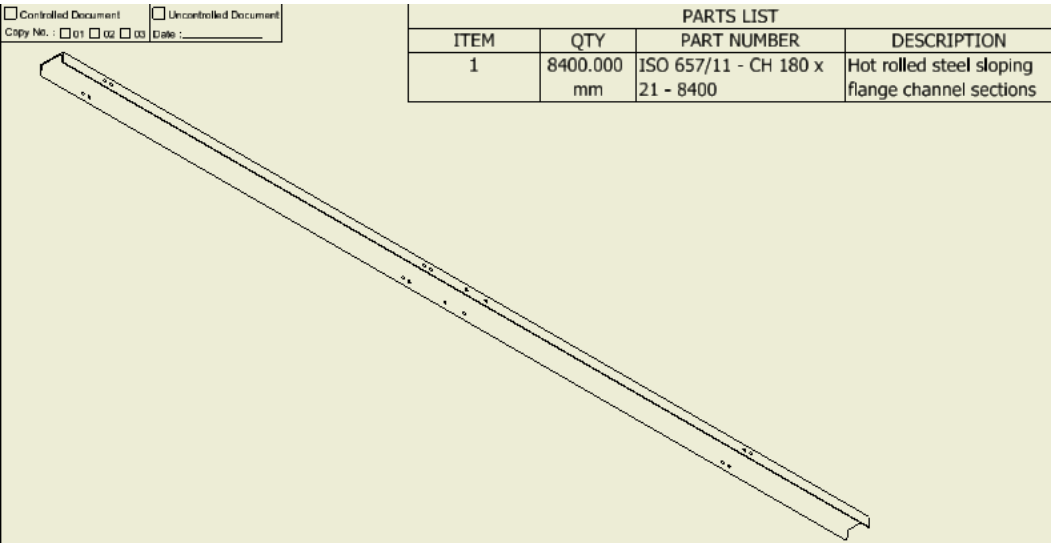


Figure 4.10 Design of the C-Beam for the Structure

The design for the sliding guide rails consists of the guide rails, shaft, bushing, bearing, and retaining ring. The bearing functions to keep the shaft intact while it moves and reduces the vibration from the outside force. The retaining ring is used to retain the shaft assembly and the bearing. The design for the sliding guides can be seen in **Figure-4.10**.

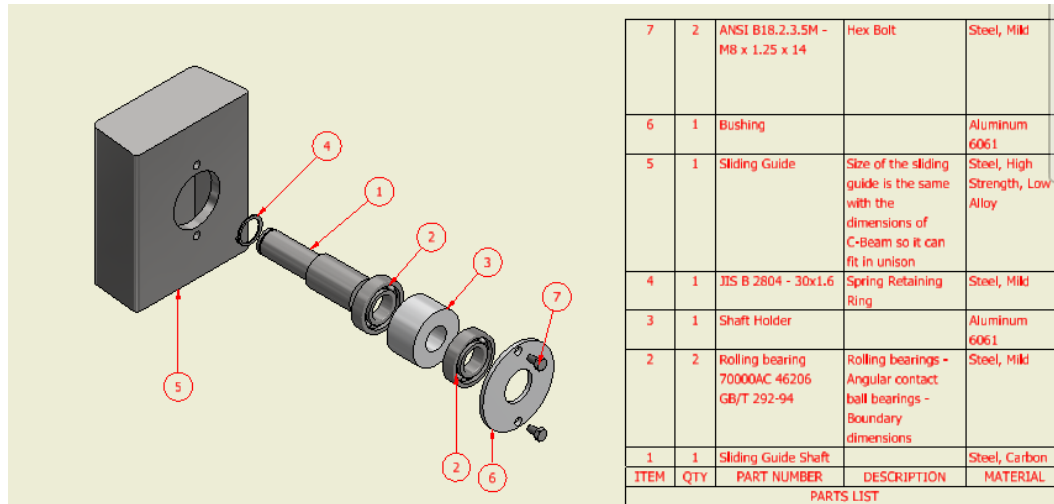


Figure 4.11 Sliding Guide assembly

The assembly for the sliding guide then attached to the lift car. The sliding guide that is needed for the car consist of 4 sliding guides. And the position is at the end of each car corner, welded with a holder plate so it can lift up the car along the guide rails frame.

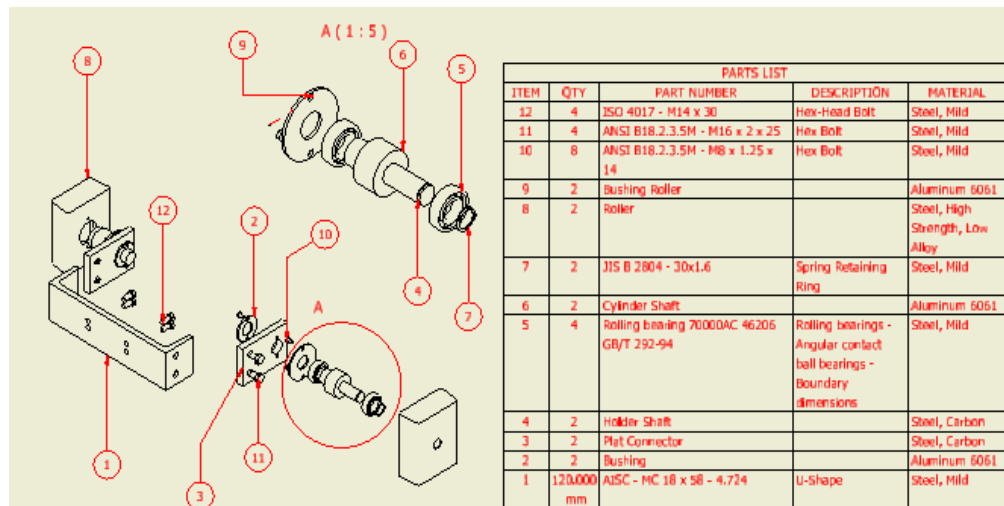


Figure 4.12 Assembly of the sliding guide holder

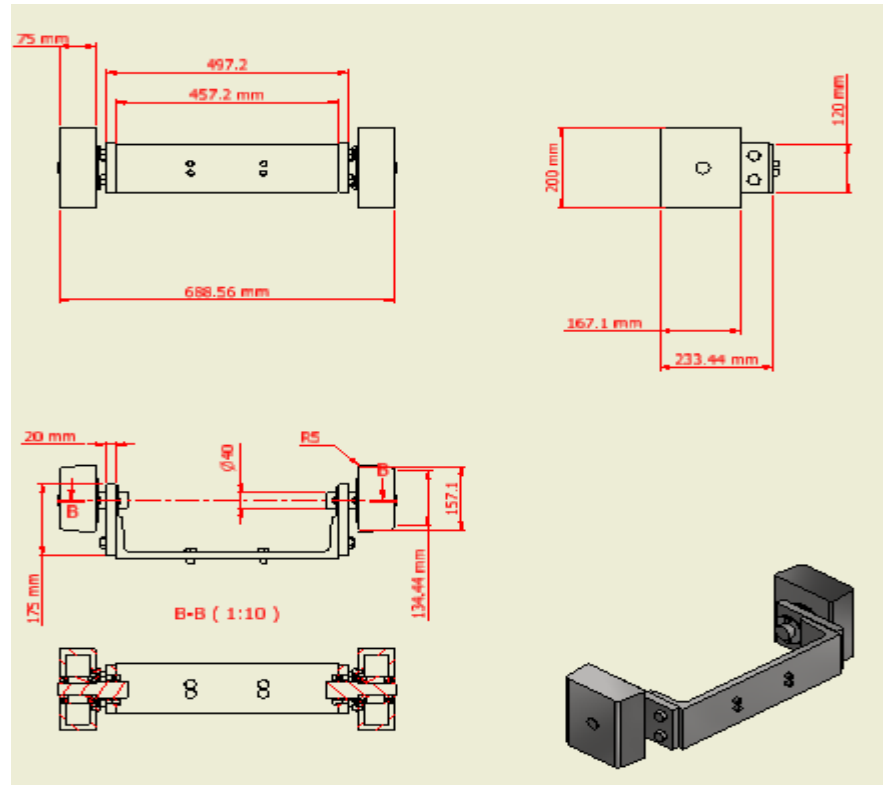


Figure 4.13 Drawing for the sliding guide holder

4.2.3 Movement system explode view

As explained before the movement system is the component that assists the car in traveling up. This system consists of the assembly of the cylinder assembly, a shaft, 2 gear sprockets, and roller chain. Inside the shaft are the part that crucial to retain the shaft from outside force so the shaft doesn't move. The assembly of the cylinder with the assembly of the sprocket mechanism is joint by 2 bolts. This assembly doesn't need welding because the component needs to maintenance from time to time, especially the cylinder. So, the component must be easy to disassemble for the situation when it requires maintenance.

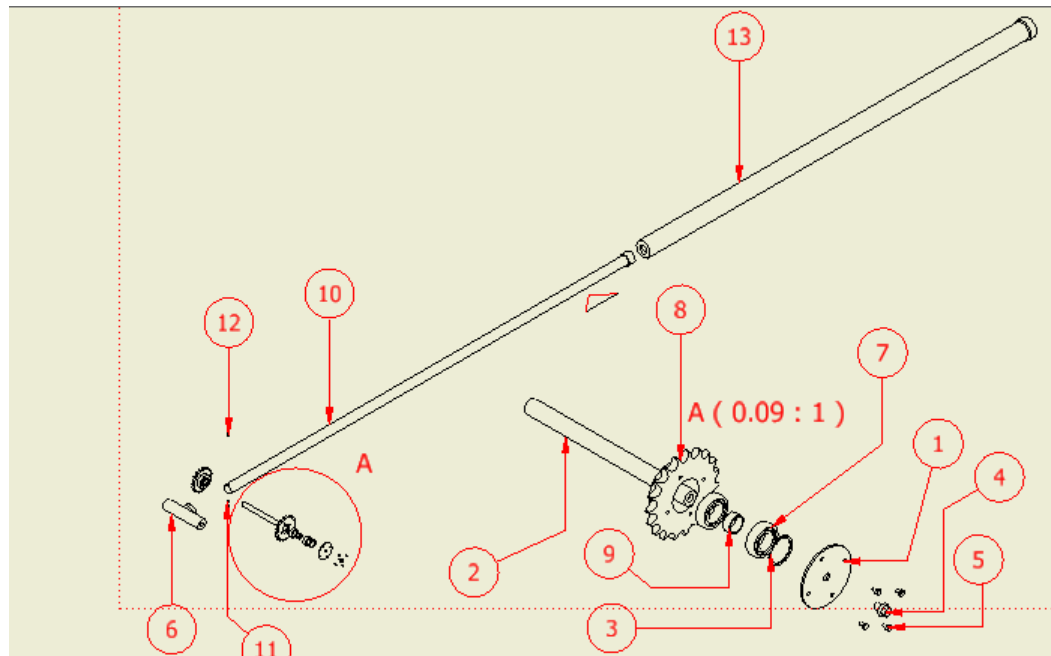


Figure 4.14 Exploded view of the Movement component

ITEM	QTY	PART NUMBER	MATERIAL	DESCRIPTION
13	1	Barrel	Steel AISI 4142 400 QT	
12	2	Bolt GB/T 5783 M8 x 20	Steel, Mild	Hexagon head bolts - Full thread
11	2	JIS B1252 - 8 1L	Steel, Mild	Conical Spring Washer
10	1	Rod	Steel AISI 4142 400 QT	
9	2	JIS B 1582 Type 1 A - 30x35.5x16	Copper, Alloy	Cylindrical Bush
8	2	RS80-1B-19T	Steel, Carbon	
7	4	JIS B 1521 SKF (D) - SKF 6206-Z	Steel, Mild	Deep groove ball bearings single row with Z shield SKF
6	1	Body	Steel, Carbon	
5	8	ANSI B18.2.3.5M - M6 x 1 x 10	Steel, Mild	Hex Bolt
4	2	ANSI B 18.6.7 M / IFI 513 - M12x1.75 x 16	Steel, Mild	Hex Flange Head Machine Screw
3	2	ANSI B27.7 - 52	Steel, Mild	General Purpose Tapered and Reduced Cross Section Retaining Rings Basic Internal Series 3BM1 Retaining Rings
2	1	Shaft	Steel, Carbon	
1	2	Bushing	Steel, Carbon	

Table 4-2 Bill of Material of the movement component

4.2.4 Wheelchair Chock

The wheelchair chock is one of the improvisations in this design. The chock serves for maintaining the position of the wheelchair while it parked inside the lift car. The principle is same with the chock for a motorcycle. But this chock had a smaller dimension and are adjusted with the wheelchair wheel size. The chock will prevent unnecessary movement while in the lift, and the position is near the button panel.

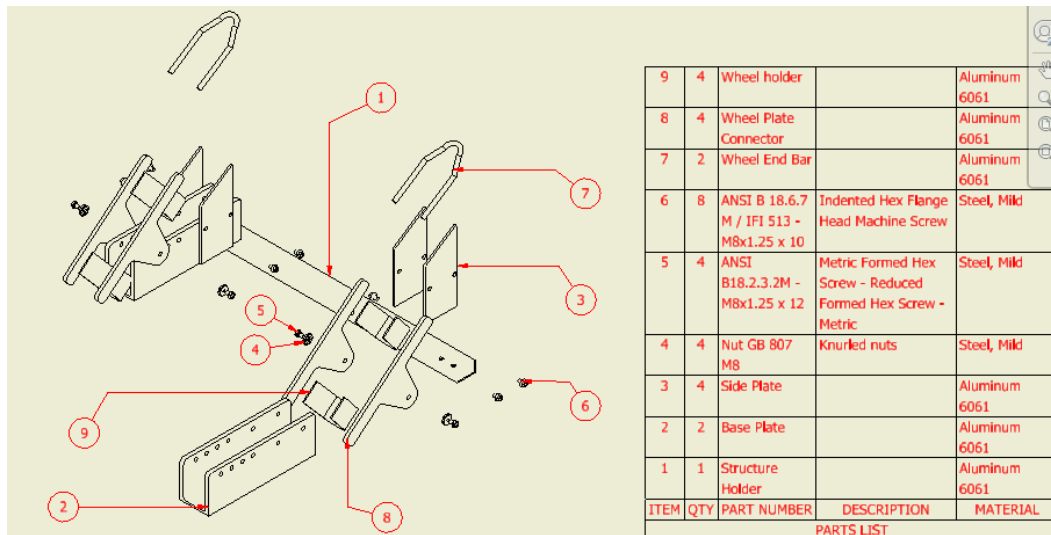


Figure 4.15 Chock Assembly

The working principle is the wheel lock position are slanted in the beginning. When the wheel of wheelchair passes the lock, the chock will shift it movement degrees and automatically lock the wheelchair. To unlock it, the wheelchair just needs to move forward so that the angle of the chock can be directed again.

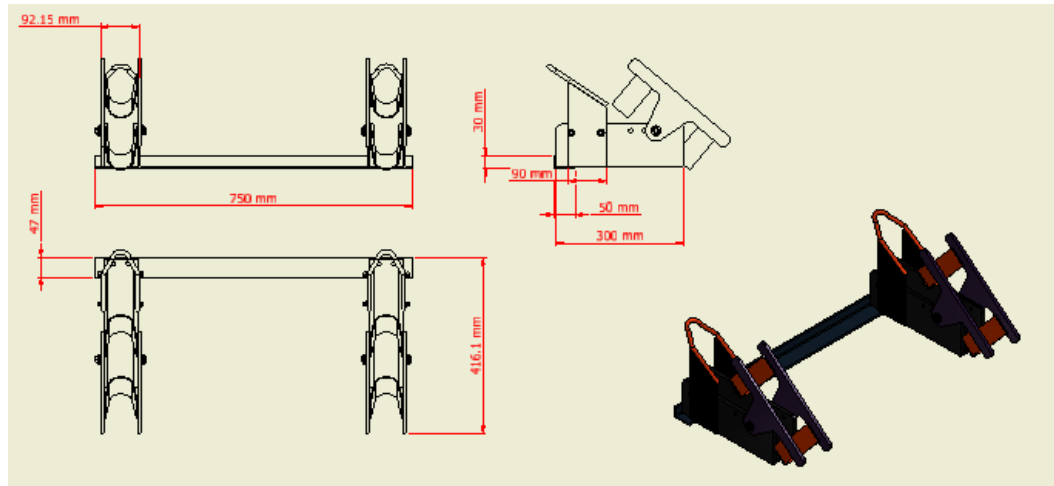


Figure 4.16 Drawing of the Chock

4.3 Analysis and Discussion

The analysis that is done in this research is FEA analysis for stress load. The type of the analysis that is done in this research are von Mises stress, 1st principal stress, and 3rd principal stress. The main point of the FEA analysis is the von Mises stress analysis because the von Mises stress is used to predict yielding of materials under any loading condition from results of simple uniaxial tensile tests [10]. Hencky (1924) offered a physical interpretation of von Mises criterion suggesting that yielding begins when the elastic energy of distortion reaches a critical value [12]. For this reason, the von Mises criterion is also known as the *maximum distortion strain energy criterion*.

With the von Mises stress, the safety factor of the machine can be calculated. In this research, the safety factor of the assembly will also be done in FEA analysis in Autodesk Inventor. because for some part that is not assembly component, the safety factor cannot be done manually because of the part and the material difference that is attached.

For the analysis, because there are many components in this machine, the analysis will be divided into several main analyses of the part that is critical to the operation. The analysis will be done in:

- Car Platform

- Sliding Guide
- Bottom chain holder that is fixed to the Car
- Fixed chain holder at the guide rails beam.

4.3.1 Analysis on the car platform structure

The analysis on the car platform is done with the force from the load of the maximum capacity. The analysis tested the strength of the platform and the frame structure that holds the lift car together. The force of the analysis is directed down because the weight of the load will always push the platform down. The force that is used is 4903.33 N equivalent to 500 kg. To round up the results the force will be round up to 5000 N.

As the force push the platform down, in **Figure-4.17** can be seen the area that got the most contact on the platform. The red area shows the most stress that is taken and has the most displacement out of the structure. The material for the platform is Aluminum 6061 with yield strength 240 MPa and the frame that holds the platform are steel mild with yield strength 207 MPa. The minimum safety factor for this component is 2.

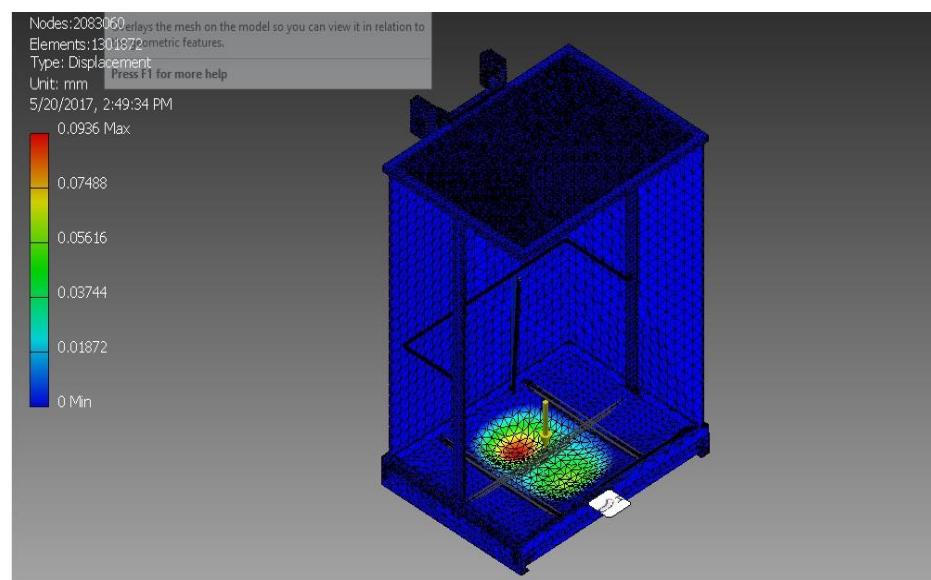


Figure 4.17 FEA for car Platform

Figure-4.18 shows the von Misses stress of the car where the force is given on top of the car. The force on the car platform affects the frame structure that holds the car platform, so the frame got the same amount of force that is given to the platform. The maximum stress results from this analysis are 9.039 MPa and

the minimum is 0 MPa. The body that has the most yield stress is in the frame that holds the platform as shown in **Figure-4.19** and **4.20**

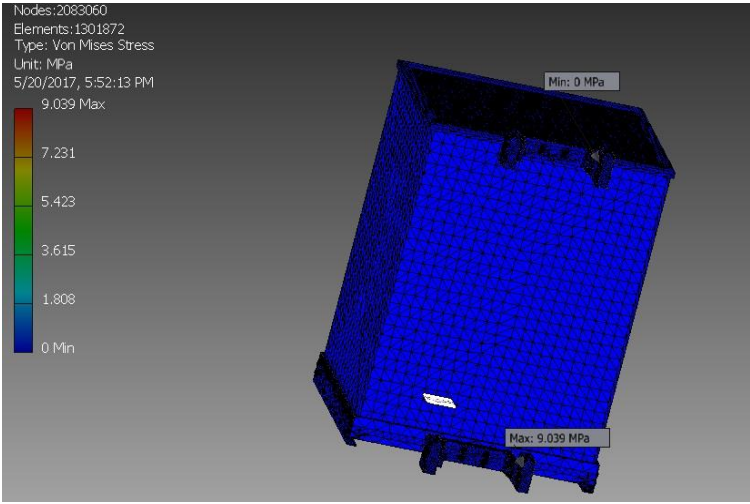


Figure 4.18 Results of von Mises Stress on Car platform

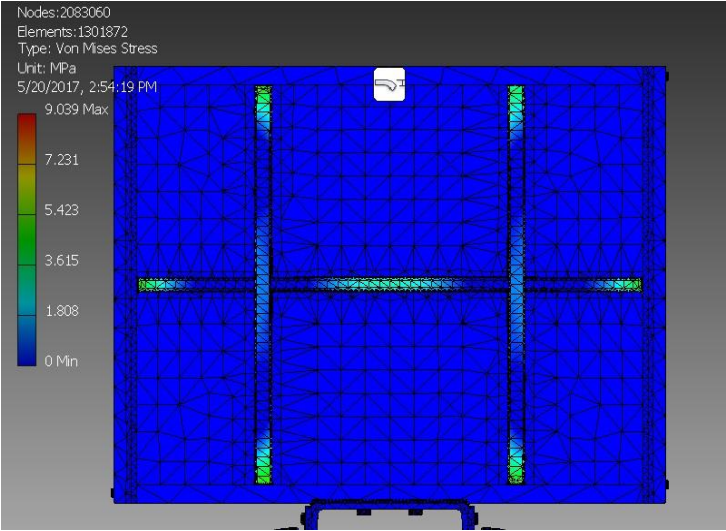


Figure 4.19 Bottom view of the von Mises stress result

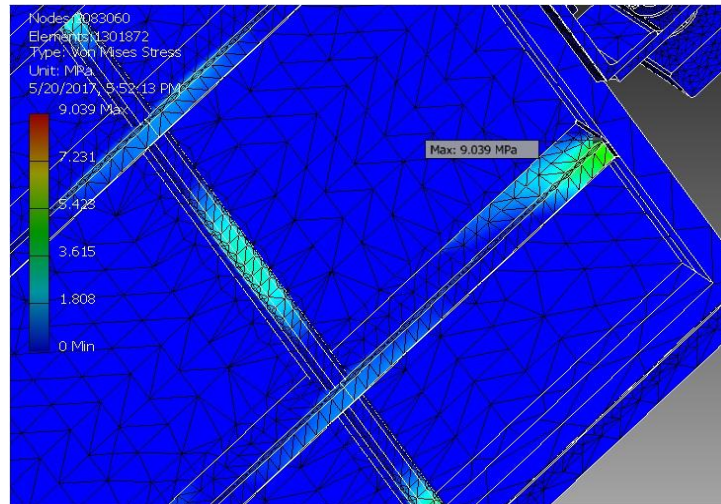


Figure 4.20 Maximum von Misses stress

Besides von Misses stress, there are also 1st principal stress and 3rd principal stress result. The 1st principal stress shows the maximum tensile stress induced in the assembly/part due to the loading condition. While the 3rd principal stress shows the maximum compressive stress induced in the part due to loading condition. **Figure-4.21** and **4.22** show the result of the analysis. For the 1st principal stress, the maximum stress is 8.396 MPa while the minimum is -3.607 MPa. And for the 3rd principal stress, the maximum stress is 3.03 MPa and the minimum is -12.89 MPa.

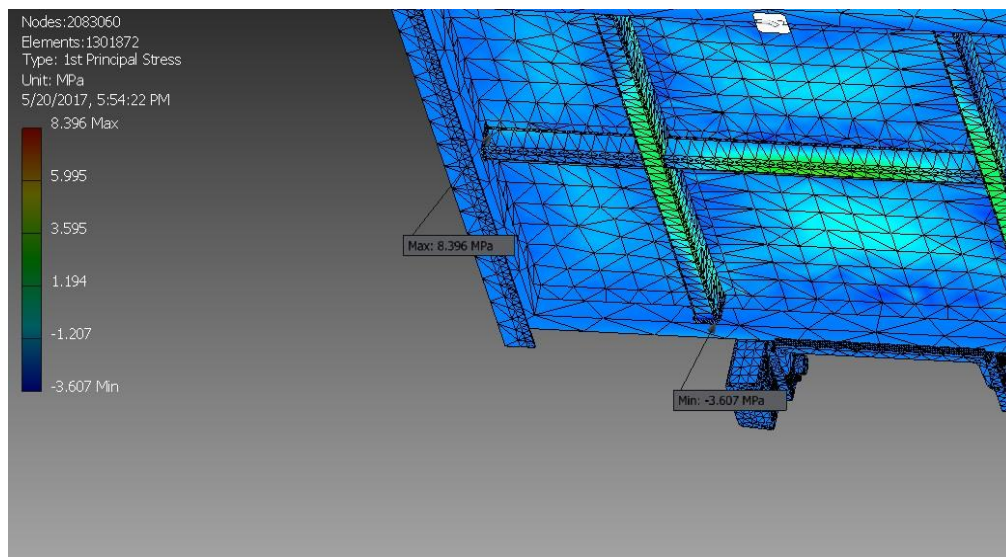


Figure 4.21 1st principal stress of car platform

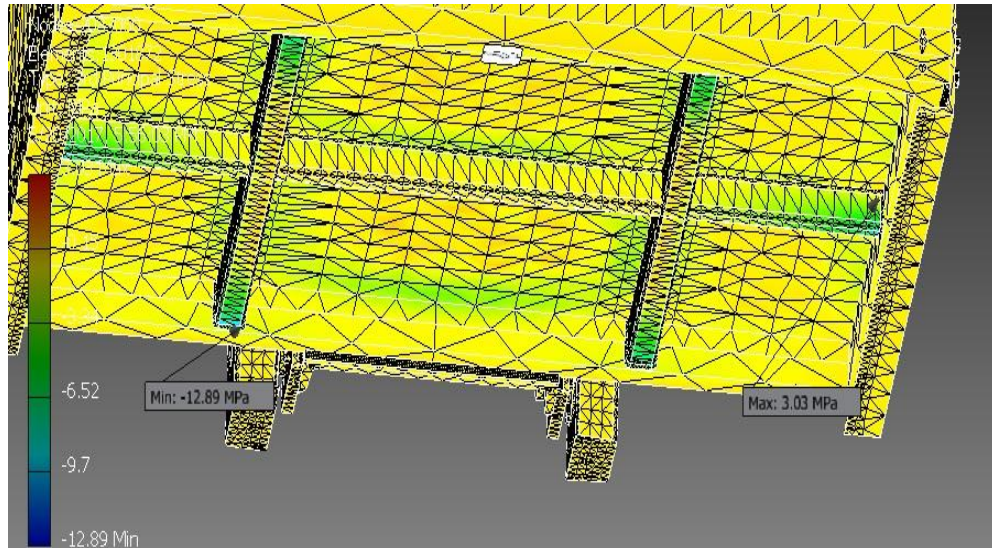


Figure 4.22 3rd principal stress of the car platform

With the von Mises stress result, the displacement and the safety factor of the structure are obtained. Normally for safety factor to know the value, the calculation is $Sf = \frac{YS}{DS}$ with YS as yield strength and DS are design stress. Because the component are consist of many part and the material are different from each other. With the help of Inventor FEA analysis the, SF can be calculated by the computer. Figure-4.24 show the safety factor are 6.81. For this structure, because the safety factor is >2 this structure is safe.

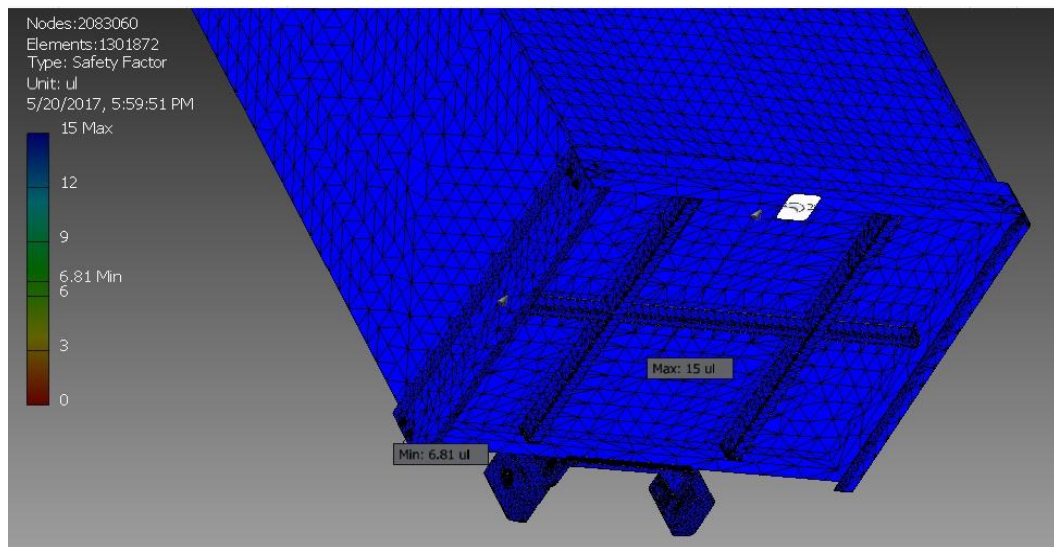


Figure 4.23 Safety Factor result of Car assembly

The displacement for the simulation can be seen in **Figure-4.24**. The maximum displacement value is very little in the condition of maximum load that

applies are 500 kg. The result show displacement at 0.0936 mm. This shows that the structure of the platform is really safe.

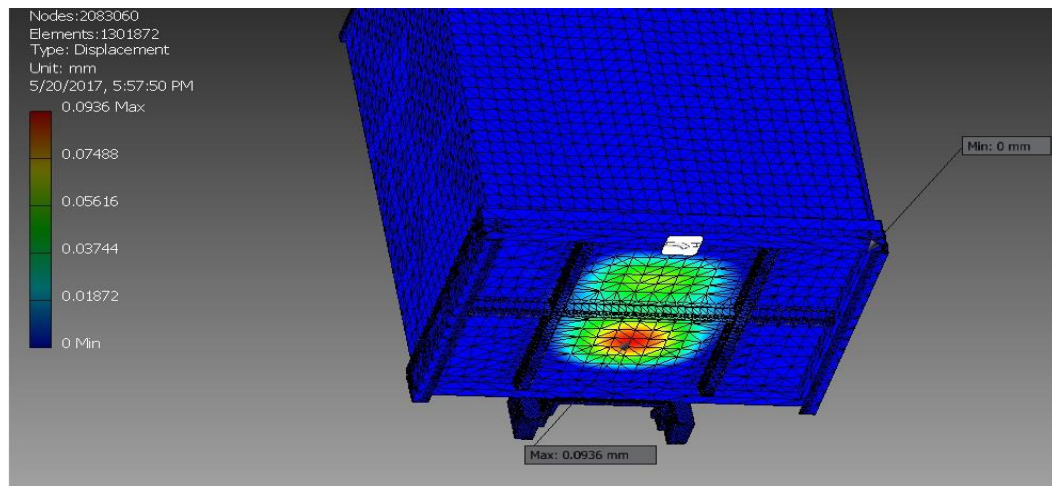


Figure 4.24 Displacement of the Car assembly structure

4.3.2 Analysis on the sliding guide assembly

The analysis of the sliding guide is done in 4 places, that is the shaft that holds the sliding guide and the holder to the car. The shaft gave the force from the load of the car structure and the load capacity that equals to F_{lift} . The value of the F_{lift} is 2000 kg because it is divided into 4 different area, the load for each sliding guide is $2000 \text{ kg}/4 = 500 \text{ kg}$. The force will be rounded up so it equal to 5000 N.

In **Figure-4.25**, each of the sliding guides is given the same amount of force. The direction of the force is downwards to simulate when the car is going down. The same value of the results should be expected if the direction changes to face upwards. From the results, the maximum amount of von Misses stress is 1.993 MPa in a total of all 4 assemblies while the minimum is 0 MPa. The analysis is done in assembly to shows the results closest to real value. The minimum safety factor for this component is 2.

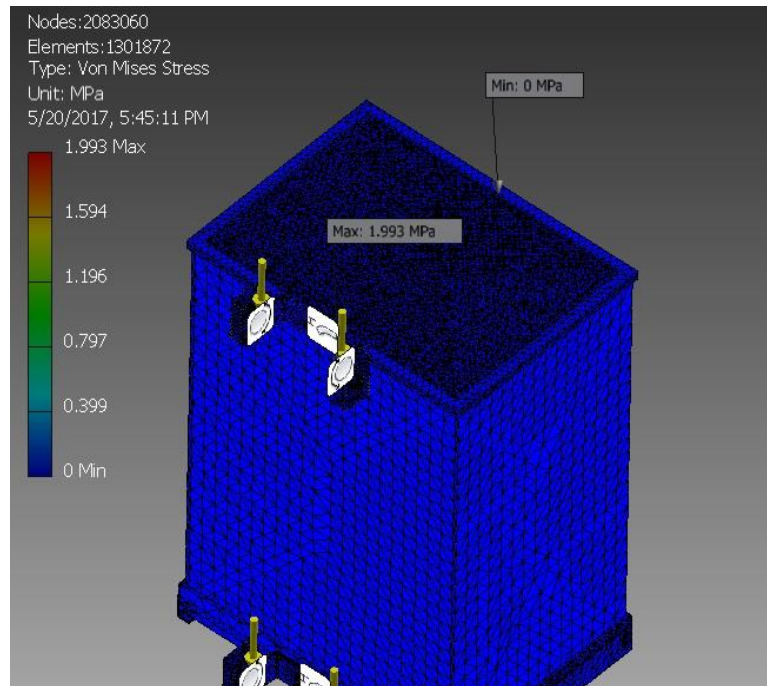


Figure 4.25 Sliding Guide Analysis results

From **Figure-4.26**, the area that is in red shows the most stress that is taken and has the most displacement out of the structure. While the area that has minimum stress is shown in blue for the shaft of the guide, the material is steel carbon A36 with yield strength 250 MPa.

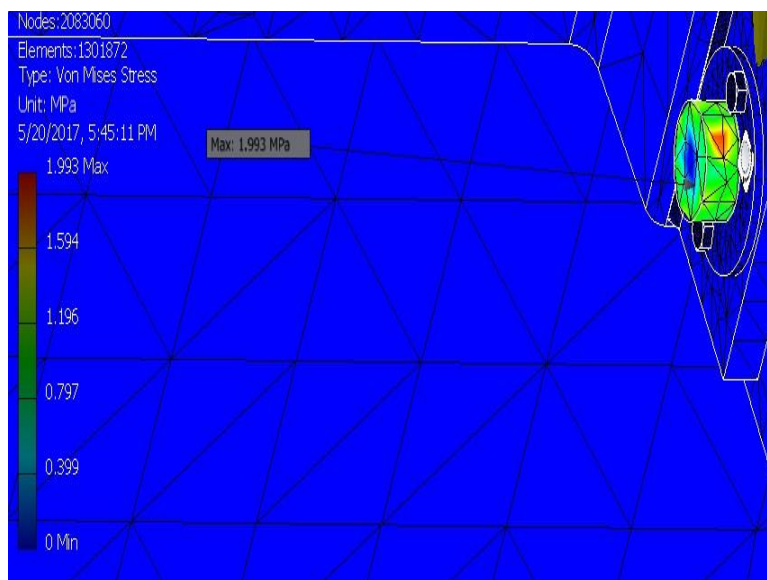


Figure 4.26 Maximum von Mises stress

For the results of the analysis of 1st principal stress can be seen on **Figure-4.27**. The red area shows maximum tensile stress in loading condition with the

value of 2.302 MPa. While the blue area shows the least amount of tensile stress in loading condition with the result of -0.889 MPa.

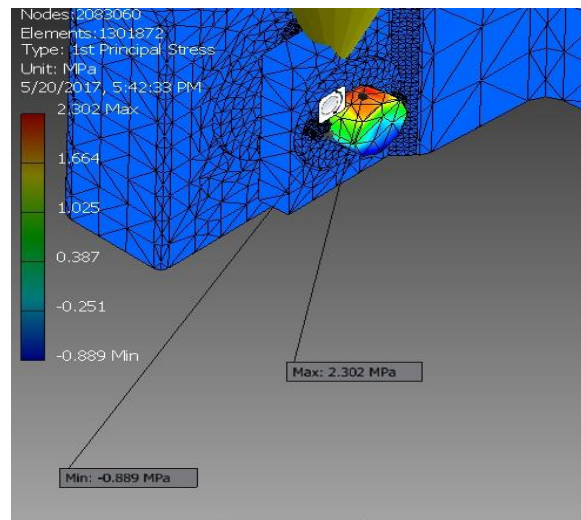


Figure 4.27 1st principal stress of the sliding guide

In **Figure-4.28** the 3rd principal stress value from the result is shown in the area that has color in it. The red indicates that it has the maximum compressive stress in loading condition which in this component is 0.926 MPa. While the blue area indicates it has the least amount of compressive stress at -2.336 MPa.

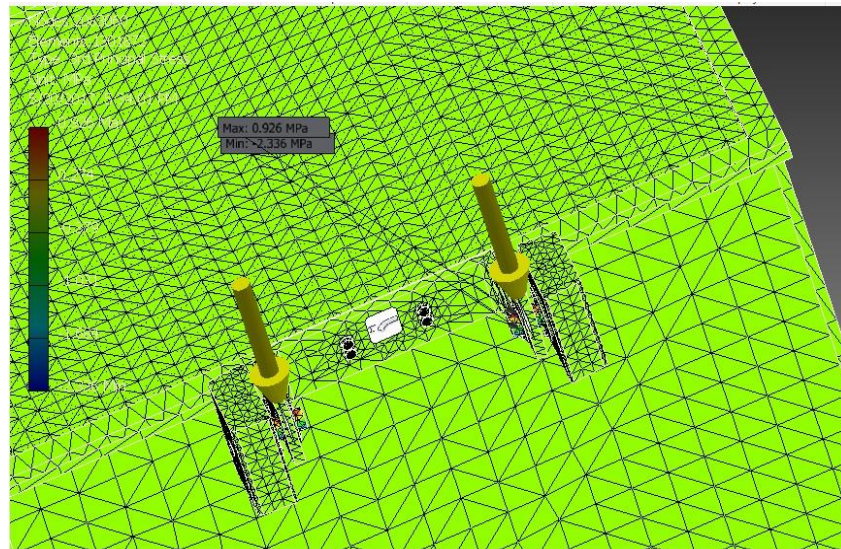


Figure 4.28 3rd principal stress of the sliding guides

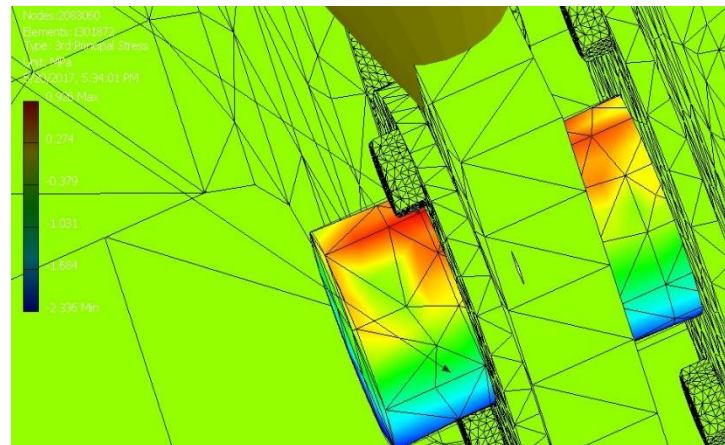


Figure 4.29 Enlarge view of the 3rd principal stress

With the von Mises stress result, the displacement and the safety factor of the structure are obtained. Because this component also consists of many parts and the material is different from each other the calculation for the safety factor and displacement will be done with help of the computer. Figure-4.24 show the safety factor is 15. For this structure, because the safety factor is >2 this structure is safe.

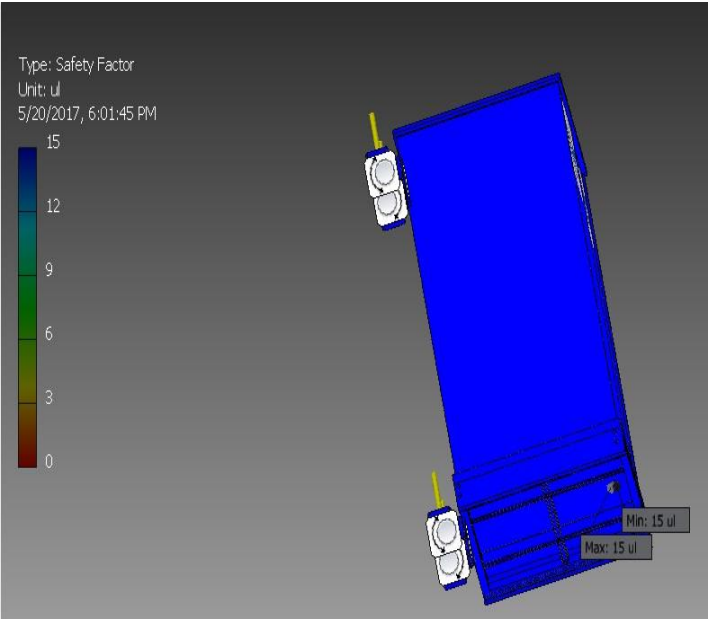


Figure 4.30 SF results of sliding guide

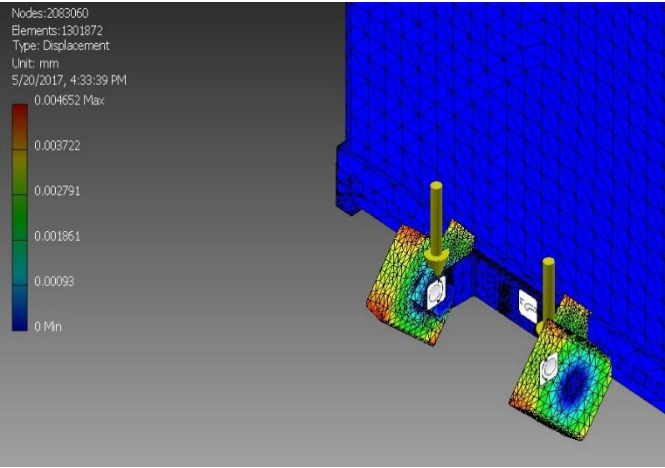


Figure 4.31Bottom slider displacement adjusted 1x

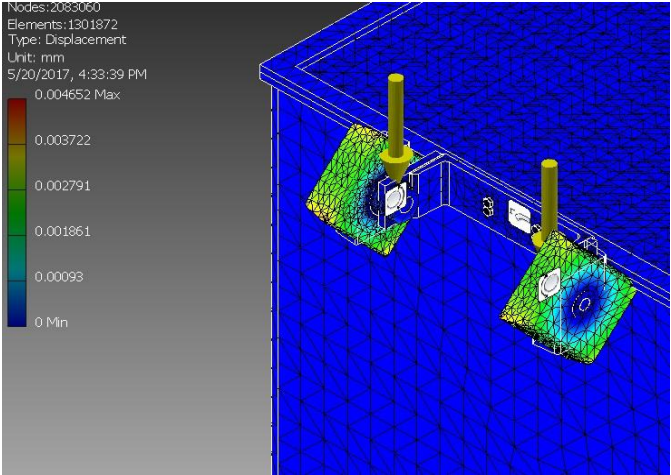


Figure 4.32 Upper slider displacement adjusted 1x

For the maximum displacement of the sliding assemblies, the amount from the analysis is 0.004652 mm. The displacement is very little so, this assembly for the component is safe. In **Figure-4.31 & 4.32** the displacement is adjusted at 1x than the real condition, to shows the direction of the displacement. In **Figure-4.33** the condition of the displacement is in real condition.

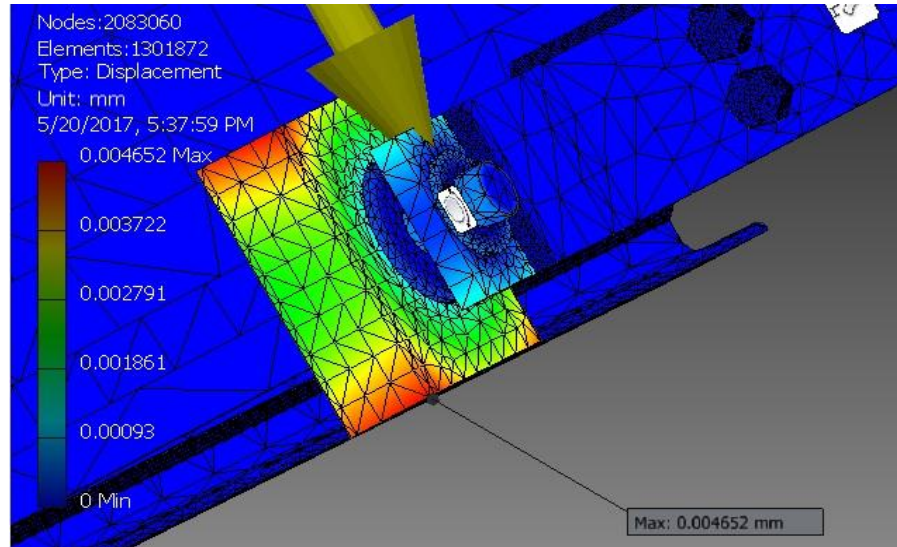


Figure 4.33 Real time displacement of the sliding guides

4.3.3 Analysis on the bottom chain holder

The analysis for this component will be based on the holder for the chain strands that are attached to the car assembly. The chain is given the force that equals to lift the load of the whole structure that equals to 2000 kg. The force is divided per strands because there are 2 strands so per strand have an acting load of $2000 \text{ kg} / 2 = 1000 \text{ kg}$. And the load is divided in each end of the strands so the load in each end are $1000 \text{ kg} / 2 = 500 \text{ kg}$. The force that works in the component is 5000 N per holder that is equal to 500 kg.

The condition for this analysis is that the lift is in the condition of going up. So, the force that applies to the component is facing upwards because the chain is pulling the holder. The gravity will also apply in this analysis, so the gravitational force will also apply in the analysis facing downwards. The material for this holder is steel carbon same with the material for the sprocket gear and chain strands of the

movement system. This material has the yield strength of 250 MPa. The minimum safety factor for this component is 1.

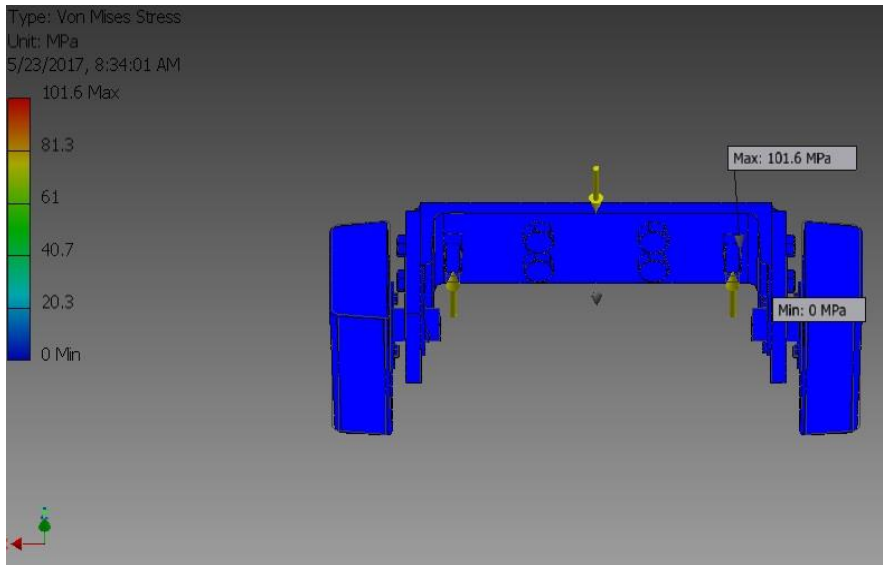


Figure 4.34 von Misses stress for the bottom chain holder

From **Figure-4.35** and **4.36**, the area that is in red shows the most stress that is taken with the value of 101.6 MPa and have the most displacement out of the structure. While the area that has minimum stress is shown in blue area with the result of 0 MPa.

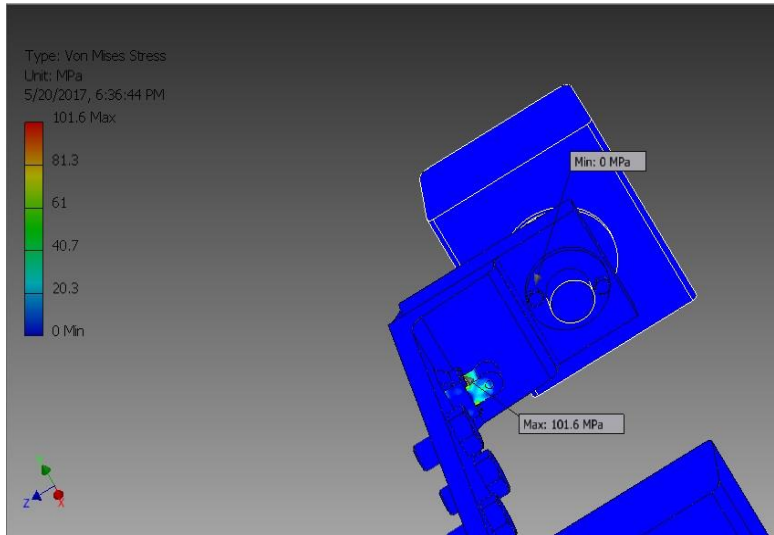


Figure 4.35 Maximum and minimum value of von misses

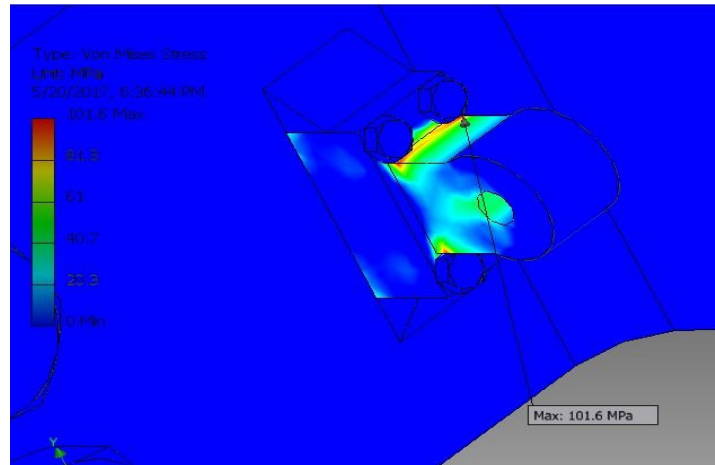


Figure 4.36 Enlarge view of maximum von misses stress

For the results of the analysis of 1st principal stress can be seen on **Figure-4.37 & 4.38**. The red area shows maximum tensile stress in loading condition with the value of 122.2 MPa. While the blue area shows the least amount of tensile stress in loading condition with the result of -3.61 MPa.

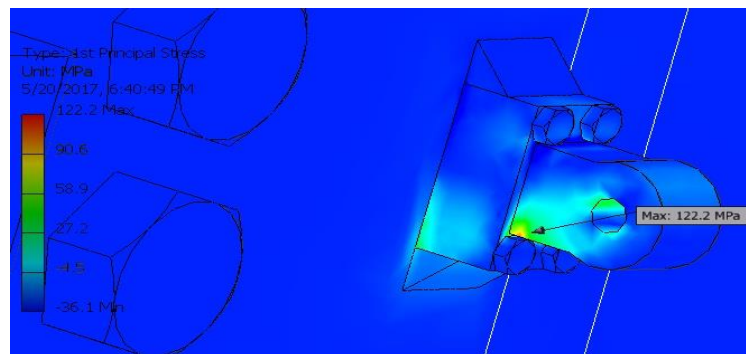


Figure 4.37 Max 1st principal stress

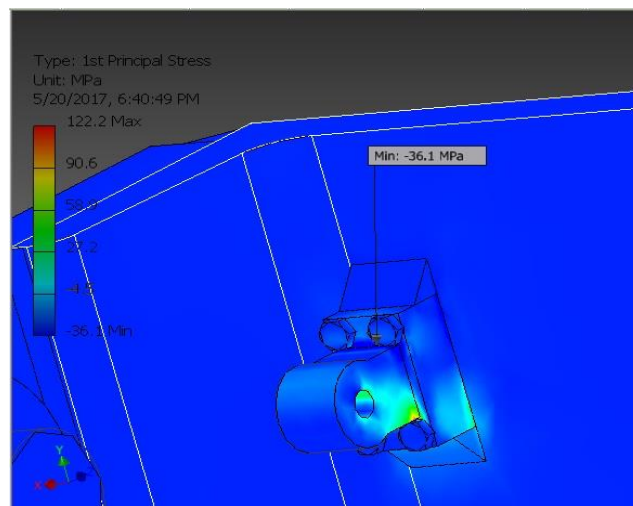


Figure 4.38 Minimum von Misses stress

In **Figure-4.39** the 3rd principal stress value from the result is shown in The red area. The red area indicates that it has the maximum compressive stress in loading condition which in this component is 36 MPa. While the blue area in **Figure-4.40** indicates it has the least amount of compressive stress at -123 MPa.

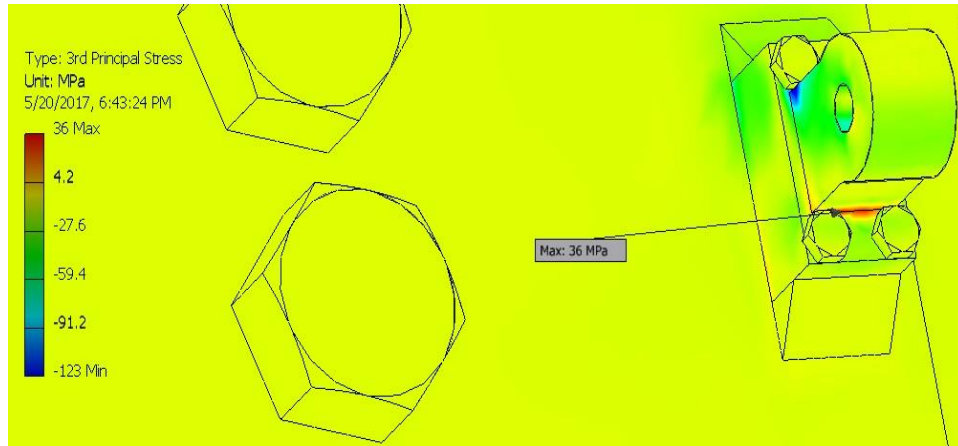


Figure 4.39 Maximum 3rd principal stress

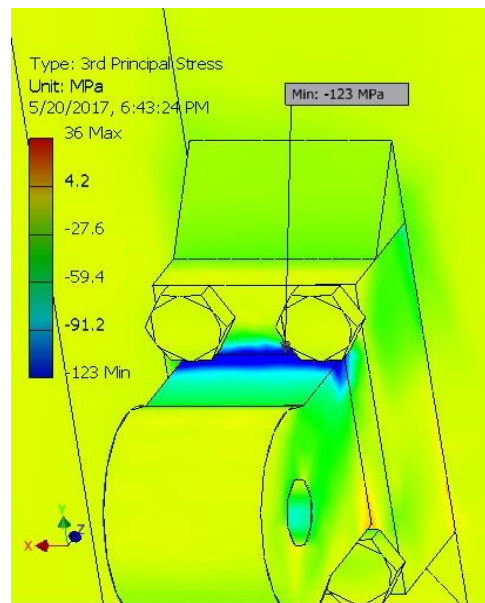


Figure 4.40 Minimum 3rd principal stress

With the von Misses stress result, the displacement and the safety factor of the structure are obtained. The calculation from the FEA software indicates that for this component the safety factor is 2.04, this can be found on **Figure-4.41**. For this structure, because the safety factor is >1 this structure is safe.

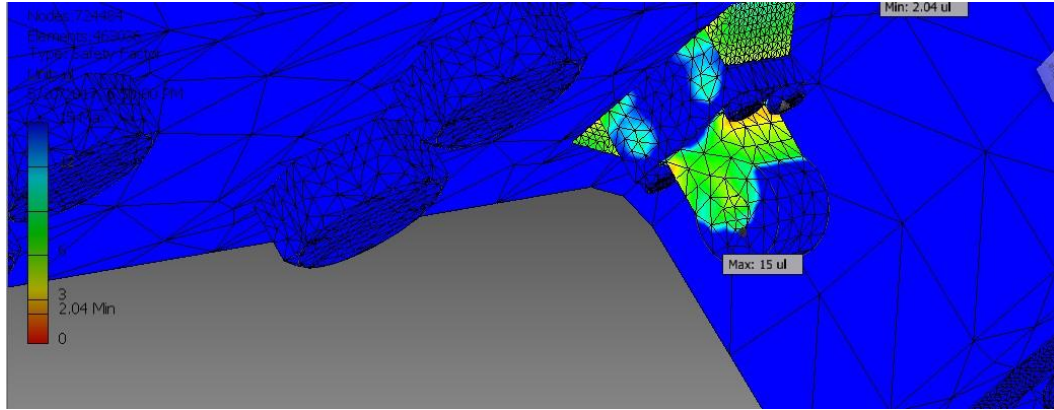


Figure 4.41 SF for bottom chain holder assembly

For the maximum displacement of the bottom chain holder from the analysis are 0.02564 mm. The displacement is very little so, this assembly for the component is safe. In **Figure-4.42** the condition of the displacement is in actual condition.

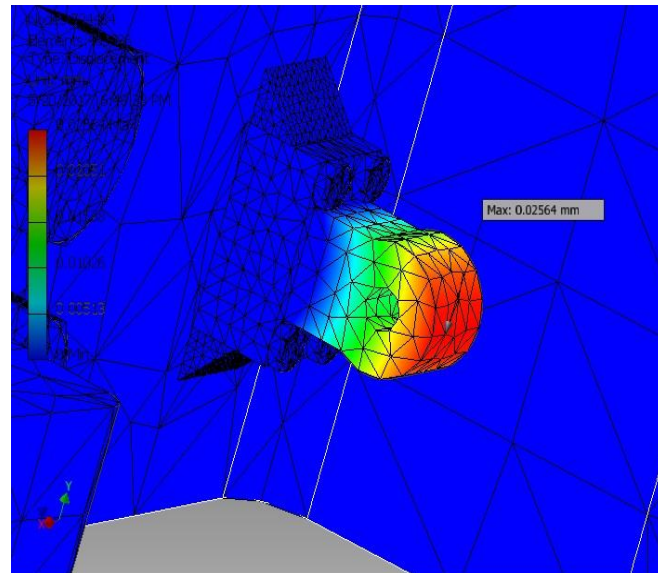


Figure 4.42 Displacement of the bottom chain holder

4.3.4 Analysis on the fixed chain holder

The analysis for this component has the same boundaries condition with the bottom chain holder. The difference is that this assembly is fixed to the guide rails of the beam structure. While the bottom holder can move up and down to lift the car.

The condition for this analysis is that the lift is in the condition of going up. So, the force that applies to the component is facing downwards for giving the

same reaction as the force that applies to the bottom chain holder. But when the bottom chain holder past the fixed holder post, the force will face upwards, while the force of the bottom holder goes down. The material for this holder is steel carbon same with the material for the sprocket gear and chain strands of the movement system. This material has the yield strength of 250 MPa. The minimum safety factor for this component is 1.

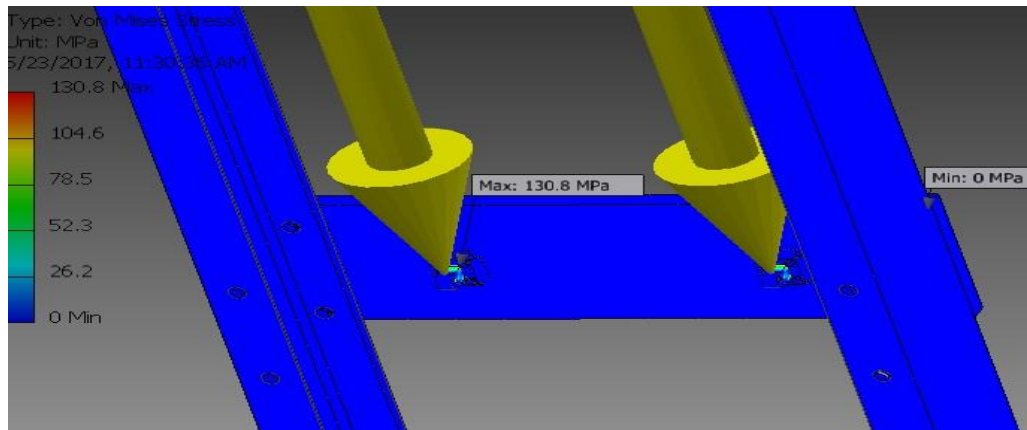


Figure 4.43 von Mises stress of fixed chain holder

From **Figure-4.43** the area that is in red shows the most stress that is taken with the value of 130.8 MPa and have the most displacement out of the structure. While the area that has minimum stress is shown in blue area with the result of 0 MPa. The maximum von Mises stress is used to determine the safety factor of the component. **Figure-4.44** shows the maximum von Mises stress.

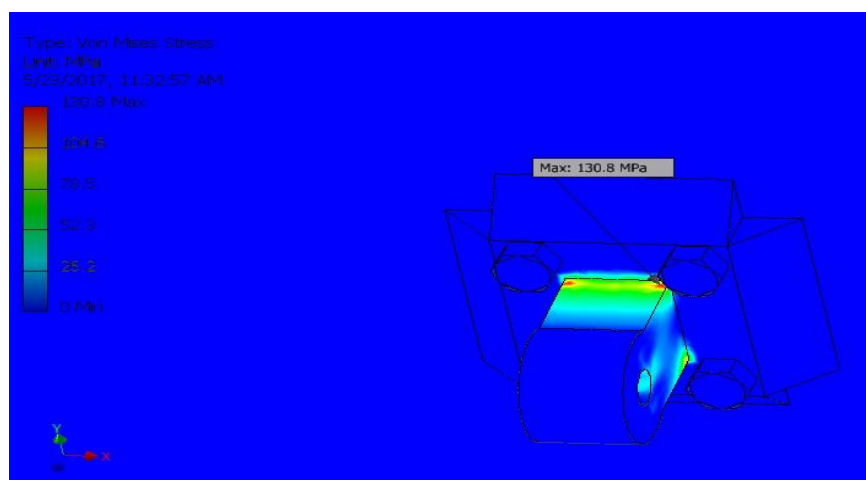


Figure 4.44 Enlarge view of the von Mises stress

For the results of the analysis of 1st principal stress can be seen on **Figure-4.45 & 4.46**. The red area shows maximum tensile stress in loading condition with the value of 144.4 MPa. While the blue area shows the least amount of tensile stress in loading condition with the result of -35.1 MPa.

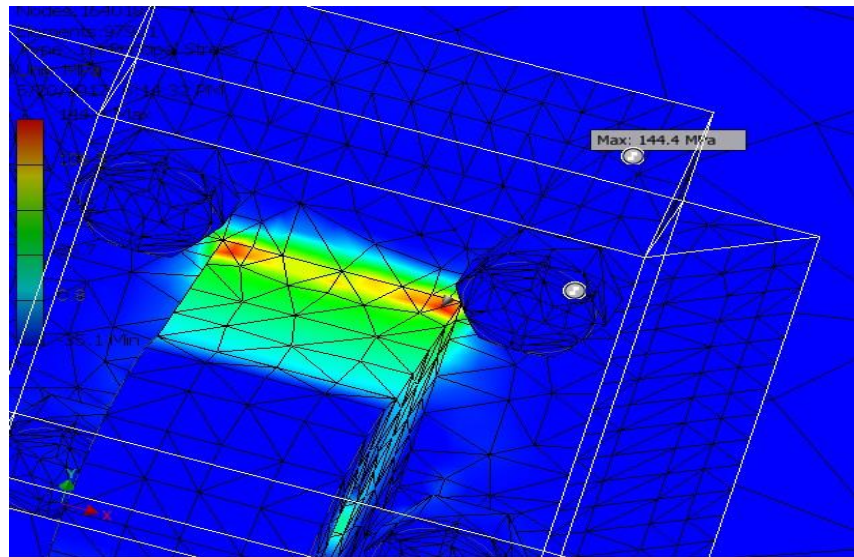


Figure 4.45 Maximum 1st principal stress

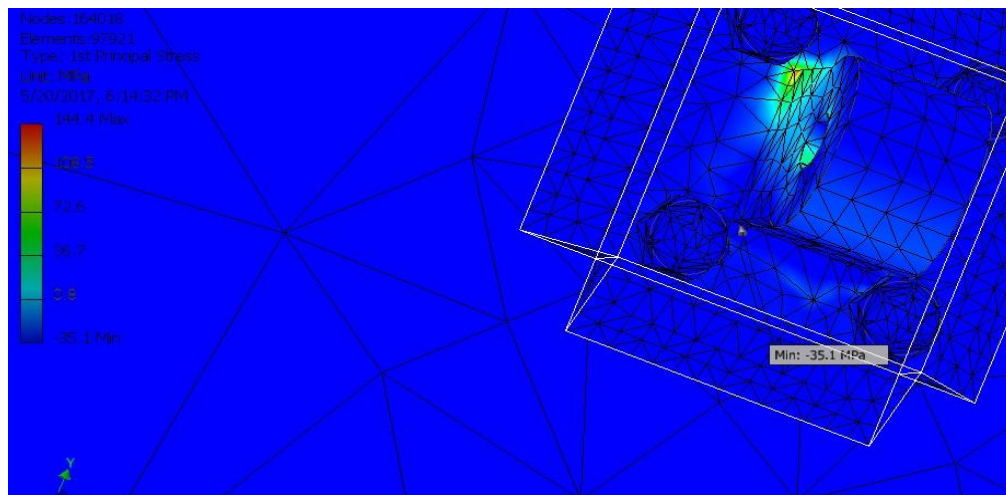


Figure 4.46 Minimum 1st principal stress

In **Figure-4.47** the 3rd principal stress value from the result is shown in The red area. The red area indicates that it has the maximum compressive stress in loading condition which in this component is 35.4 MPa. While the blue area in **Figure-4.48** indicates it has the least amount of compressive stress at -143.8 MPa.

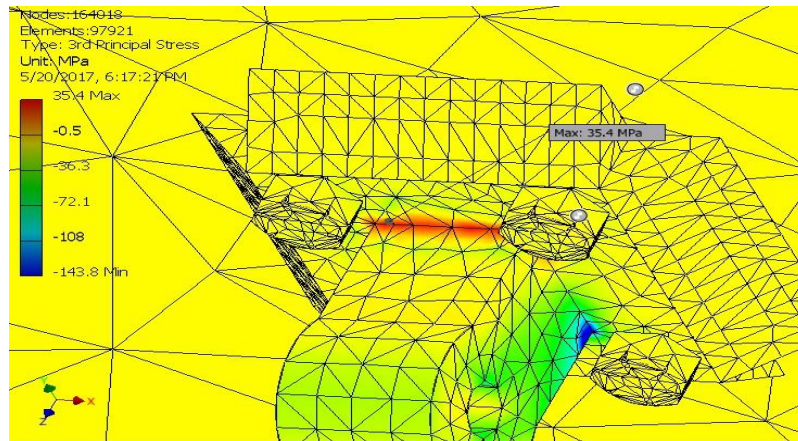


Figure 4.47 Maximum 3rd principal stress

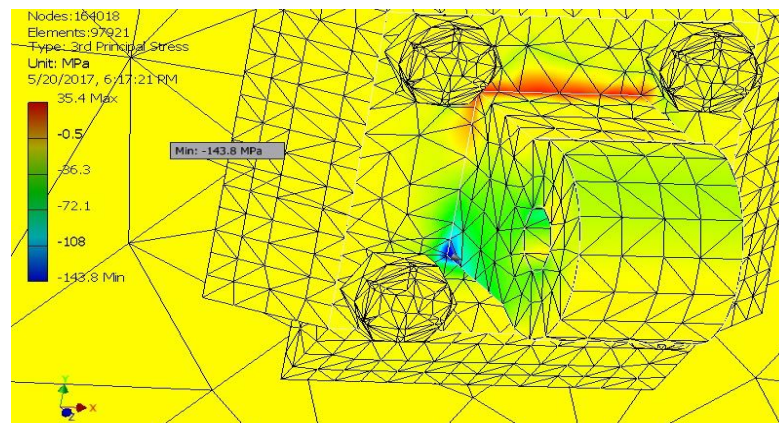


Figure 4.48 Minimum 3rd Principal stress

With the von Mises stress result, the displacement and the safety factor of the structure are obtained. The calculation from the FEA software indicates that for this component the safety factor is 1.58, this can be found on **Figure-4.49**. For this structure, because the safety factor is >1 this structure is safe.

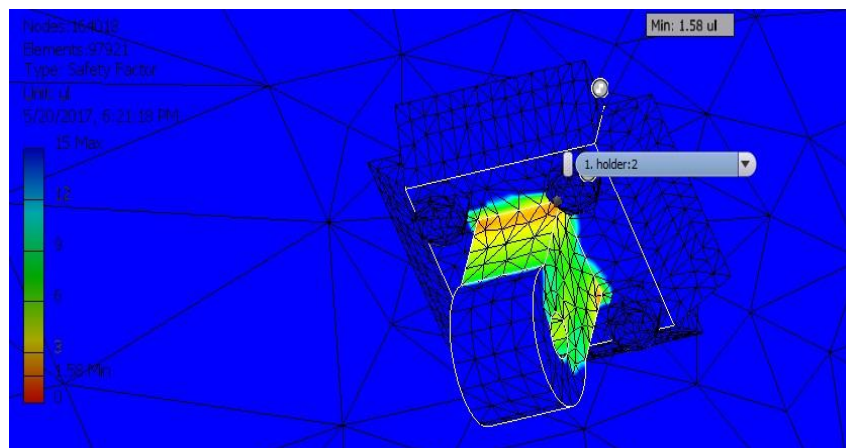


Figure 4.49 SF of the fixed chain holder assembly

For the maximum displacement of the bottom chain holder from the analysis are 0.02564 mm. The displacement is very little so, this assembly for the component is safe. In **Figure-4.50** the condition of the displacement is in actual condition.

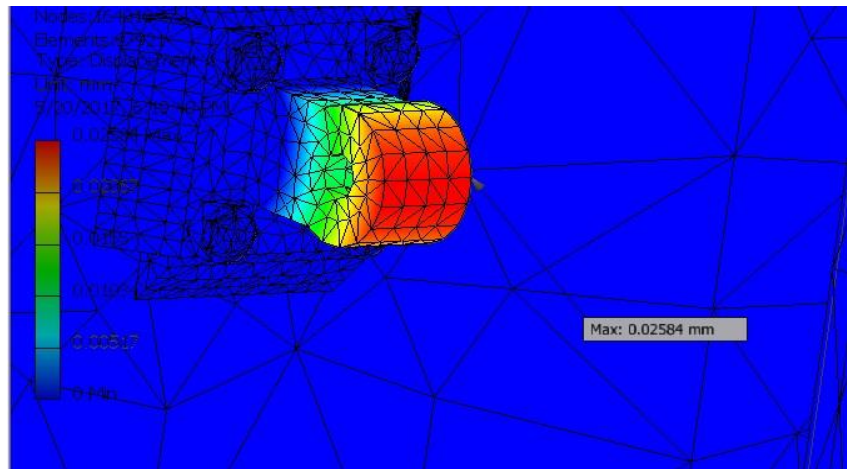


Figure 4.50 Displacement of the fixed chain holder assembly

CHAPTER 5

CONCLUSION

5.1 Conclusion

Based on the design and results of the finite element analysis for the machine it can be concluded that:

- The main design point and the calculation for the lift project go well with the results of the FEA analysis. The critical point of the structure has been proven to be safe according to the safety factor results.
- The lift met the loading condition that is given, and the lift can lift up the load and the structure are safe based on the analysis.
- The improvisation of the design that has been made are:
 - a. The shape of the guide rails is changed into sliding guides.
 - b. The addition of wheelchair chock for ergonomic design aspect.

5.2 Recommendation

In this research, there are still some flaws in the process and there are shortcomings and possible step to do in this research further in the future, and that includes:

- Possible material change in the design to cut short the price of material, should the design have manufactured in T.M.C.
- Adjustment of the material for the sliding guides, because in the analysis the safety factor reaches 15. This can be a result of 2 things:
 - a. A different material should be applied to this assembly because SF 15 is too strong. So maybe the component need adjustment to a better and cheaper material. Or,
 - b. The Finite element analysis parameter in the analysis of this part is wrong, so the results for the safety factor come out rather ambiguous even though other parameters of the result like von Mises stress come out well.
- Future research/design can be made for the elevator to travel higher or change the system to a more suitable design for people with disability. Because there are many hydraulic elevator types, and this research is just one of the many that exists.

BIBLIOGRAPHY

- [1] L. B. Archer, Systematic Method for Designers, London: Council of Industrial Design, 1965.
- [2] "engineering.myindialist," 2009. [Online]. Available: <http://engineering.myindialist.com/2009/working-principle-of-hydraulic-lift-direct-acting-and-suspended-type/#.WSF5POuGPIW>. [Accessed 21 May 2017].
- [3] "Electrical KnowHow," 04 2012. [Online]. Available: [3] <http://www.electrical-knowhow.com/2012/04/elevators-types-and-classification.html>. [Accessed 21 May 2017].
- [4] L. Janovský, Elevator mechanical design, New York : Ellis Horwood, 1993.
- [5] I. a. IISc, "Hydraulic Systems," vol. Modul 5, no. Lecture 1.
- [6] CenTec, "Mechanical Theory/Technology," vol. Bearings, 2002.
- [7] M. o. S. Construction, American Institute of Steel Construction, 1987.
- [8] G. a. Timoshenko, Mechanics of Materials, PWS Publishing Company, 1997.
- [9] D. Kiritsis, C. Eemmanouilidis and A. Koronios, .Engineering Asset Management ,, Proceedings of the 4th World Congress on Engineering Asset Management (WCEAM), 2009.
- [10] R. von Mises, Mechanik der festen Körper im plastisch deformablen, Zustand. Göttin. Nachr. Math. Phys, 1913.
- [11] Tsubaki, *Tsubaki Drive chains and sprocket*, Tsubaki corporation.
- [12] T. M. T. o. Plasticity, Oxford: Clarendon Press.

ATTACHMENT