Modernized 6 and 10-ton Dock Levelers

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MASTER THESIS

Modernized 6 and 10 ton Dock Levelers

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Abstract
This Master Thesis is made in collaboration with ASSA ABLOY Entrance Systems and addresses the issues and problem areas of two dock leveler models; 60 kN and 100 kN to find a new improved design. After the following product development process, a new concept was created which could withstand applied forces exceedingly.

The main purpose and goal of the project was to find a dock leveler design which could be produced with fewer components, a lower weight and made with more modern manufacturing techniques, all while meeting specific standards for dock levelers. The project started with a literature study of safety standards, product data sheets, as well as a various FEM-analyses of current dock levelers. This pre-study served as the basis for the following stages of concept generation, concept selection, testing, conclusion, and discussion.

Ulrich and Eppinger's model for product development was the main method used. Some adjustments were made to fit the project. Testing and verification of the final concept was performed with a number of FEM-simulations for different load cases.

Conclusions identified from the project were the areas of high stress and thereby areas needing improvement. The several FEM-analyses conducted gives a good representation of stresses in different load cases but should be supplemented with physical tests. The final design was constructed mainly of folded sheet metal and rectangular pipes with the assembling methods being welding and bolted joints. Overall, the new concept has fewer parts, less weld usage, uses modern manufacturing techniques, and a more robust cylinder design.

Keywords: *Dock leveler, FEM, stress, sheet metal, load case*

Sammanfattning

Detta examensarbete har utförts i sammarbete med ASSA ABLOY Entrance Systems och tar itu med problem och promblemområden hos två lastbryggsmodeller; 60 kN och 100 kN för att hitta en ny förbättrad design. Efter följande produktutvecklingsprocess har ett nytt koncept tagits fram som bättre klarar av pålagda krafter.

Huvudsyftet och målet med projektet var att hitta en design på lastbryggan som kunde produceras med färre delar, ha en lägre vikt och tillverkas med modernare tillverkningsmetoder samtidigt som den klarar av specifika krav för lastbryggor. Projektet började med en litteraturstudie av säkerhetsstandarder, produktdatablad, samt en mängd olika FEM-analyser på de nuvarande lastbryggorna. Denna förstudie användes som grund för de efterföljande stegen av konceptgenerering, val av koncept, testning, slutsatser och diskussion.

Ulrich och Eppingers modell för proktutveckling användes som den huvudsakliga metoden. Några modifieringar har gjorts för att passa projektet bättre. Testning och verifiering av det slutliga konceptet har gjorts med hjälp av flera FEM-analyser för olika lastfall.

De slutsatser som har dragits från projektet är var de olika problemområdena befinner sig och på så sätt vilka delar som behövde förbättras. De många FEM-analyserna som gjorts gav en bra uppskattning av spänningar i olika lastfall men bör kompletteras med fysiska tester. Den slutgiltiga designen bestod till mestadel av bockad plåt och rektangulära rör som sedan sattes ihop med svetsfogar och skruvförband.

Nyckelord: *Lastbrygga, FEM, spänning, plåt, lastfall*

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We also extend our gratitude to Mads Bertelsen, the Product Manager for docking at ASSA ABLOY. Bertelsen helped us with questions regarding the actual products and the different models. Moreover, we would like to thank Marcel Grobin and Sune Lind who, in addition to Löfgren and Bäcklund, both took part in a workshop regarding hydraulic cylinders. The workshop provided vital insights and furthered our work.

Finally, we would like to thank the people at the division of Product Development at the Department of Design Sciences at LTH who helped us with the thesis. Especially to our supervisor Per Kristav guidance and confidence in our process, and a thank you to our examiner Axel Nordin.

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List of acronyms and abbreviations

IDS - Industrial Door Solutions
CAD - Computer-aided design
FEM - Finite Element Method
S235 - Structural Steel with yield strength 235 MPa
S355 - Structural Steel with yield strength 315 MPa
BOM - Bill of Materials

1 Introduction

1.1 About Assa Abloy

Assa Abloy group is a global leader of access solutions. The company offers products like locks, doors and other entrance solutions for both commercial, industrial, and private use. The Assa Abloy Group was formed through a merger between the Swedish ASSA and the Finish Abloy in 1994. Today, the company has grown considerably by expanding their business and acquisitions of other companies. As of 2019, the company has over 47500 employees.[1]

Assa Abloy group is divided into different divisions, where Assa Abloy Entrance Systems is the largest. Their product portfolio includes automatic, industrial and commercial, high-performance, residential garage, hangar doors and loading dock equipment — a complete range of automatic entrances for secure and convenient access to the front, back and interior of any building.[2]

Within Entrance Systems, there are several departments focused on different areas and business segments. Industrial Door Solutions (IDS) handles loading dock equipment and industrial doors, high-performance doors and services. This Master Thesis will be executed under the IDS department and the resources and expertise will mainly come from IDS.

1.2 Problem Statement

Assa Abloy produces dock levelers for industrial applications in a number of varying models. The master thesis will focus on the DL6010SA Swing Autodock (60 kN) and DL6111SA Swingdock Autodock (100 kN) models. The existing design has shown to have some problem areas where it does not meet the current standard for dock levelers. In addition, the current model is constructed with many smaller parts welded together which is both relatively expensive and time consuming to produce.

1.3 Goal

The aim of the Master Thesis project is to design a new generation of dock levelers, improving the current design in several aspects. The new design should be based on modern manufacturing techniques and material optimization all whilst maintaining the required standards and load cases. Additionally, minimizing the amount of components used, and the meters of weld needed is preferred.

1.4 Delimitations & Scope

Some delimitations were to be set to restrict the scope of the project. The Master Thesis will exclusively study the dock leveler models DL6010SA Swing Autodock (60 kN) and DL6111SA Swingdock Autodock (100 kN), both in their respective largest dimensions available, with a hinged lip. Focus will lie on perfecting and improving parts that have problem areas in the design on the current models and not create a brand new design. Concept development has exclusively been done on the DL6111SA

Swingdock Autodock (100 kN)-model, as it is seen as the worst case scenario. In the future the 100 kN will be the base for down scaling so the concept and design can be applied for other models, which are required to withstand less load.

1.5 Dock Leveler Definition

A dock leveler bridges the gap between vehicle and loading dock to ensure smooth and safe transfer of goods. Usually, a dock leveler consists of a stationary elevated platform and a ramp that can be adjusted to the height of the lorry and create a safe pathway between the truck and building. There are both manually and automated dock levelers.[3]

The main components of a dock leveler are the frame, the platform, the lip, and the cylinders. The lip can be either hinged or telescopic. A schematic sketch of a dock leveler can be seen in Figure 1.1. Further explanations of the main components of a dock leveler is available in section 3.1.

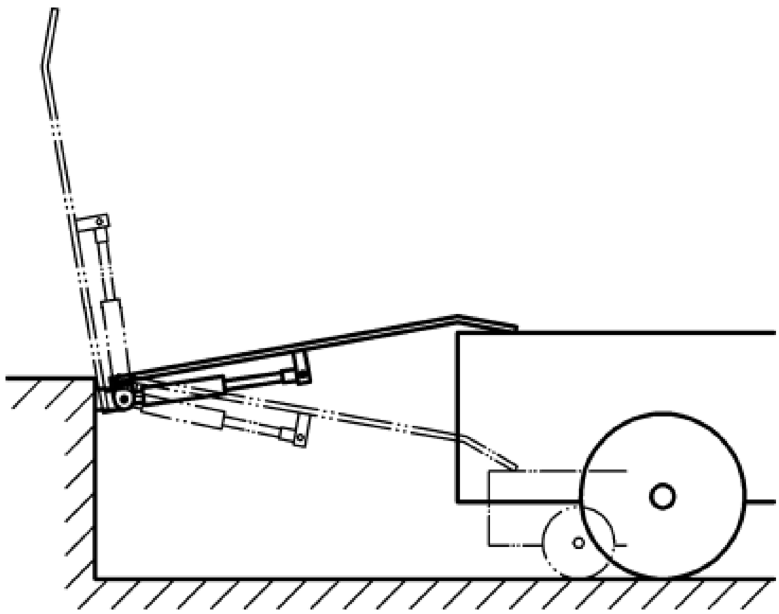

Figure 1.1: *An Automatic loading dock [4]*

2 Methodology

To achieve the set goals, given the problem statement, a number of methods are to be employed, and are described below. Additionally, how the methods will be implemented to fit the project and its delimitations are described. The time allocation for the project is presented in Appendix F.

2.1 The Product Development Process

The project will be following Ulrich and Eppinger's Product Development Process [5, pp. 12-18], where the authors propose a method for developing engineered products from the planning stage to the finished product. A defining feature of the method is the iterative process. The generic process described in their book is used as a basis. Their approach are six stages from planning to production, see Figure 2.1. The method is then applied to our project by taking our scope and circumstances into account. Therefore, the step "production ramp-up" will not be applicable since this thesis will end in a proposed design and not a full production plan. The "testing and refinement" activity has a limited execution in the project due to this activity only being preformed virtually and not with physical testing.

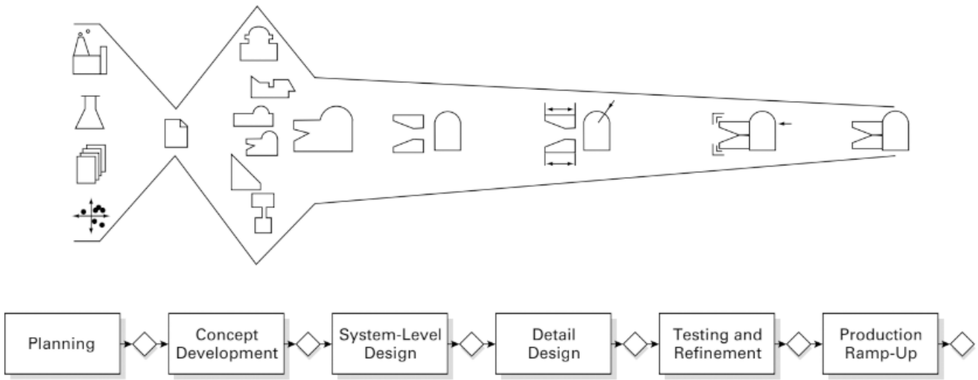

Figure 2.1: *Ulrich & Eppinger's Generic Product Development Process and its activities [5, p. 14]*

In the planning stage the activities time allocation, mission statements, and a prestudy are performed. Afterwards the concept development stage starts, where product specifications are established from the results of the planning stage. Below, the iterative steps of the Concept Development Process are presented in Figure 2.2. Identifying customer needs is a step which is already done for us with the existing product, and therefore the step is outside the scope of the project.

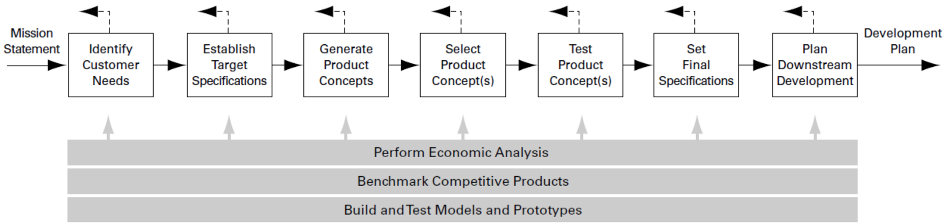

Figure 2.2: *Ulrich & Eppinger's activities for concept generation [5, p. 16].*

Concept generation is the part where ideas are developed by brainstorming, sketching, and research. All the information in this section is based on the method described by Ulrich and Eppinger [5, pp. 16-18]. In the selection of product concepts, the concepts are compared in a systematic way to evaluate which are favorable. In the project, the FEM-analyses of the load cases from the standards will be a requirement. Ulrich and Eppinger describe the concept testing stage as a process more directed against customer surveys, which will not be used due to the given scope. Setting final specifications will be important and planning for downstream development will help with the later parts of the process. During the concept development stage, economic analysis will be performed continuously. Benchmarking of competitive products will be focused on the comparison with the current dock leveler, not other products on the market. Building and testing models will be executed virtually in CAD-software and FEM-analyses.

In the system level design, major subsystems and interfaces are defined. However, with the given delimitations, much of the subsystems are already determined. In the detail design stage, part geometry, tolerances and material choices are decided. Here, the detail design will be a vital step, as much of the major geometries are already given. The ambition was to test the final concepts with measuring equipment to validate the FEM-analysis. however, due to the time limitations it sadly had to be pushed to further development.

2.2 Method for Literature Survey and Pre-study

The method of literature study allows for building up knowledge and background information regarding the dock leveler and its problem areas. The literature study will be conducted by analysing the following documents:

- The standard for dock levelers EN 1398
- Product data sheets
- Product installation guides

Additionally, a part of the pre-study is talking to people in the company with relevant knowledge regarding the dock leveler, to gain information about current problems and focus areas.

An overview of the 3D-models and the main components will also be a part of the pre-study. FEM-analyses of the current models are a vital part of the pre-study to understand the problem areas and get a comprehensive overview. This method will be executed in Solidworks Simulation software for different loading scenarios. A study of the cylinders will also be a part of the research.

In summary, the combination of the methods are presented below in the flow chart in Figure 2.3, representing the method derived from Ulrich and Eppinger with adjustments to fit the project. More in-depth information regarding methodology, especially the different parts of the Ulrich and Eppinger-method will be present in the beginning of each relevant section. There, adjustments from the original method to better fit the project will also be presented.

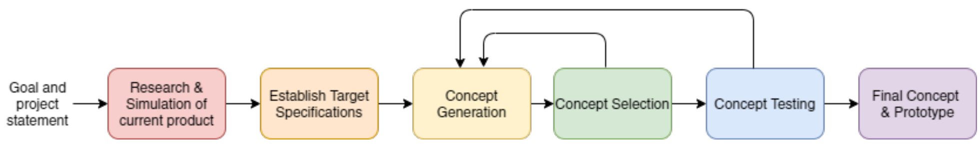

Figure 2.3: *The product development process used in this project, derived with adaptions from Ulrich and Eppinger's process*

3 Research & Pre-study

According to the method described above, research was conducted to understand the problems and possibilities.

3.1 Current Design CAD-Model

The basis of the whole project are the current models of the dock levelers. Therefore it is vital to present and understand all the parts and get an overview. Different views of the 100 kN CAD-model and the most significant components are marked in the Figures 3.1-3.3 below. The material used is mainly S235 which is a structural steel.

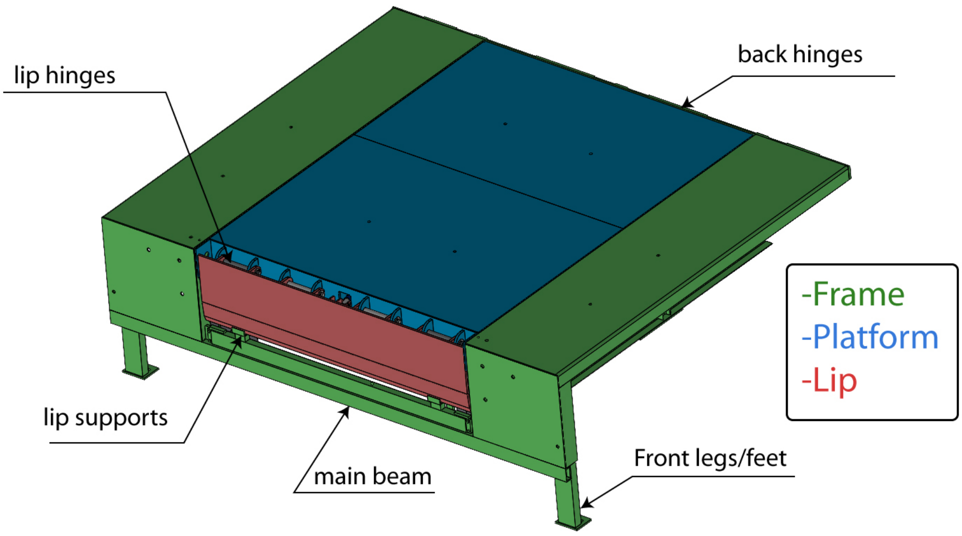

Figure 3.1: *Important components in the 100 kN dock leveler. Green components make up the frame, blue the platform, and red the lip.*

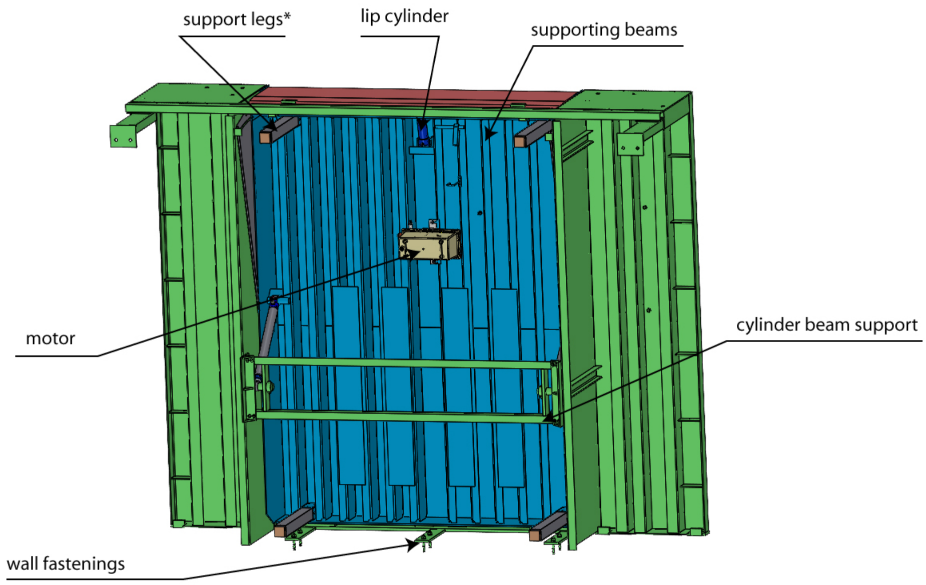

Figure 3.2: *The underside of the 100 kN dock leveler and its components. * Support legs are only used in the assembling process*

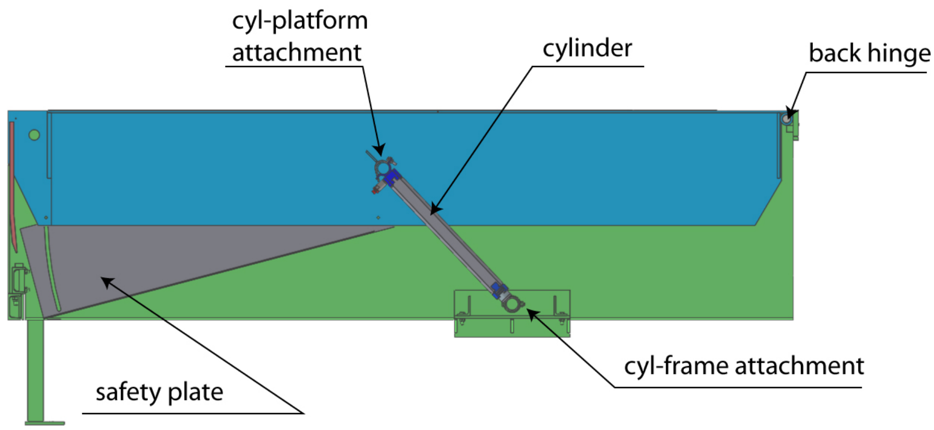

Figure 3.3: *Cross section of the 100 kN dock leveler and its components*

In the pre-study the two models studied are 60 kN and 100 kN. Below is a comparison of the two. They are very similar but mainly have differences in size, amount of beams, and the cylinder attachments. Also, the lip-hinges are slightly different.

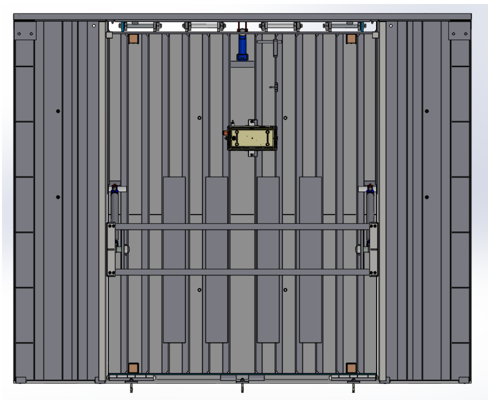

Figure 3.4: *Underside of 100 kN model*

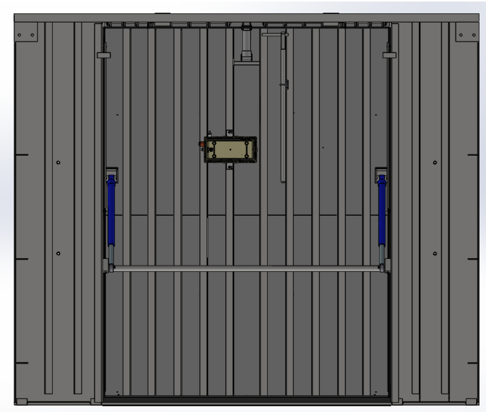

Figure 3.5: *Underside of 60 kN dock model*

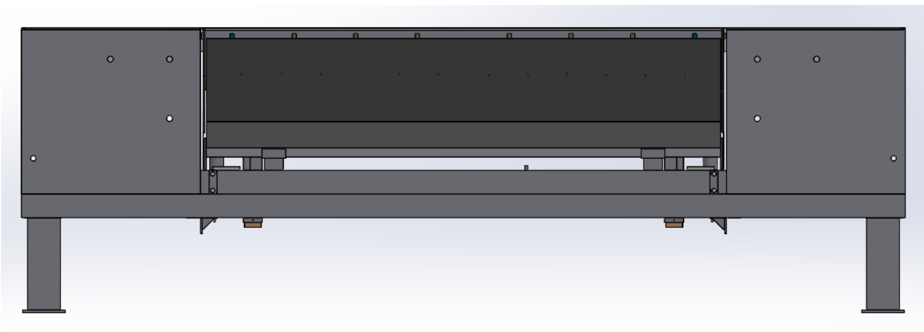

Figure 3.6: *Front of 100 kN dock leveler. Note the two main beams.*

Figure 3.7: *Front of 60 kN dock leveler. Note the single main beam.*

3.2 Product Data Sheet

From the product data sheets for the 60 kN and 100 kN models, a general feel for the product and the different add on attachments were given. Different alternatives were for an example the swing lips, colours, and equipment. Specifications regarding the dimensions and what capacity they have were also given in the data sheet for the 60 kN [6] and the 100 kN respectively [7]. For both models, the decision was made to work with the largest version of each.

3.3 Safety Standard for Dock Levelers

The standard EN 1398 contained all the information necessary regarding the safety requirements for all types of dock-levelers [4]. From our preliminary delimitations, some of the information in the standard is not applicable for the dock leveler studied here. The type of dock leveler used have the following properties which must be considered when reading the standard:

- Size $> 1,25$ m
- Automatically operated
- Swing lip
- Horizontally stored when not in use

Therefore the standard was analyzed with the aforementioned characteristics. In general, the standard calls for the possibility of passage of forklifts and similar industrial trucks over the dock leveler in this size. The forces used when calculating are the following, according to the standard [4]:

Primary loads and forces are as follows

- dead loads;
- rated loads plus dynamic effects.

Supplementary loads and forces are considered to be:

- wind forces;
- braking and starting loads;
- inertia forces;
- impact loads.

Load combinations and the different load cases were listed, with the safety factors for the respective cases, see Table 3.1.

Table 3.1: *Applicable factors and loads at different load combinations [4].*

Applicable factors and loads at different load combinations	**Primary loads**				**Supplementary loads**			
	Dead loads (factor)	**Rated load (dynamic factor)**	**Safety against yield stress (factor for combined loads) ***	**Safety against yield stress (factor for not combined loads) ***	**Inertia forces, factor**	**Out of service wind load (kN/m2)**	**Impact loads (at 1 m)**	**Braking and starting loads (factor) ****
Clause	5.1.2.2.2	5.1.2.2.3	5.1.5.2	5.1.5.2	5.1.2.2.6	5.1.2.2.4	5.1.2.2.7	5.1.2.2.5
Normal operation, leveller in use, or not in use	1	1,4	1,33	1,5	–	–	–	0,3
Cross traffic operation, leveller in stored position	1	1,4	1,33	1,5	–	–	–	0,3
Leveller in stored position, no rated load, wind load can occur	1	–	1,33	1,5	–	1	1	0
Exceptional situation, emergency stop	**1**	**1**	**1**	**1**	**1,4**	–	–	0

* Safety factor against the yield stress is 1,33 when primary and supplementary loads are combined, or 1,5 when not combined loads

** Braking and starting loads are acting in traffic direction

As our size of the dock leveler is $> 1,25$ m, then, according to the standard the rated loads including dynamic effects must be considered as axle loads. The axle load is to be calculated as acting over two rectangular areas at 1 m lateral distance. The contact areas are derived from the wheel load [N] divided by 2 $[N/mm^2]$, and have a ratio of $W : L = 3 : 2$.

The maximum gradient of the platform at its highest and lowest operational positions should not exceed $12,5\%$ (7^o). The resistance to buckling for compressed components by applying safety factor $S = 1,33$.

If the vehicle loading surface is tilted along the longitudinal axis, the dock leveler must have sufficient torsional flexibility to make up for eventual tilting in the lorry. A lateral deflection of minimum 3% of nominal width. Additionally, the dock levelers must adjust to changes in height (the free floating condition) during the loading operation. Permanent deformation of the deck plate supporting sections must be a maximum of 3% of the span.

Crushing and shearing hazards should be designed to be avoided. Rigid side panels should be used to avoid crushing/shearing of feet. The gap between the frame and the lip edge must be a minimum of 25 mm [4].

Automatic safety devices, electrical parts, labels, controls systems, etc were not part of the given scope for this project, and were therefore not analyzed in the standard.

3.4 Installation Manual

There are two main ways the company suggests in their installation manual for installing the dock leveler [8]. One is with a forklift which can withstand a force > 35 kN, with the fork width of 2 m, see Figure 3.8. The other is with lifting equipment, where the hook can withstand at least a 30 kN load, see Figure 3.9. Four lifting eyes are placed on the dock, where either the forks of the forklifts are to be placed, or the chains to the lifting equipment are placed.

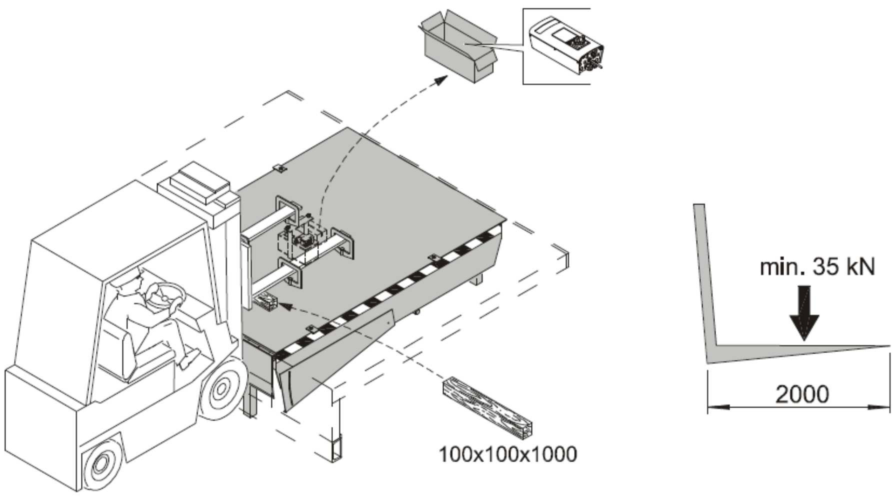

Figure 3.8: *Installation with a forklift, according to the manual [8]*

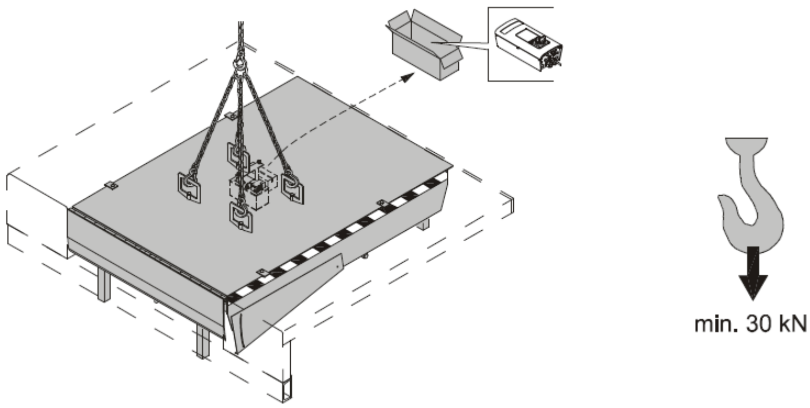

Figure 3.9: *Installation with a lifting device and hook, according to the manual [8]*

3.5 Loading Cases

From the standard researched in section 3.3 and discussions with our supervisors, two main loading cases and an additional one focused only on the frame were identified to be studied further with FEM-analysis.

1. **Cross traffic**
    - Lip stored in vertical position
    - Forklift truck driving on platform
    - Cylinders not in use
2. **Loading**
    - Lip in horizontal position, resting on the lorry bed
    - Forklift truck driving on platform and lip
    - Cylinders not in use
3. **Load is only on frame**
    - Forklift truck drives or stands only on the frame
    - Lip and platform are free of load

Illustrations of the two main cases can be seen in Figures 3.10 and 3.11.

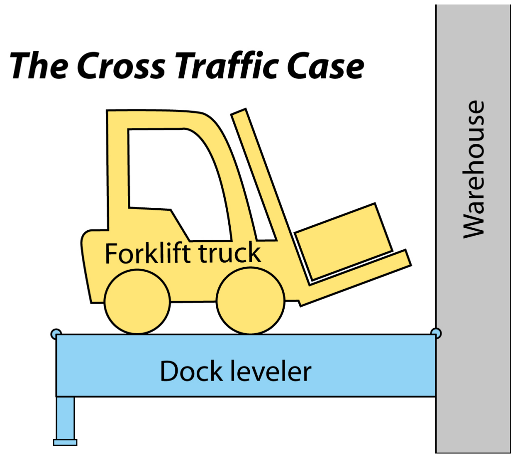

Figure 3.10: *Schematic of the Cross Traffic Case.*

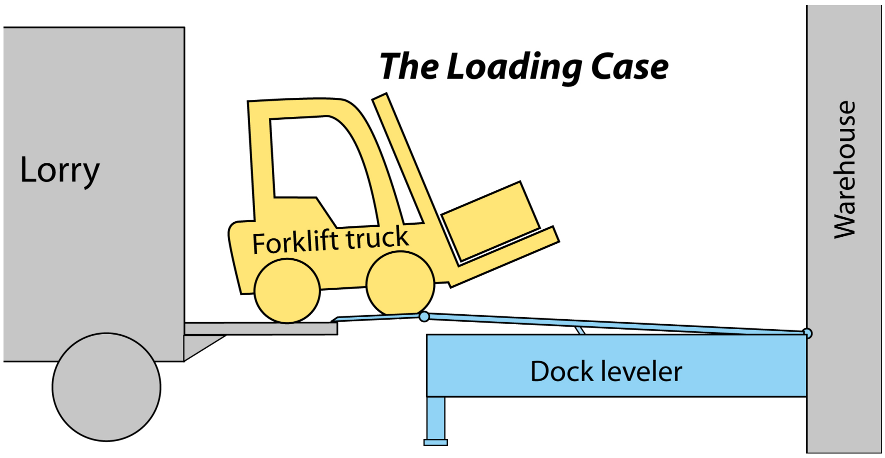

Figure 3.11: *Schematic of the Loading Case.*

3.6 FEM-Analyses of Current Design

Analyses were made on CAD-models of the current dock levelers to get a better understanding of how they were built up, as well as providing a basis of comparison with the later to come new improved design. Another incentive was to become familiar with the software and the boundary conditions for the different load cases.

The analyses were conducted using the three cases described in section 3.5, where the dock leveler is split into two main free bodies: *platform with lip* and *frame*. To make these separate analyses, the relationship between the forces are also described for each case. The 60 kN and 100 kN dock levelers were studied separately but generally speaking the stresses were based in the same areas on the two models. The applied force F was multiplied by the safety factor 1,4 to account for the dynamic factor of the rated load as seen in Table 3.1.

For all analyses the material was set to S235-JR, as the current model mostly consist of this material. The meshing was set to a high fineness with a standard mesh and a small global size and tolerance. The mesh had to be fine enough, while still allowing for the analyses to run efficiently.

3.6.1 Simplifications

After much deliberation and discussion with supervisors and supporters, the decision was made to simplify the loading cases in a couple of ways to be able to run the analyses smoother.

Horizontal platform

In reality, the dock leveler's platform can be angled differently, either going up or down. However, for ease of calculations, it was chosen to only study the case where the platform is in its horizontal mode.

Removal of parts

The dock leveler CAD-models provided by ASSA ABLOY contain over 100 parts, from bolts, nuts to components of the electrical motor. It was decided to remove the parts which will not contribute to the stresses and loads of the different cases. Such parts include small bolts, pins, electrical equipment, and more. The cylinders were also removed in the three cases studied, as they will not bear any load. However, a deeper analysis of the cylinders loading and the corresponding attachments is discussed in section 3.7. Moreover, the removal of the small parts made the meshing process in the FEM-simulations significantly easier. Simulations could also run quicker.

Main load

A way to simplify the main load is by using a uniform load as a rectangle over the whole platform width by the lip hinges, instead of the two truck-wheels. The FEM-analysis then becomes much simpler while still giving us an overview of the stresses and how the certain area is affected. See Figures 3.12 and 3.13.

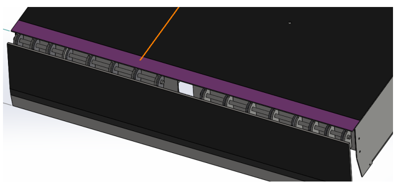

Figure 3.12: *Uniform load*

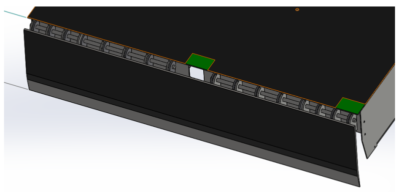

Figure 3.13: *True load*

Back hinges

To use the method of setting up forces with the method described in Figure 3.17 and Figure 3.28, a flat surface was needed to apply the load. Since the hinges between the platform and the frame consisted of several cylindrical components, these needed to be replaced with rectangular extrudes in order to perform the analyses. See Figure 3.14 and 3.15 for comparison between the two cases.

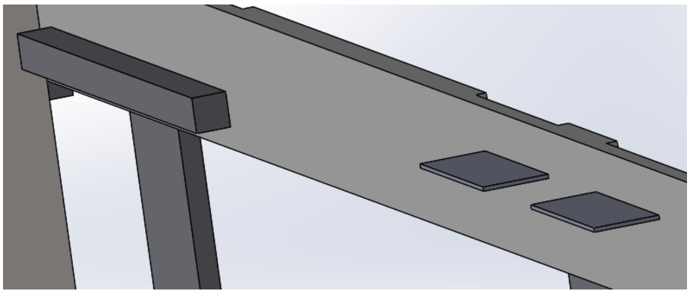

Figure 3.14: *Simplification of back hinges*

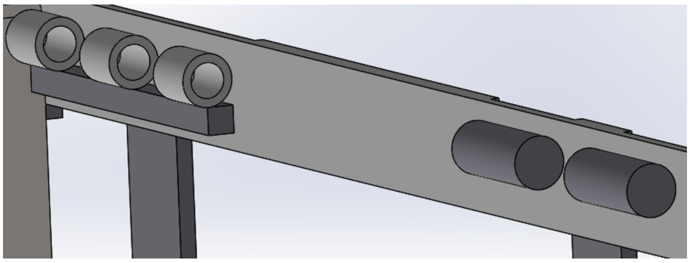

Figure 3.15: *Real back hinges*

Pin connector
An additional simplification was regarding the hinges between the platform and the lip. From several discussions and trial and error with our supervisors, it was decided a pin connection should be used in the analysis. However, this type of connection in Solidworks will not show the stress on the actual pin for the analysis which can be seen in Figure 3.16 in dark blue. Other types of connections proved to be near impossible to work with. Therefore, it is important to consider the pins will experience stresses and deformations in reality.

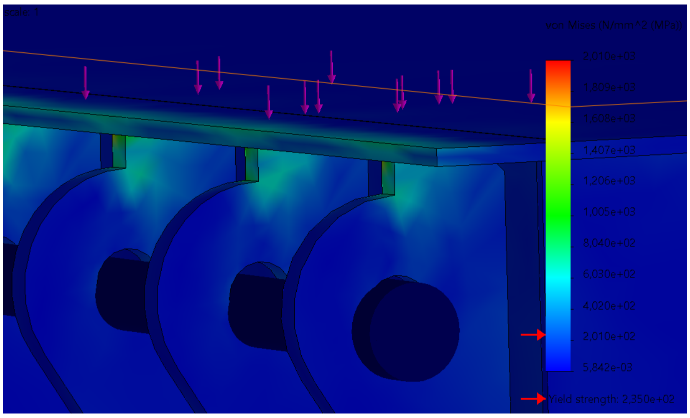

Figure 3.16: *Hinge between lip and platform which is shown in dark blue*

3.6.2 The Loading Case

The analysis started with the platform, where the applied load is. Then, to use the reaction forces from the applied load on the platform to the frame, the following diagram in Figure 3.17 was used to calculate the reaction force R_2 from the hinges, which will be the same on the platform and on the frame. The distances and the mass was evaluated using Solidworks.

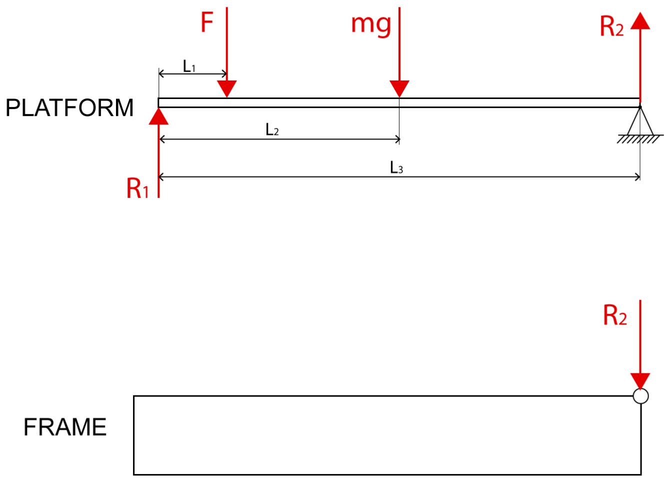

Figure 3.17: *Force diagram over the load case "Loading" on platform and frame*

From Figure 3.17, the following torque equilibrium relationship was derived:

$$\overset{\frown}{R_1}: \quad FL_1 + mgL_2 - R_2L_3 = 0 \tag{3.1}$$

From Equation 3.1, an expression for calculating R_2 is derived, which can later be applied on the frame in the FEM-analysis.

$$R_2 = \frac{FL_1 + mgL_2}{L_3} \tag{3.2}$$

With the data collected for the lengths and forces applied, R_2 could be calculated. In Table 3.2 the forces needed for the analyses are presented. R_1 will not be used for this load case since the lip will rest on the lorry bed and not transfer any forces to the frame through the lip supports as shown in Figure 3.17. R_1 has therefore not been calculated. See Appendix A for calculations.

Table 3.2: *Given and calculated values for forces in the 60 kN and 100 kN dock levelers, in the load case "Loading"*

Loading	**60 kN**	**100 kN**
Force F (including safety factor)	84 kN	140 kN
R2	14,55 kN	26,437 kN

Platform

The following boundary conditions and forces were added to the platform. These are also shown in Figure 3.18.

Table 3.3: *Boundary conditions and force application for platform in load case "Loading"*

Boundary condition/Force	**Placement**
Fixed support	Back edge of platform
Roller/Slider support	Edge on underside of lip
Force F	Right above hinges between lip and platform

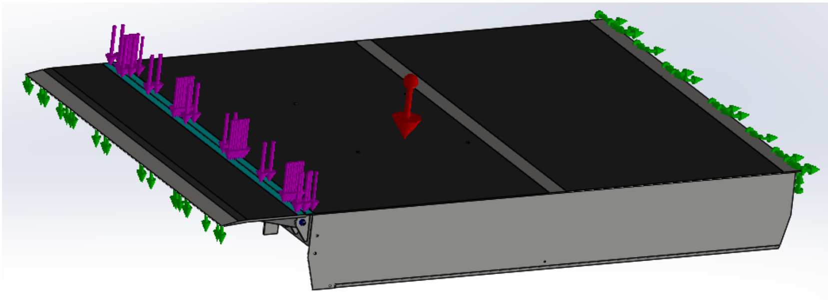

Figure 3.18: *Boundary conditions and force application on platform in load case "Loading"*

The stress-distribution in MPa can be seen in Figures 3.19-3.22. Since the load is concentrated over the hinges the stress distribution was also most noticeable in that area. You can detect very high stresses on the underside of the lip since the contact surface with the lorry bed essentially was a very thin rectangle.

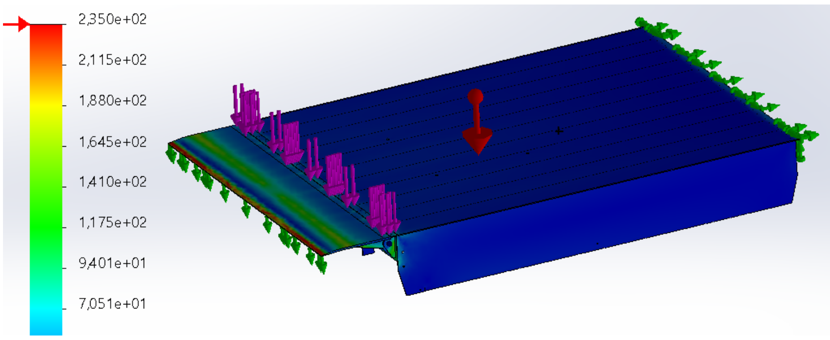

Figure 3.19: *Stress distribution for 60 kN platform*

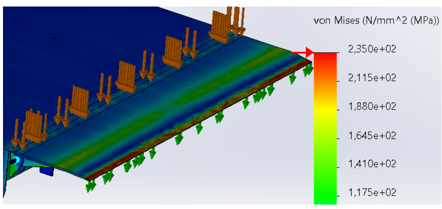

Figure 3.20: *Stress distribution on lip 60 kN*

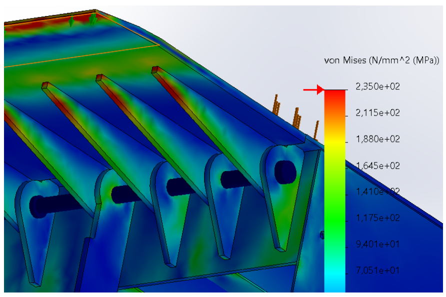

Figure 3.21: *Close up of stress distribution on underside of lip 60 kN*

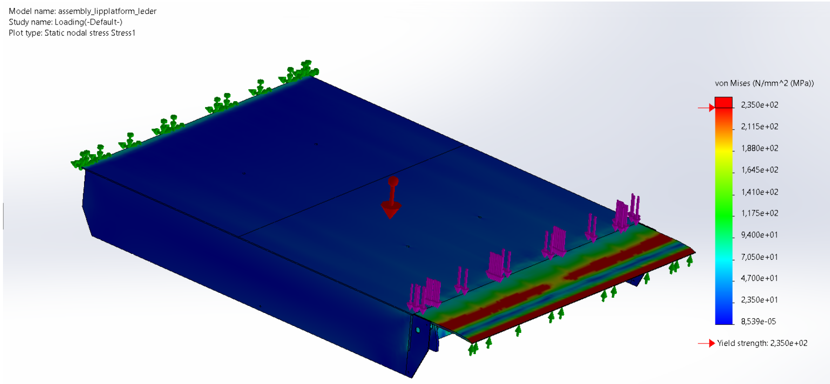

Figure 3.22: *Stress distribution for 100 kN platform*

Frame

The applied force from the forklift truck on the platform is transferred to the frame by the back hinges. The following boundary conditions and forces were applied to the frame which also can be seen in Figure 3.23.

Table 3.4: *Boundary conditions and force application for frame in load case "Loading"*

Boundary condition/Force	Placement
Fixed support	Feet, cut outs and holes on back beam
Roller/Slider support	Top surface of the three middle extrudes on back beam (hinges)
Force $R2$	Top surface of the outermost extrudes on back beam (hinges)

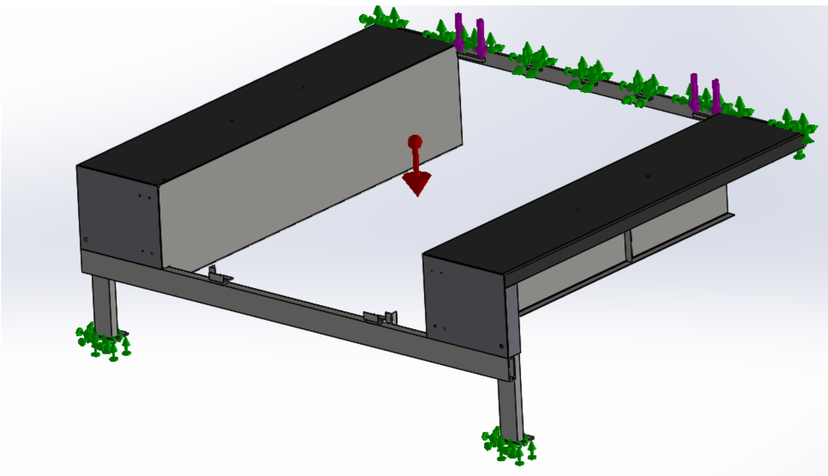

Figure 3.23: *Boundary conditions and force application on frame in load case "Loading"*

Since the applied force is relatively small, the stresses becomes barely noticeable. The small amount of stresses that appear are concentrated on the back hinges and the holes of the back beam. See Figures 3.24-3.27

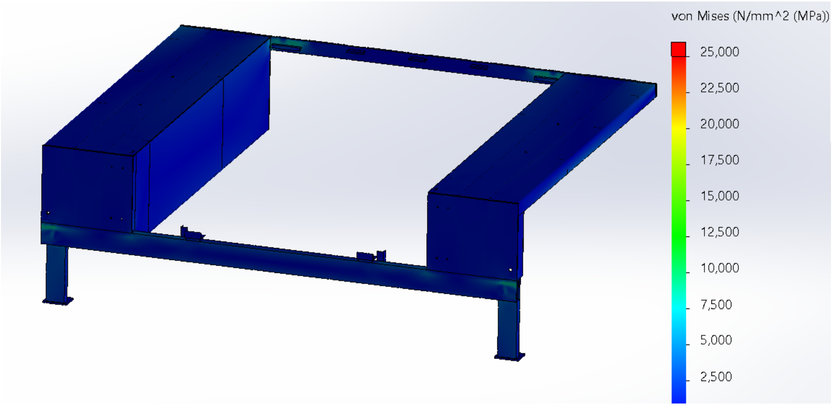

Figure 3.24: *Stress distribution on frame 60 kN*

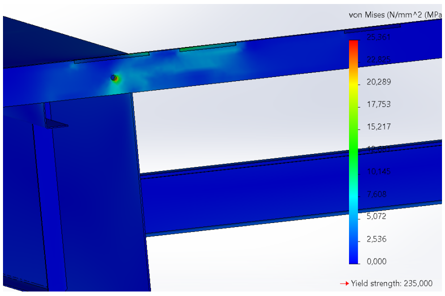

Figure 3.25: *Stress distribution on back beam of frame 60 kN*

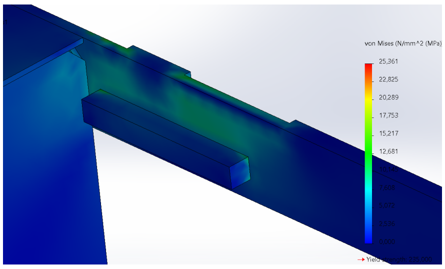

Figure 3.26: *Stress distribution on back hinges of frame 60 kN*

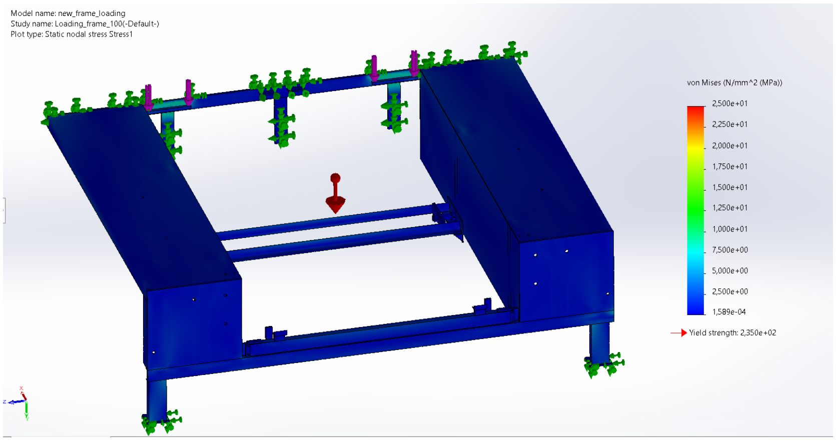

Figure 3.27: *Stress distribution on 100 kN frame in the loading case*

3.6.3 The Cross Traffic Case

Similarly to section 3.6.2, a diagram over the forces had to be drawn up. From the conditions described for Cross Traffic in section 3.5, the diagram can be seen below in Figure 3.28.

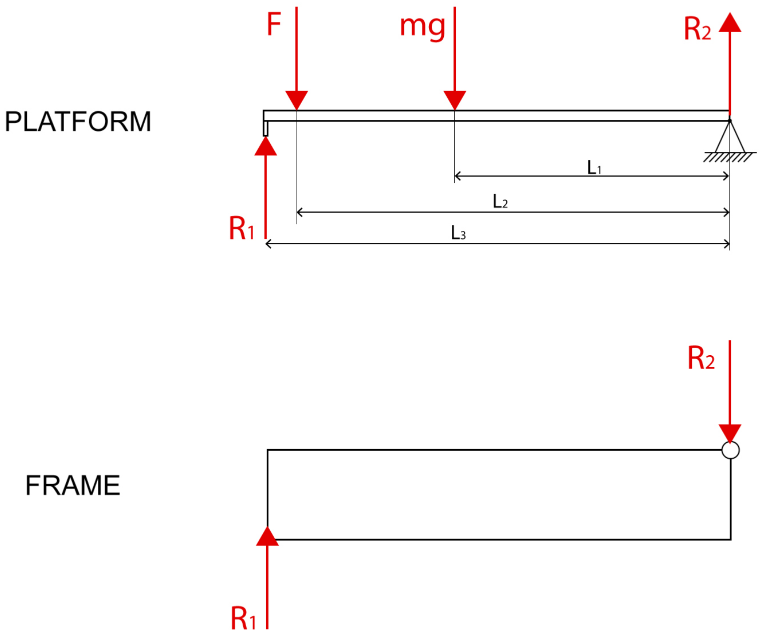

Figure 3.28: *Force diagram over the load case "Cross Traffic" on platform and frame*

Here, R_1 and R_2 must be calculated from the platform, to later be applied for the analysis on the frame. From Figure 3.28, the two following force and torque equilibrium equations can be derived:

$$\uparrow: \qquad R_1 + R_2 - F - mg = 0 \tag{3.3}$$

$$\overset{\frown}{R_2}: \qquad R_1 L_3 - F L_2 - mg L_1 = 0 \tag{3.4}$$

From Equations 3.3 and 3.4 expressions for R_1 and R_2 are derived, and used to calculate the force necessary to apply on the frame.

$$R_1 = \frac{F L_2 + mg L_1}{L_3} \tag{3.5}$$

$$R_2 = F + mg - R_1 \tag{3.6}$$

The calculated forces are presented below in Table 3.5. For the Cross Traffic load case $R1$ is needed as the lip will rest on the lip support and not the lorry bed as shown in Figure 3.28. See Appendix A for calculations.

Table 3.5: *Given and calculated values for forces in the 60 kN and 100 kN dock levelers, in the load case "Cross Traffic"*

Cross Traffic	**60 kN**	**100 kN**
Force F (including safety factor)	84 kN	140 kN
R1	85,85 kN	115,78 kN
R2	5,15 kN	35,26 kN

Platform
The following boundary conditions and forces were applied to the platform which can also be seen in Figure 3.29.

Table 3.6: *Boundary conditions and force application for platform in load case "Cross Traffic"*

Boundary condition/Force	**Placement**
Fixed support	Back edge of platform
Roller/Slider support	Lip edge
Force F	Top front edge of platform

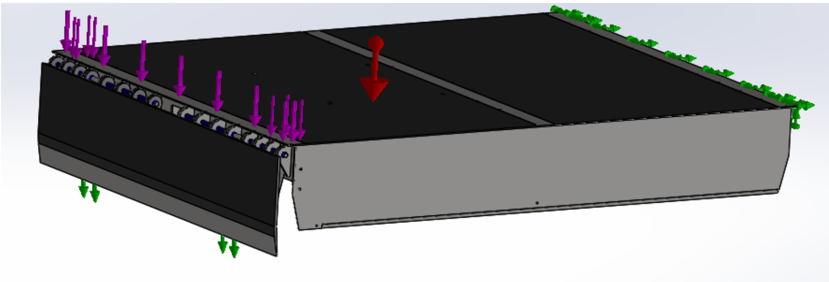

Figure 3.29: *Boundary conditions and force application for platform in load case "Cross Traffic"*

After running the analyses, there were high stresses located on the lip in the area where it rests on the lip supports.

There were also some smaller stresses on the back edge of the platform where it was fixated. See Figures 3.30-3.34 for the stress distribution on the platform.

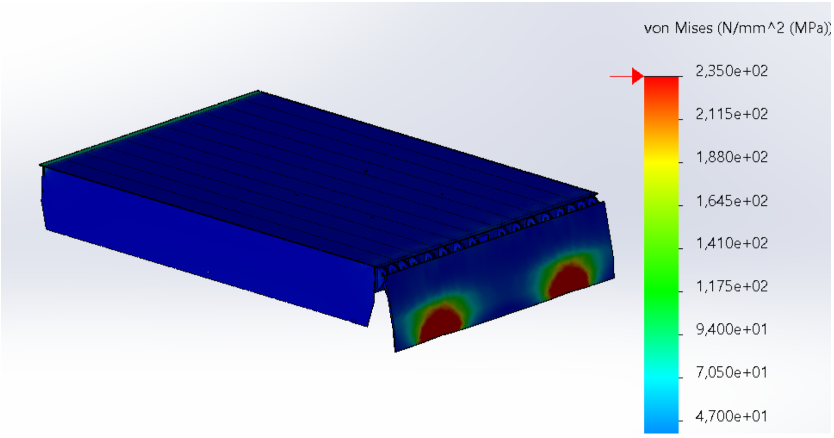

Figure 3.30: *Stress distribution on platform 60 kN*

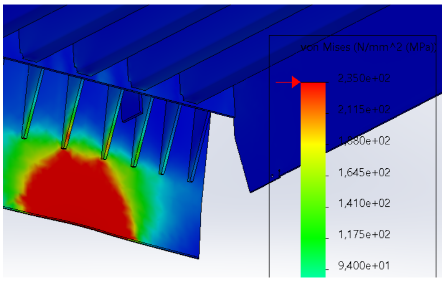

Figure 3.31: *Stress distribution on underside of lip 60 kN*

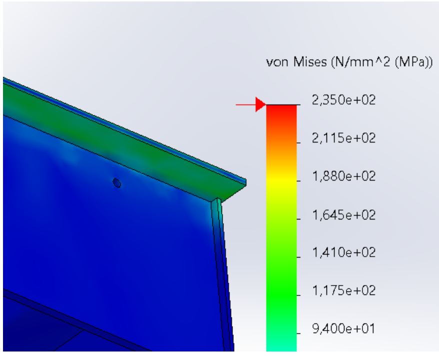

Figure 3.32: *Stress distribution on backside of platform 60 kN*

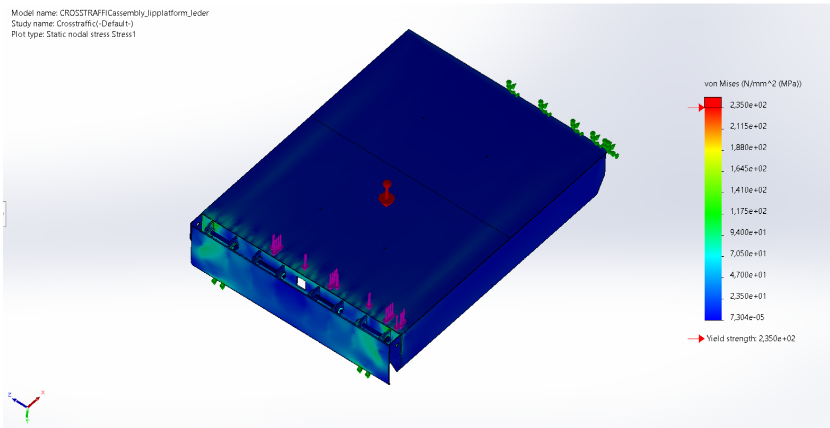

Figure 3.33: *Stress distribution on 100 kN platform*

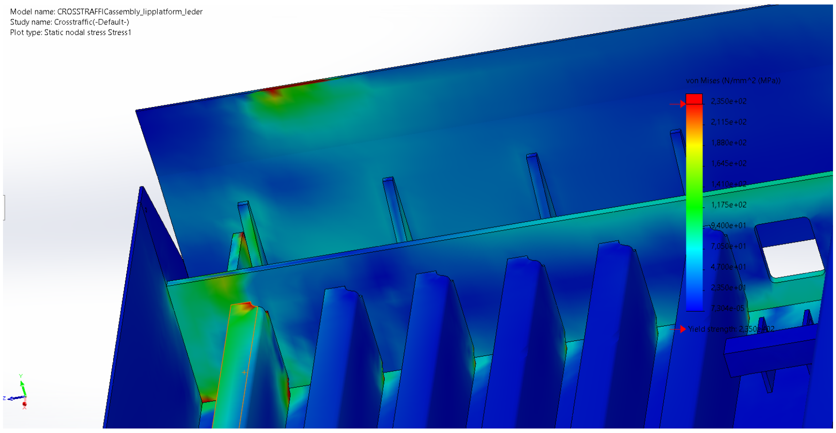

Figure 3.34: *Close-up of stress distribution on 100 kN platform*

Frame

When the forklift truck drives on the platform, forces are transferred to the frame both through the back hinges and through the lip down to the lip supports, which are mounted on the frame. The following boundary conditions in Table 3.7 and forces were applied to the frame which can also be seen in Figure 3.35.

Table 3.7: *Boundary conditions and force application for frame in load case "Cross Traffic"*

Boundary condition/Force	**Placement**
Fixed support	Feet, cut outs and holes on back beam
Roller/Slider support	Top surface of the three middle extrudes on back beam (hinges)
Force $R1$	On lip supports
Force $R2$	Top surface of the outermost extrudes on back beam (hinges)

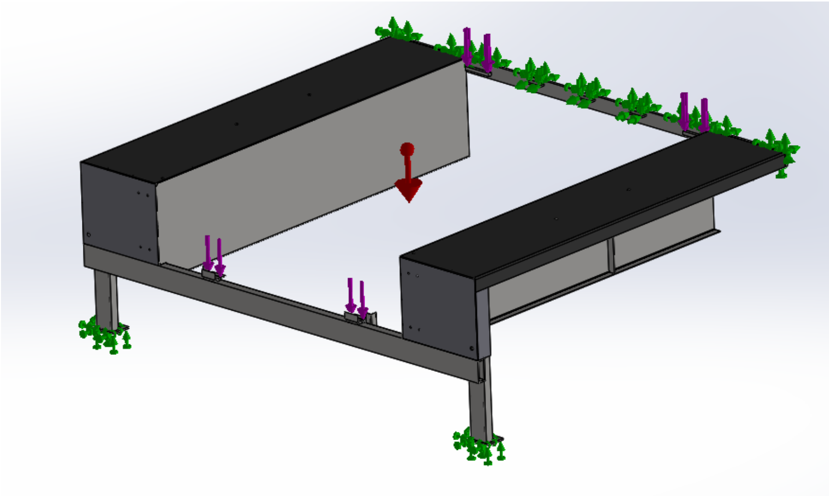

Figure 3.35: *Boundary conditions and force application for frame in load case "Cross Traffic". The green arrows represent a fixed support. The purple arrows display the added forces R1 and R2. The red arrow is the mass-gravity.*

The analysis showed large stresses located on the front beam and on the lip supports. Since the applied force on the lip supports was quite large the results are as expected. Some smaller stress concentrations also showed up around the holes on the back beam. See Figure 3.36-3.39 for the stress distribution throughout the frame.

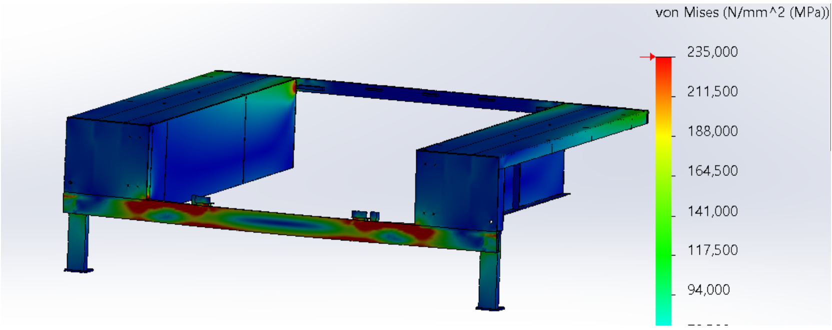

Figure 3.36: *Stress distribution on frame 60 kN*

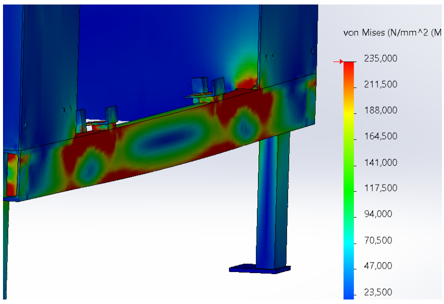

Figure 3.37: *Stress distribution on front beam of frame 60 kN*

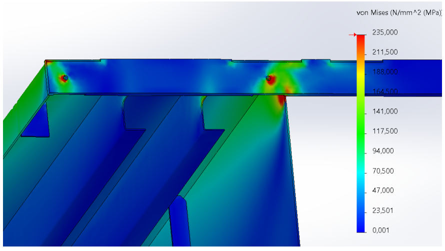

Figure 3.38: *Stress distribution on back beam of frame 60 kN*

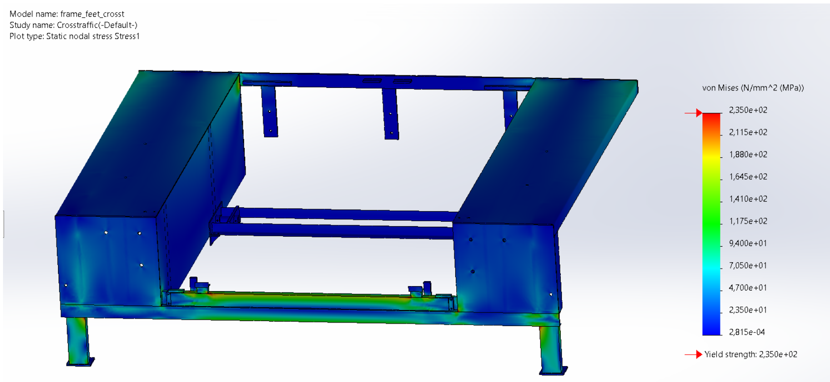

Figure 3.39: *Stress distribution on 100 kN frame*

3.6.4 The Load Only on Frame Case

Unlike the previous two load cases, no equation system had to be set up for this load case since the entire load is placed on the frame directly. The results found from the study should not be too heavily considered for the future concept development since the real life load case will divide the forces applied between the platform and the frame. This load case is only tested to get a better understanding of where certain stresses appear. Table 3.8 shows what boundary condition were set up and Figure 3.40 gives a visual representation.

Table 3.8: *Boundary conditions and force application for frame in load case "Load only on frame"*

Boundary condition/Force	Placement
Fixed support	Feet, cut outs and holes on back beam
Roller/Slider support	Top surface of the three middle extrudes on back beam (hinges)
Force F	On two rectangular surfaces on one side of the frame

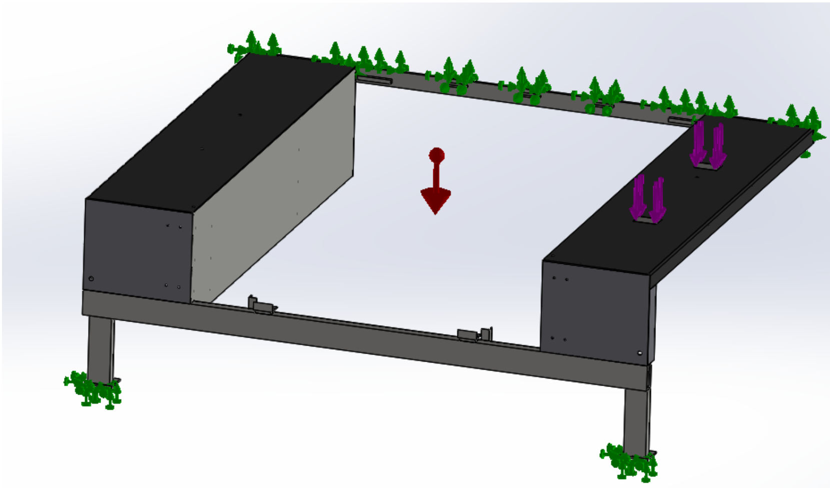

Figure 3.40: *Boundary conditions and force application on frame in load case "Load only on frame"*

After running an analysis the following results were found, see Figures 3.41 and 3.42. As expected, there are high stresses located right where the force was applied. Additionally, the stress has spread out on the supporting beams underneath the frame.

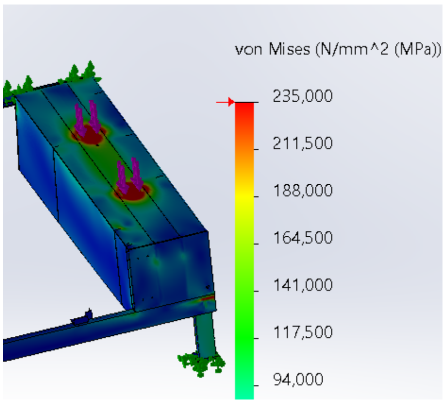

Figure 3.41: *Stress distribution on top side of frame 60 kN*

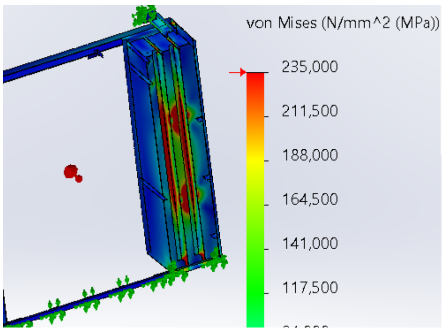

Figure 3.42: *Stress distribution on under side of frame 60 kN*

3.7 Cylinder Study

An important feature of the dock leveler are the two main cylinders which move the platform up and down. From discussing with supervisors and the workshop on cylinders described below in section 3.7.2, the significance became even more apparent. Therefore, a further explanation about the cylinder mechanism, functions, and calculations on the attachments is crucial. However, the inner workings of hydraulic cylinders are outside the scope of this project.

3.7.1 Cylinder Components

A schematic overview of the main parts of a hydraulic cylinder can be viewed in Figure 3.43. The piston rod can move back and forth, creating the movement required for the platform to move up or down. The front ear is attached to an axis on the dock leveler's frame. The back ear is attached on the axis on the dock leveler's platform.

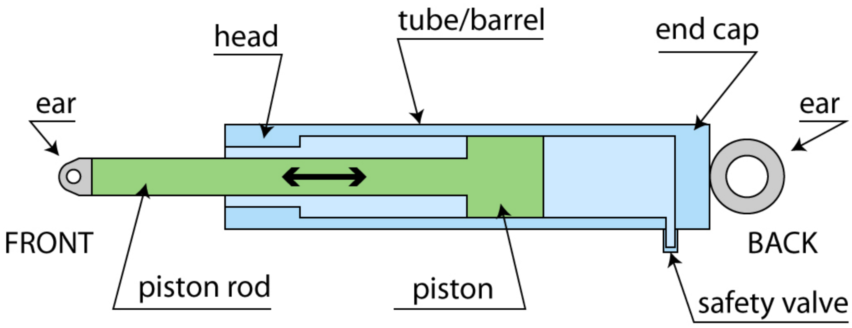

Figure 3.43: *Main parts of a hydraulic cylinder*

Cylinders are linear actuators, only taking up force in the axial direction. For this dock leveler, single-acting cylinders are used. Single acting cylinders can only push a load, not pull. To push the piston rod out, a high pressure fluid is pumped into the end cap chamber. An external force is necessary to return the cylinder to its original retracted state [9].

3.7.2 Cylinder Workshop

A workshop regarding hydraulic cylinders at ASSA ABLOY was held, where the aim was to study cylinders which had been used in actual application, but had some damages. An expert in hydraulic cylinders was present and provided deep insight into the subject. In the workshop, cylinders were cut into two and broken down to further study problem areas. Through the workshop, a deeper understanding of cylinders and how they operate was obtained. The most important lesson from the workshop was how significant the problems were with aligning the parts (ears welded on the cylinder for an example) in production and how uncentered they could be.

These problems causes *radial forces* which should be avoided at all cost, as it leads to further stresses and leakage. As mentioned in section 3.7.1, a cylinder should only work in an axial direction, never in a radial. Consequently, a future cylinder attachment and ear should be designed to remove the possibility of radial forces to occur.

3.7.3 Cylinder Movement Study

According to the product data sheet the platform with lip has a specified vertical working range. For the 100 kN variant the working range above dock is $A = 410$ mm and below dock $B = 310$ mm. The range of the cylinder angle is important for how the forces will be applied and therefore how the stresses will distribute on the attachments. Therefore, it is essential to study the working range of the angles. As the model received from the company does not come with a working cylinder mechanism to move the platform, the study was done with trigonometry. With the help of trigonometry and lengths measured in the CAD-model, the angles could be calculated with Matlab, see Appendix B. The trigonometric relationships and lengths are pictured below in a graph environment, allowing for easier visualisation. The calculations were done for the extreme cases, where the platform is in its highest position A in Figure 3.44, and its lowest position B in Figure 3.45. The angle of interest is the cylinder angle α.

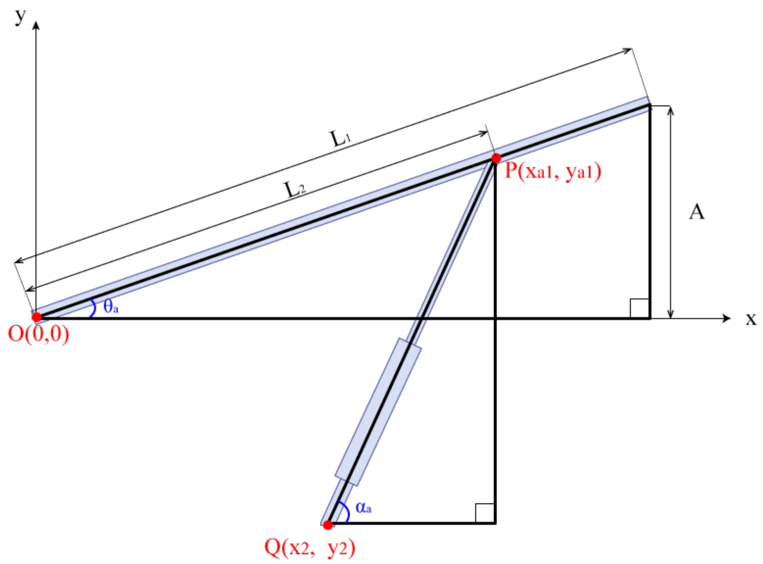

Figure 3.44: *Schematic of angles in position A. The platform is in its highest position. Point O is the back hinge of the platform, where it attaches to the frame. Point P is where the cylinder is attached to the frame. Point Q is the attachment point between cylinder and platform. Note: The schematic is not in proper scale and is exaggerated for visibility. α is cylinder angle. θ is the platform angle.*

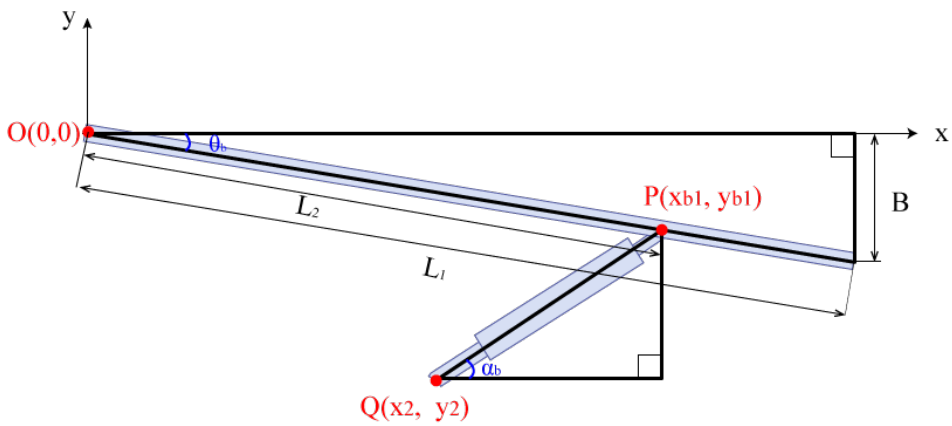

Figure 3.45: *Schematic of angles in position B. The platform is in its lowest position.*

Values for α are presented in equations 3.7 and 3.8 below.

$$\alpha_b \leq \alpha \leq \alpha_a \tag{3.7}$$

$$39,9^\circ \leq \alpha \leq 54,4^\circ \tag{3.8}$$

3.7.4 Cylinder Forces Scenarios

Besides the two main cases and the additional frame case, a fourth scenario is the "cylinder case". From talking to supervisors with insight into how the dock levelers work, the following information was gathered. Normally, in regular usage, the cylinders will only be used to move the platform up and down, *never* taking up load in cross traffic or loading scenarios. But if for some reason in the loading case, the lorry vehicle drives away too early, the cylinders must suddenly take the load where the lorry bed supported before. This could cause the cylinders to fall downwards and experience such a high pressure that the safety valve will start and the oil will start spilling out.

This case could cause extreme forces being applied to the cylinder-frame attachment, causing it severe damage, according to some physical testing made by ASSA ABLOY. As this case deals with rapidly moving parts (i.e. the platform falling downwards) it is not possible to calculate accurately using non time dependent methods. One idea from our supervisors was to use Impulse with a time and velocity. However, as both the change in time and velocity is unknown and difficult to estimate, the idea was disregarded as it would require real-life studies to accurately describe.

Another idea could be using the maximum pressure inside of the cylinder when the safety valve sets in which is not completely established, as stated by our supervisors. However, it seemed to be around the range of 175 bar. The force in the cylinder could then be expressed as Equation 3.9, where the area A corresponds to the inner cross-section of the cylinder. Here the inner radius is 22, 5 mm.

$$R_{cyl} = pA = p\pi r^2 = 27,8kN \tag{3.9}$$

However, this calculation does not take the movements or the angles into account. And with advice from supervisors on how to proceed, with the set time constraint of the project, it was decided to only study the "regular use case". There, the cylinders move the platform to the correct position and the decision was made to make calculations statically. Whilst not accurate to the extreme scenarios, it will at least provide a basis for where the stress concentrated areas on the cylinder attachment can be identified, as well as to study how the angle affects the cylinder force. A schematic of the forces of interest is presented below. Case A can be seen in Figure 3.46 and case B in Figure 3.47.

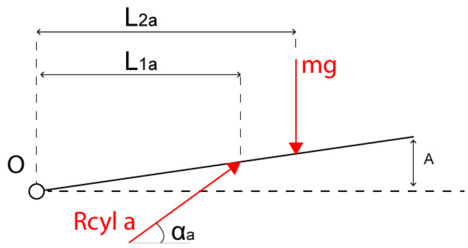

Figure 3.46: *Case A*

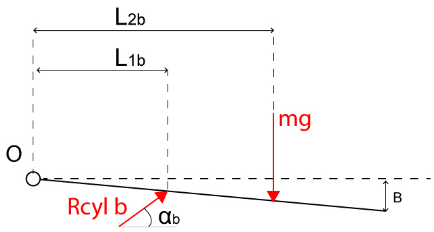

Figure 3.47: *Case B*

Note how the magnitude of the force is not of much interest, what is studied is the places of high stress on the cylinder attachments, and how the angle affects magnitude and stresses. The following torque-equation around the point O represents both case A and B in equation 3.10.

$$\overset{\frown}{O}: \quad R_{cyl} sin\alpha L_1 - mgL_2 = 0 \tag{3.10}$$

$$\Rightarrow \quad R_{cyl} = \frac{mgL_2}{sin\alpha L_1} \tag{3.11}$$

Plugging in angles for case A and B from Equation 3.8 as well as the mass and the lengths for each case, the forces were calculated using Matlab, see Appendix B.

- $R_{cylA} = 13kN$
- $R_{cylB} = 16kN$

When solving for R_{cyl} the sinus-factor is in the denominator. To minimize the force R_{cyl}, the sinus-factor should be maximized. With the angle span calculated in Equation 3.8, the largest angle will give the smallest force. Therefore, a vital conclusion can be drawn and used for concept development later: *larger angles will result in smaller forces.*

FEM-simulations on the cylinder-frame attachment were done using the calculated angles and forces. To simulate it realistically, the axis/pin was removed and a bearing load in the calculated angle represented the force instead on the inside of the cylindrical part of the attachment, see Figure 3.48.

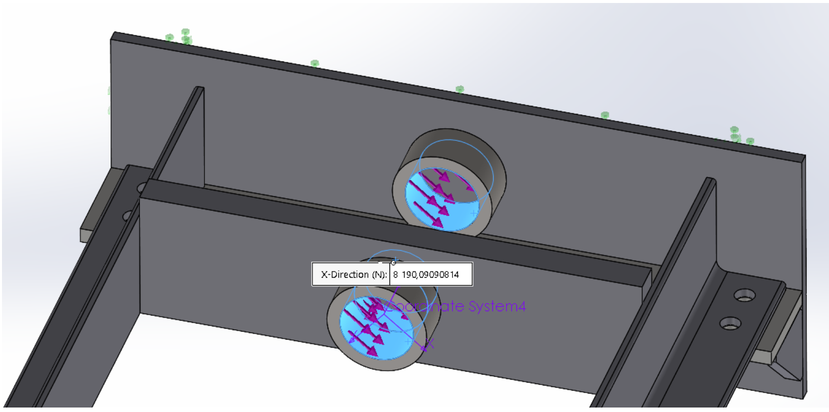

Figure 3.48: *FEM set-up for the angle and force B with a bearing load.*

FEM-simulations with the calculated angle and force for case B were done and had the following results. Stresses seemed most prevalent where the L-shaped beam meets the flat surface and triangular plate, see Figures 3.49 and 3.50.

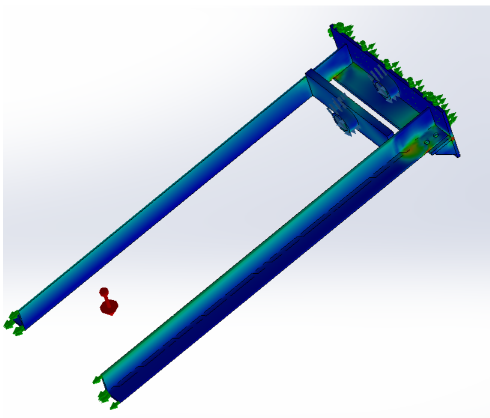

Figure 3.49: *Stresses in position B*

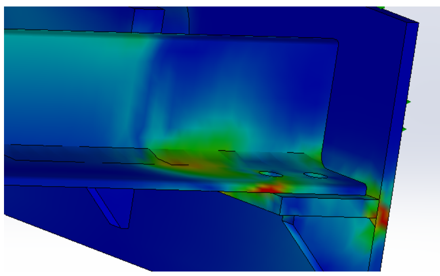

Figure 3.50: *Close-up of stresses in position B*

Similarly, the stress was simulated for position A, with its angle and force. The results show less stress compared to B, but roughly concentrated in the same areas, see Figure 3.51 below.

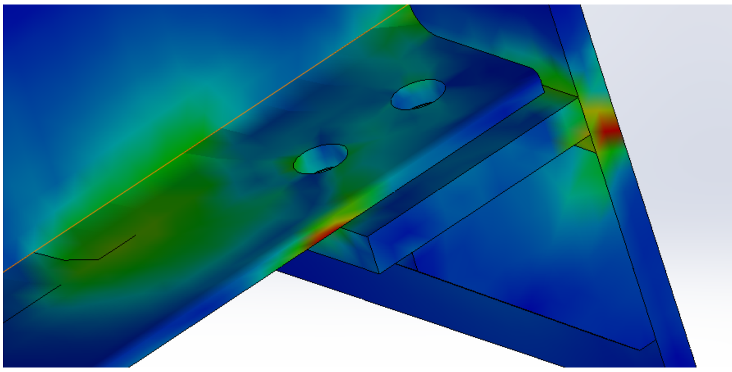

Figure 3.51: *Stresses for position A*

4 Product Specifications

Based on all the research and preliminary analyses of the current dock-leveler, a list of product specification could be made. They were divided into specifications which the design *must fulfill* and *desirable* specifications.

Musts

- Dimensions: nominal length: 3000 mm, normal width AD: 3750 mm och leveler width 2200 mm
- Material: S235 (Structural Steel 235) or S355.
- Minimum torsional flexibility of 3 % of the platform width measured at the front edge of the extended lip,
- Maximum gradient of the platform in its highest and lowest operational position does not exceed 12,5 % (approximately 7°)
- Cylinder fastenings shall withstand forces with a safety factor of 1
- A vertical or horizontal minimum gap of at least 25 mm between the lip edge and the frame components shall be maintained when in supported position.
- The permanent vertical deformation of the sheets shall be max. 3 % of the span a where a is the distance between two supporting beams.

Desirable

- Minimize cost of manufacturing
- Minimize use of welding
- Minimize material usage
- Minimize number of components
- Ease of construction/manufacturing
- Ease of installation
- Base design on standard materials and dimensions
- Minimize mass
- Maximal mass shall not exceed 3500 kg
- Avoid slipping hazards

5 Concept Generation

With the product specifications clarified and with a goal in mind, the concept development process is the next step. The first step is Concept Generation which will be covered in this chapter. Here, the different parts of the dock leveler will be broken down to have individual concepts generated for each area, see section 5.3. With a combination of the individual concepts, the idea is to develop a final product proposal.

However, care must be taken so the different parts does not interfere with each other, and can work together smoothly.

5.1 The Concept Generation Method

The first step in the Concept Development phase is the Concept Generation activity. Here, the aim is to produce several concepts from the set product specifications, hopefully coming up with solutions which can be further explored, according to Ulrich and Eppinger. The described activity in relationship to the other parts of the concept development process can be viewed in Figure 5.1. [5, pp. 117-118]

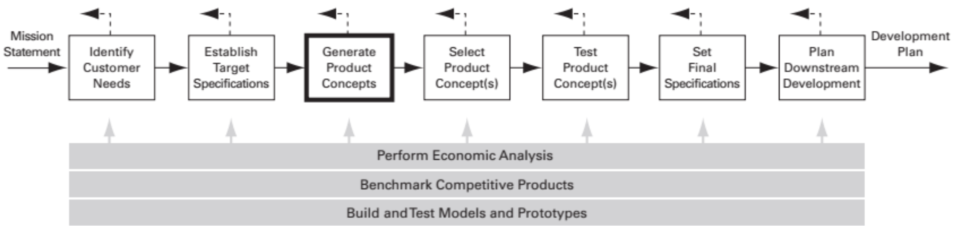

Figure 5.1: *The Concept Generation activity in relation to the other steps in the concept development process [5, p. 118]*

Ulrich and Eppinger proposes a five-step method which breaks down complex problems into simpler sub-problems [5, pp. 117-119].

1. *Clarify the problem* — Understanding and decomposing the problem. Focus on critical subproblems.
2. *Search Externally* — Gather information from experts, related products, literature and more.
3. *Search Internally* — Use methods to retrieve knowledge from the group and individuals
4. *Explore Systematically* — combination tables , classification trees to organize the ideas.

5. *Reflect on the solutions and the process* — Gain constructive feedback and improvements for future iterations.

5.2 Concept Generation Applied

In this section the concept generation method will be applied to our project and the adaptions made to fit the method to the project will be described.

1. Clarify the Problem

Here, the product specification list and our main goals in combination with the aforementioned research, the problems are clarified. All the information gathered in section 3 was useful in this step, especially to identify the areas of interest and what to focus on.

2. Search Externally

Searching for competitors solutions and how dock levelers worked in general was used in the external search in this project. Much inspiration was taken from other models of dock levelers offered by ASSA ABLOY which are currently being developed.

3. Search Internally

For the internal searching, brainstorming and individual work was done, in combination with discussion with supervisors to come up with possible solutions. Different types of methods were used in communicating ideas: simple sketches, paper mock-ups, and CAD-drawings were used to explore ideas in the different parts of the product.

4. Explore Systematically

To achieve the best possible final solution considering the time limitations, the different concepts generated were explored systematically by combining different ideas and improving them further with the considerations of stresses (evaluated with FEM), as well as material usage, manufacturability, etc.

5. Reflection

The last step described by Ulrich and Eppinger was executed parallel to the other activities in this phase. Reflections and discussion on how to further improve and change concepts was continuously done with the additional help of supervisors.

5.3 Developed Concepts

In this section all the concepts developed will be presented. The concepts will be grouped after the area they preside on in the dock leveler. The following areas of the dock leveler are presented below:

- Supporting beams on the underside of the platform
- Hinges

- Main supporting beam
- Cylinder mechanism and cylinder attachments
- Frame's construction
- Feet and legs
- Lip support

5.3.1 Supporting Beams on the Underside of the Platform

The current design for the supporting beams can be seen in Figure 5.2. There are 12 L-shaped beams incrementally welded on the tear plate and four rectangular plates welded on the beams.

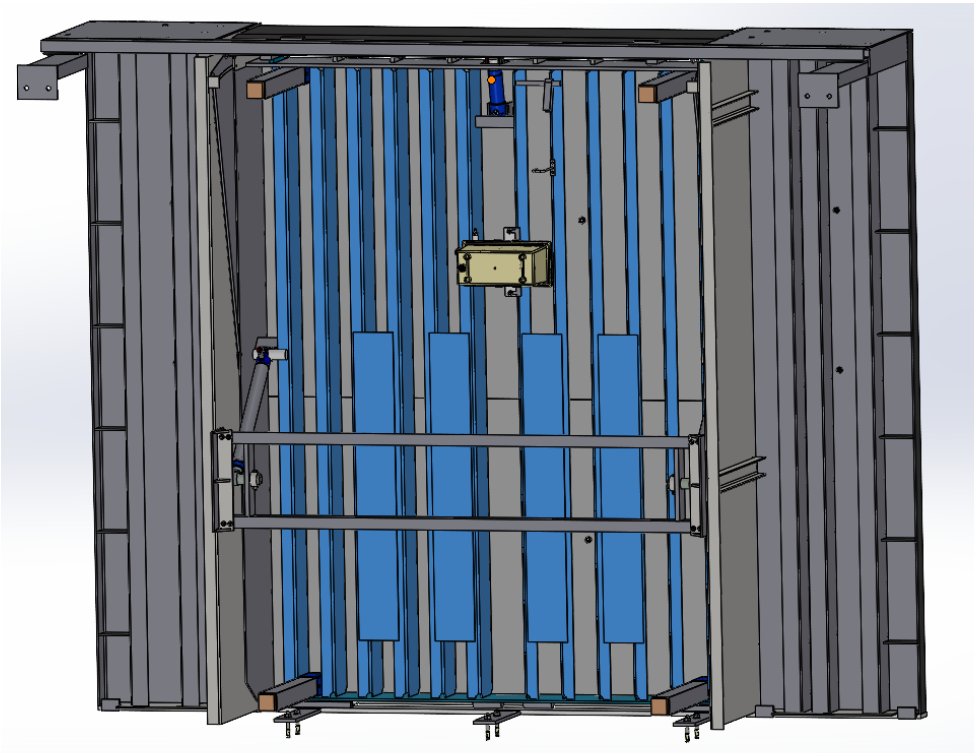

Figure 5.2: *Underside of the platform. The beams and plates are marked in blue in the figure.*

Below is a list of concepts for this section of the dock leveler.

Idea A: Folded sheet metal

Making the rectangular plate and two L-shape beam into one part would decrease the number of components, as well as decreasing the amount of weld needed. The concept is pictured below and is a sheet metal part with two bends, see Figure 5.3.

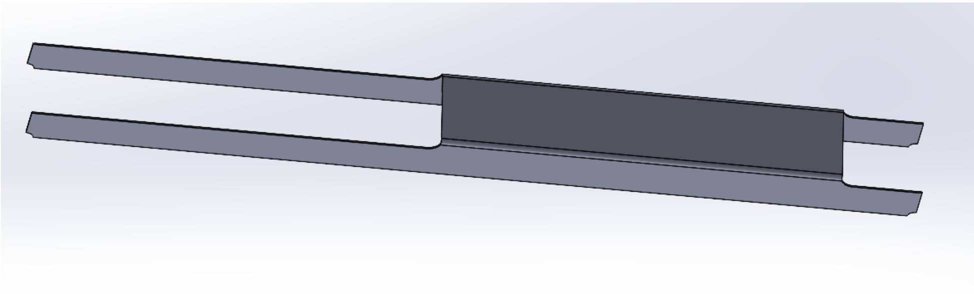

Figure 5.3: *Idea A: Sheet metal part with two bends*

Idea B: Sheet metal with L-shaped cross section
A support which is easier to produce and a bit sturdier than the original meaning less supports are needed, see Figure 5.4.

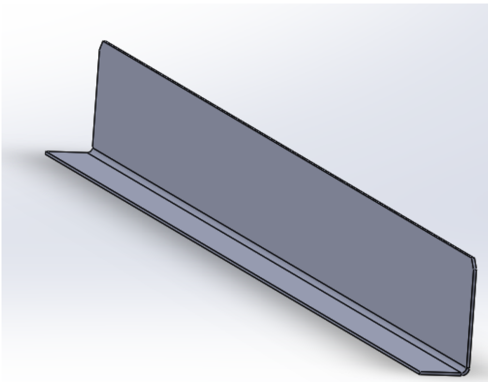

Figure 5.4: *Idea B: Sheet metal with L-shaped cross section*

Idea C: Sheet metal with U-shaped cross section
Idea C uses slightly more material but is even more sturdy. See Figure 5.5.

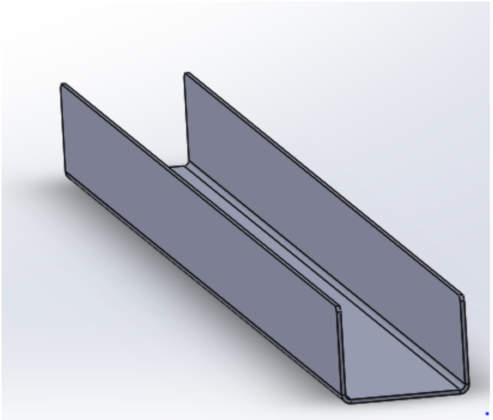

Figure 5.5: *Idea C: Sheet metal with U-shaped cross section*

5.3.2 Hinges

An issue when assembling the current dock leveler is to get the pins for the hinges in place both in the back between the platform and the house and in front between the lip and the platform. The reason for the issue is the difficulty in aligning the round holes on the hinge components so the pin can easily be fitted inside. The issue is more significant on the hinges between the lip and the platform. This is due to the relatively thin ears which will easily misshape when they are welded to the platform and the lip making it troublesome to align the holes correctly. See Figures 5.6 and 5.7 for the current hinges.

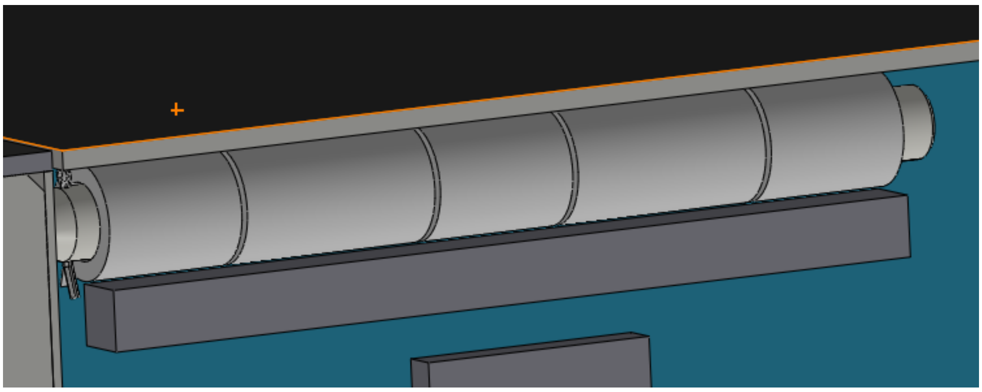

Figure 5.6: *Hinges in the back of the platform constructed with pins and pipes*

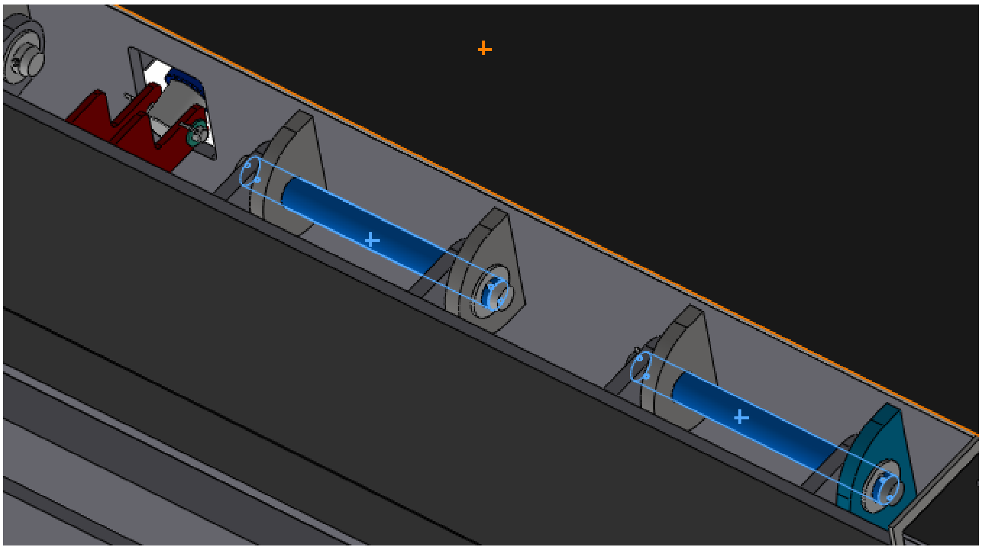

Figure 5.7: *Hinges between lip and platform constructed with pins and ears*

To solve the issue without having to choose a pin with much smaller diameter or make larger holes which would increase point stress, the following concept was created.

Idea A: Slot hole
When having a slot hole as ear-holes on both the platform and the lip, installment will become easier since there will now be a few more millimeters of space in the vertical direction, see Figure 5.8 for cross section between the lip ears and platform ears during installment. When the dock leveler is later in use, the lip will adjust vertically downwards due to gravity and the cross section between the lip ears and platform ears will be round again with the same dimensions as before. See Figures 5.9 and 5.10 for cross section during normal operation. Because movement of the lip is limited to 90 degrees, the slot shaped hole will not effect the functionality of the hinge.

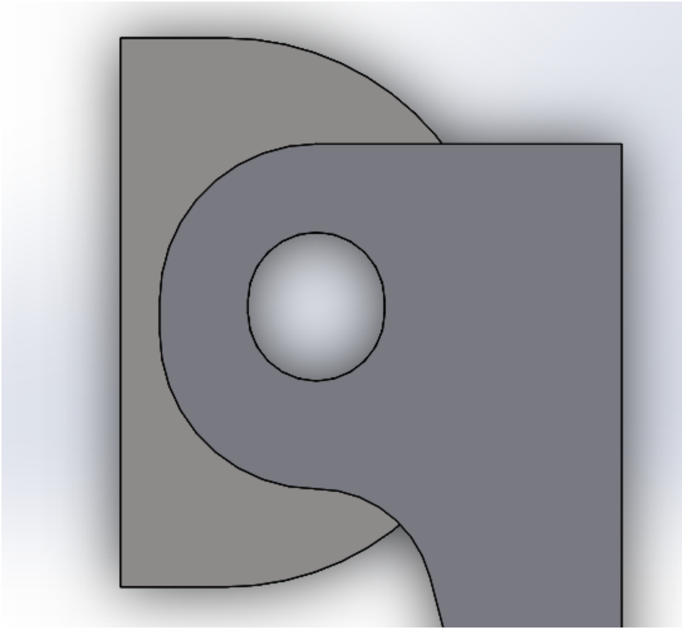

Figure 5.8: *Slot shaped cross section between lip ears and platform ears during installation*

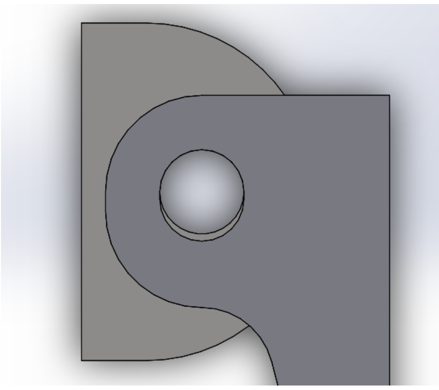

Figure 5.9: *Cross section during cross traffic*

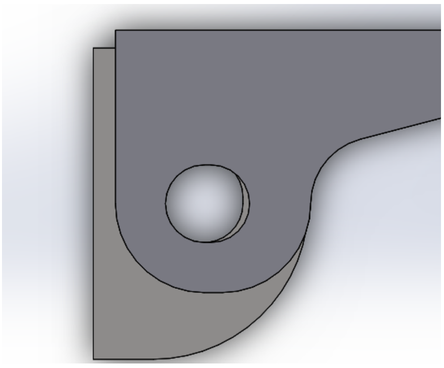

Figure 5.10: *Cross section during loading*

To make installment even easier, the ears were moved in the horizontal direction so a pin could be inserted from the front and then moved horizontally to its corresponding place instead of having to insert all of the pins from the sides. See Figure 5.11 for original placement and Figure 5.12 for improved ear placement.

Figure 5.11: *Original ear placement*

Figure 5.12: *New ear placement with more space between each pair.*

5.3.3 Main Supporting Beam

The current supporting beam can be see in in Figure 5.13 and Figure 5.14. It consist of two beams with a C-shaped cross section stacked on top of each other as well as several other smaller parts which are screwed and welded together to create additional stability. Since one of the goals was to decrease the number of components used, a concept was created with a simpler design.

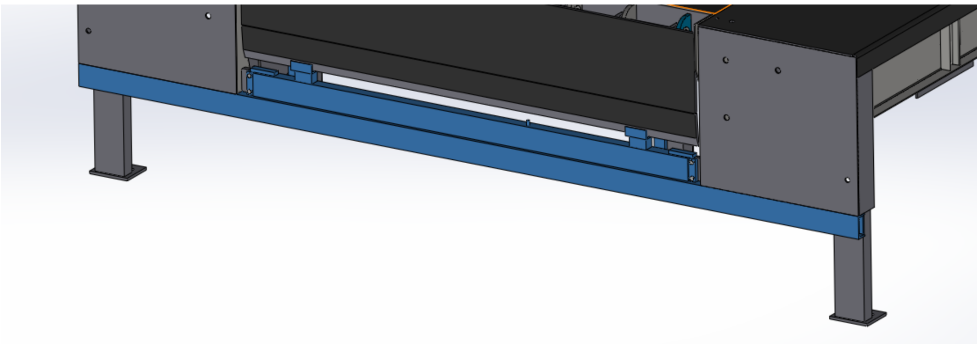

Figure 5.13: *Current main supporting beam seen in blue from the front*

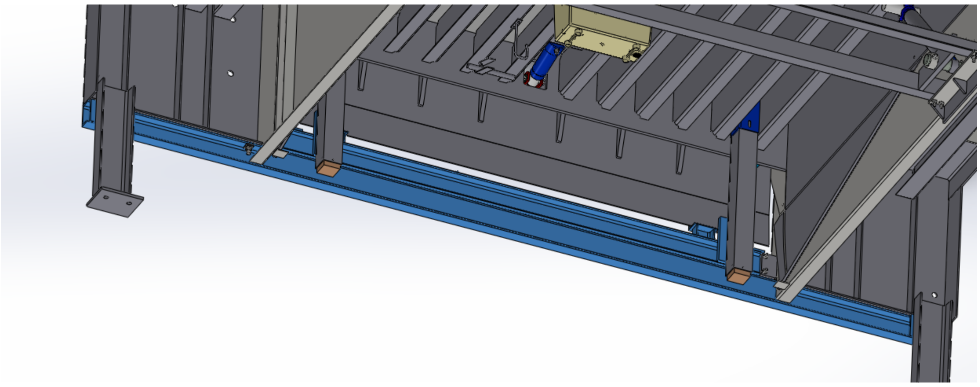

Figure 5.14: *Current supporting beam seen in blue from the back*

Idea A: Single beam with rectangular cross section
With having this type of beam, many of the smaller supporting parts could be eliminated since the rectangular beam provides better stability. A few different sizes were tested to find the most suitable one.

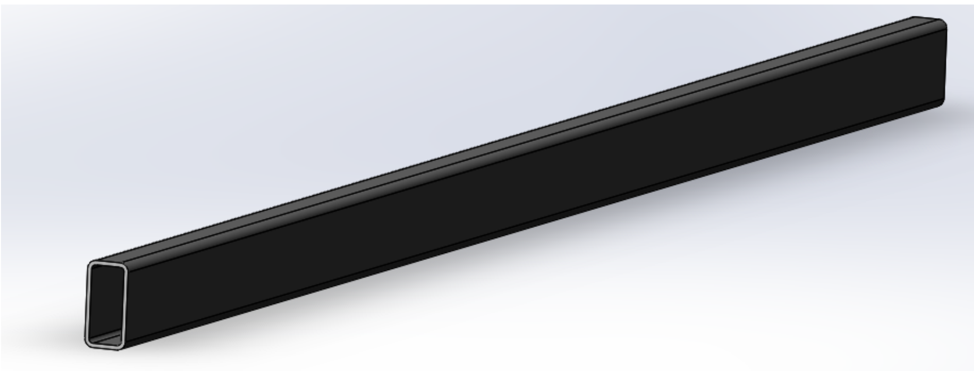

Figure 5.15: *Idea A: Rectangular beam*

5.3.4 Cylinder Mechanism and Cylinder Attachments

From our research, a significant problem of the current model are the cylinders which moves the platform up and down, and their attachments. As they tended to both break the attachments and have issues with alignment causing uneven force distribution discussed in section 3.7, new concepts had to consider these factors.

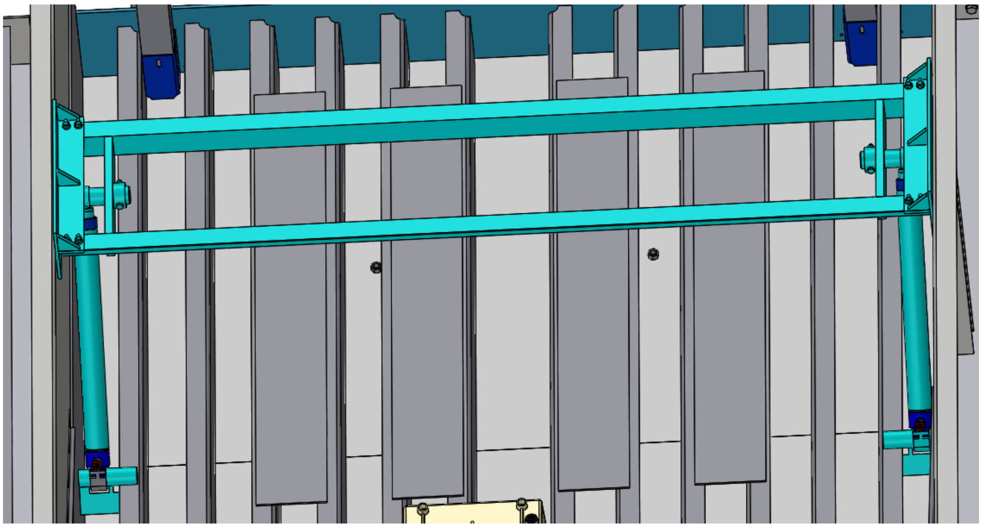

Figure 5.16: *Current cylinders and their attachments, marked in turquoise. The lower part is attached to the frame, while the top part is attached to the platform.*

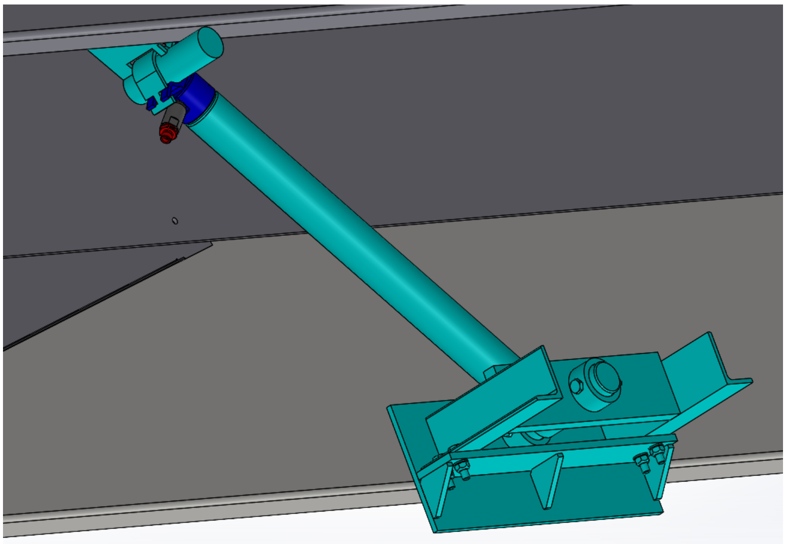

Figure 5.17: *Close-up of a sectioned view of the current cylinders*

Idea A: Sheet metal shelf
This concept replaces several parts, minimizes welding and makes for easier installation in the shelf-like attachment for the lower part in the current model in the attachment to the frame.

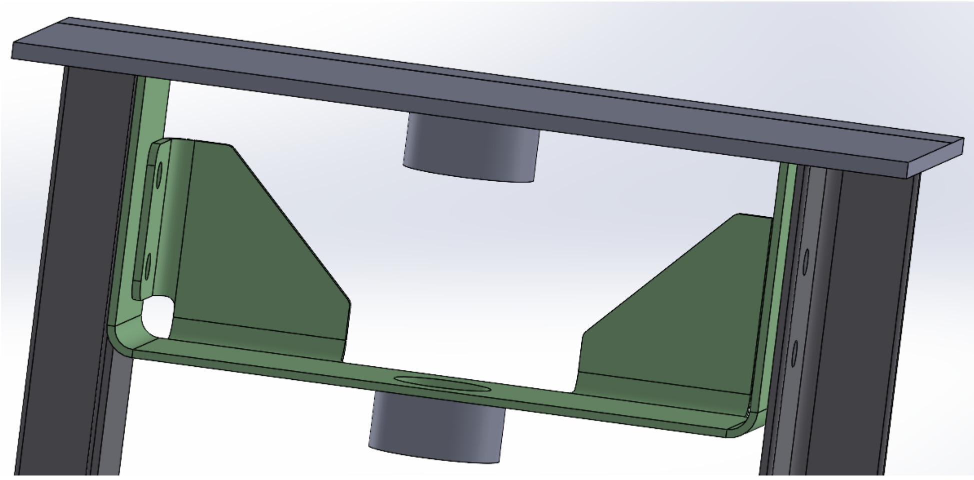

Figure 5.18: *Idea A: Sheet metal shelf for attaching to the frame*

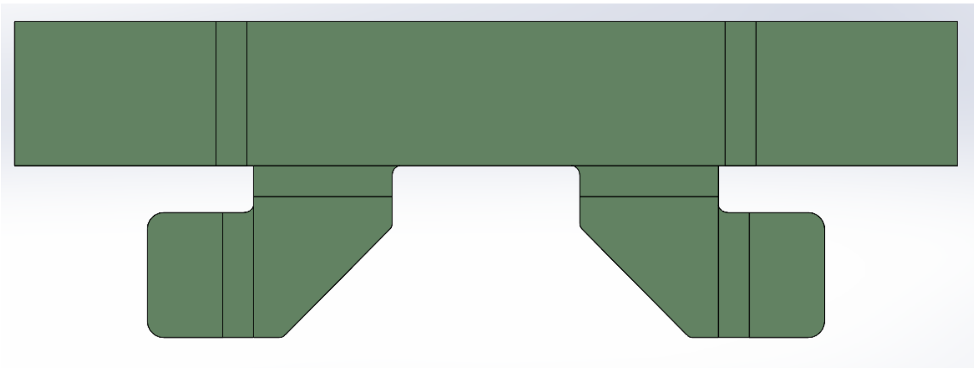

Figure 5.19: *Idea A: Sheet metal shelf for attaching to the frame, in unfolded state*

Idea B: Attaching the cylinder to the front main beam instead
Instead of having the cylinder attached to the frame further back, the idea is to attach the cylinder to the main beam on the front. This would completely eliminate a high number of parts, including the two L-shaped beams going across the dock leveler to support the cylinders. Additionally, the beam would take up the forces when the cylinders are in use.

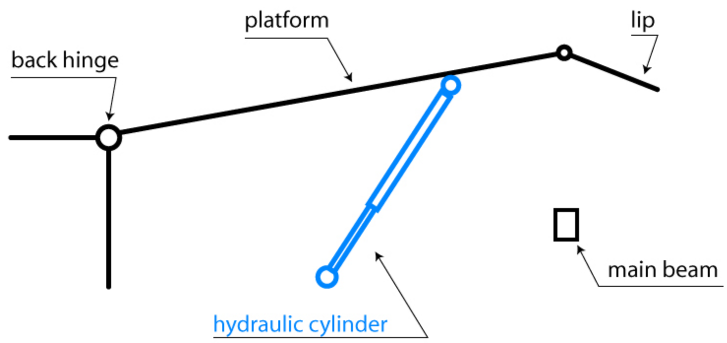

Figure 5.20: *Schematics of the current cylinder design.*

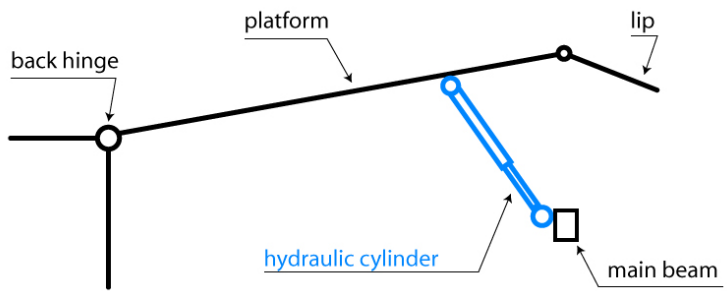

Figure 5.21: *Schematics of proposed Idea B, where the cylinder is attached to the main beam.*

To achieve this, concepts for an attachment to the main beam were generated. It was important to make the attachment in a size which would not create interference with other parts, as well as allowing for rotation of cylinder attachments (cylinder ear) around the axis. Another factor was that it should be able to be attached and installed securely on the beam.

Idea B1: Simplistic folded shelf
Simple sheet metal part with two bends.

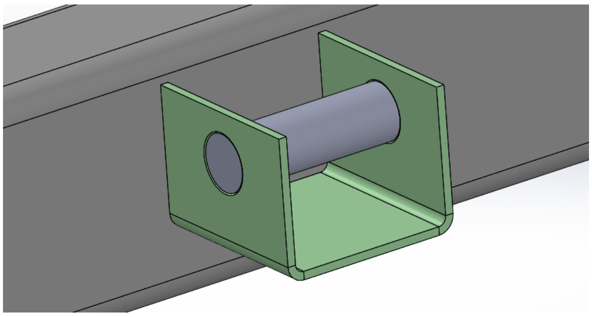

Figure 5.22: *Idea B1, attachment to beam*

Idea B2: Folded shelf, ears
Sheet metal part. The "ears" are useful when attaching the part to the beam, as it will align effortlessly and be in the correct position.

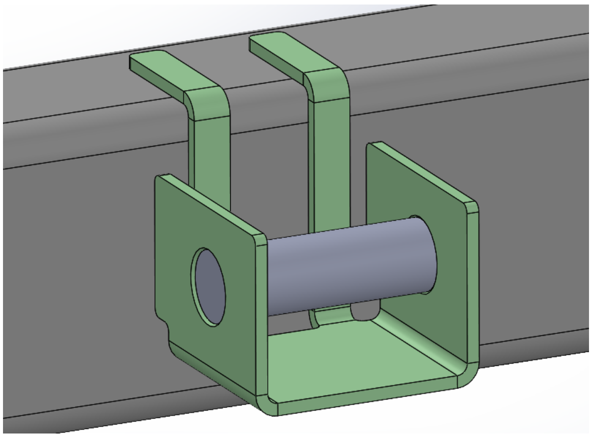

Figure 5.23: *Idea B2, attachment to beam*

Idea B3: Folded shelf, folded ears

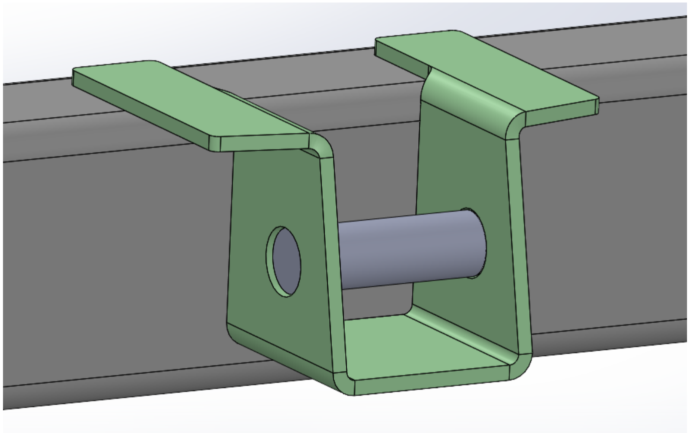

Figure 5.24: *Idea B3, attachment to beam*

Idea B4: Folded shelf, only two folds

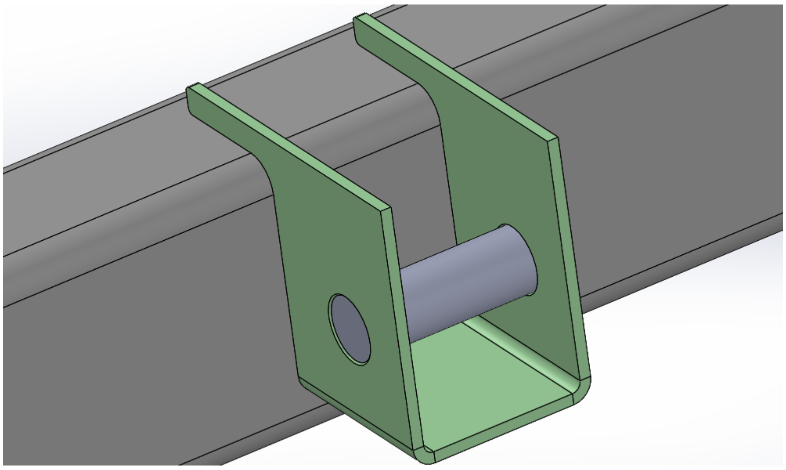

Figure 5.25: *Idea B4, attachment to beam*

Idea C: Self centering and self aligning axis and cylinder
A very significant problem identified in the research of the cylinders was how they in production could become unaligned and cause radial forces. Therefore, a concept in which the axis and the ear on the cylinders are self-centering to each other would be desirable.

Thus, and axis which has a sphere on it as shown in Figure 5.26, and a corresponding ear with a spherical indent could work, instead of a simple cylindrical shape which the current model has. The axis could be manufactured by a lathe machine. The ear could be manufactured as a laser cut sheet metal, where the sphere indent is made by a corresponding forming tool. Some grease could be used in the contact area between the ear and axis for smoother movements.

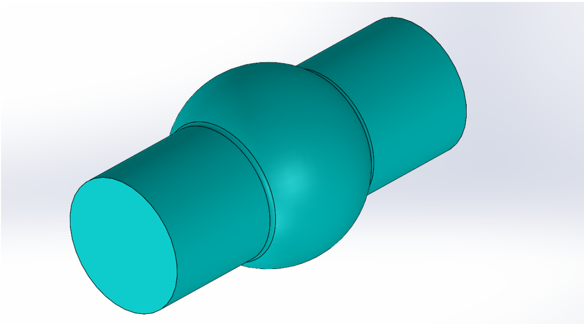

Figure 5.26: *Axis with sphere in the middle for centering purposes*

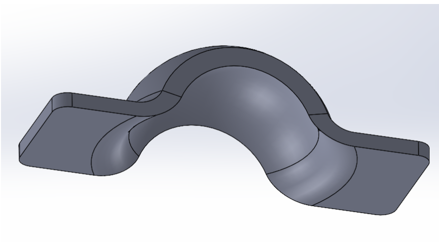

Figure 5.27: *Spherical cylinder ear*

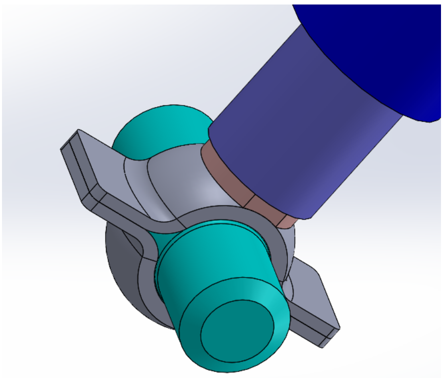

Figure 5.28: *Spherical axis and the corresponding ears. One of the ear is attached to the actual cylinder (blue).*

Different concepts for the spherical ears were developed. The idea is that the ears and the axis should be used on *both* ends of the cylinder, the end attaching to the platform and the end fixed to the frame.

The current ears and their attachment to the platform can be viewed in Figure 5.29.

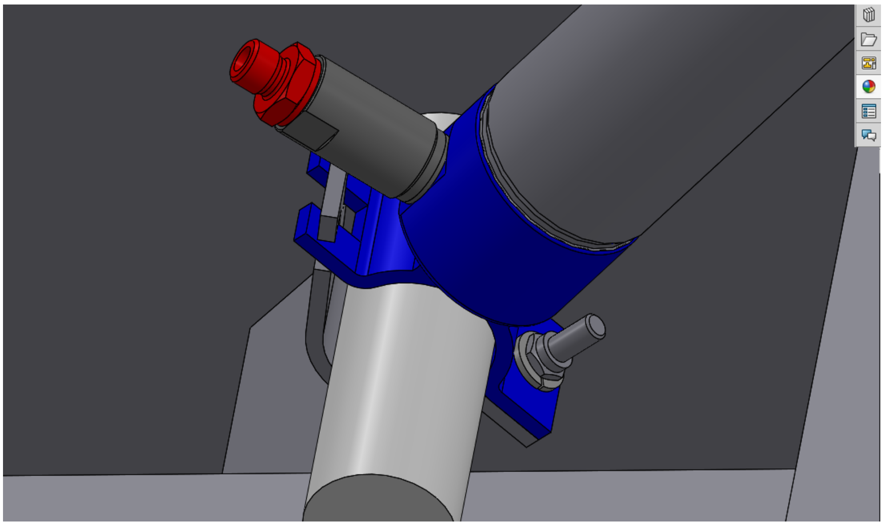

Figure 5.29: *Current ears and attachment to axis on the platform*

Idea C1: Ears with holes, carriage round-head square-neck bolt
Simple ears with a square with rounded edges cut-out. To attach the two ear parts to eachother, a round-head square neck bolt (carriage bolt) and a corresponding nut is used. With the square holes, the bolt will fit perfectly, see Figure 5.30 and 5.31. The ear part which is welded to the cylinder is identical to the part it is paired with, leading to fewer unique parts.

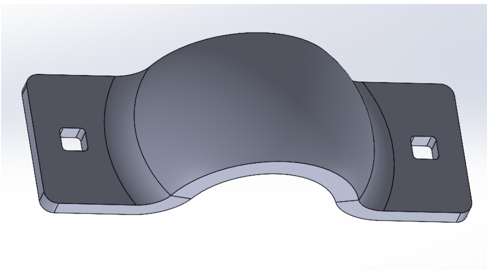

Figure 5.30: *Ears with rounded square cut-out*

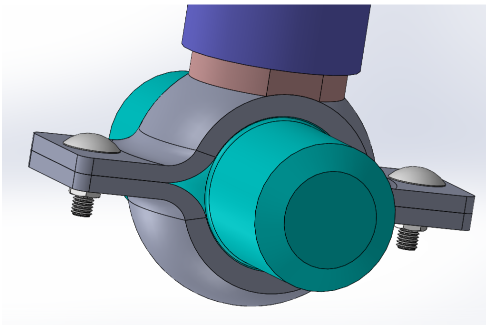

Figure 5.31: *Ears fixated with carriage bolt and corresponding nut*

Idea C2: Bent ears with cut-outs
Uses some of the original attachment concept where a bolt is not needed to fixate the axis between the two ears.

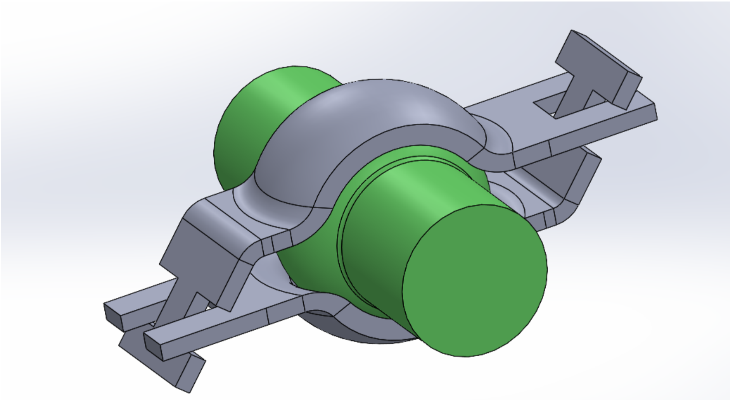

Figure 5.32: *Idea C2. Ears with bent design, similar to original*

Idea D: Cylinder-Platform attachment

A more robust and durable design for the cylinder-platform attachment. For the current design, see Figure 5.29. For this idea, a short L-shaped beam is welded together with two plates.

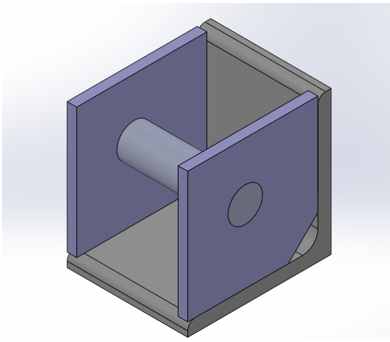

Figure 5.33: *Idea D. Attachment cylinder-platform.*

5.3.5 Frame's Construction

The current frame sides are mainly constructed of flat sheet metal and supporting beams as well as some smaller metal plates. See Figures 5.34-5.36 for reference. Since most of the sheet metal parts have a relatively small contact area with each other it can be tricky to assemble.

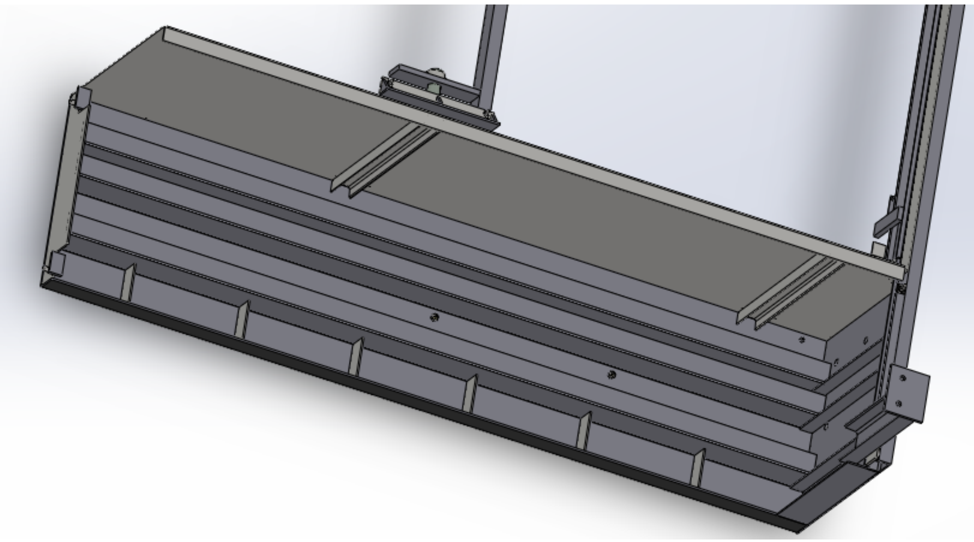

Figure 5.34: *Underside of frame side*

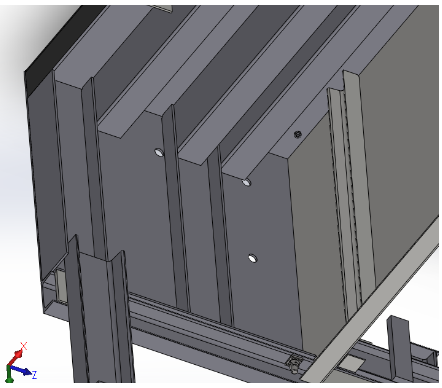

Figure 5.35: *Close up of frame inside*

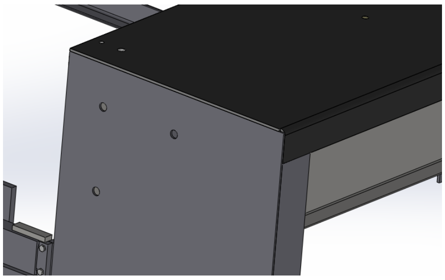

Figure 5.36: *close up of frame front side*

The goal here was to reduce number of parts but still keep the stability of the frame and possibly also make the frame easier to assemble. The different concepts were focused on specific areas of the frame and are presented below.

Idea A: Folded sheet metal shell

A way to make installment easier is to have tabs overlapping each other on each sheet metal plate to easier orient where they are suppose to go, see Figures 5.37-5.39. This also helps with giving some extra support since the sheet metal is doubled up in those overlapped places. To be able to assemble the frame with the main support beam, a few boreholes were added on the front side and a small L-shaped plate on the inside.

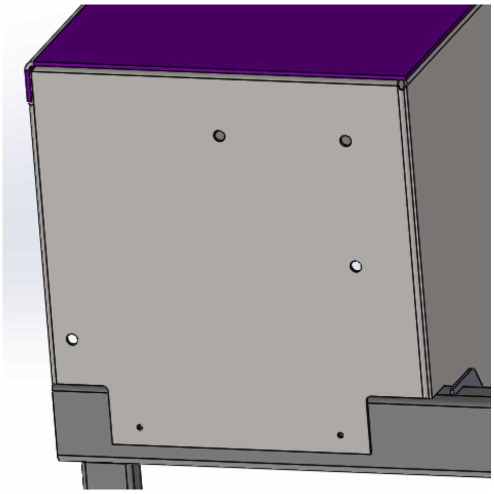

Figure 5.37: *Front side sheet metal with bore holes*

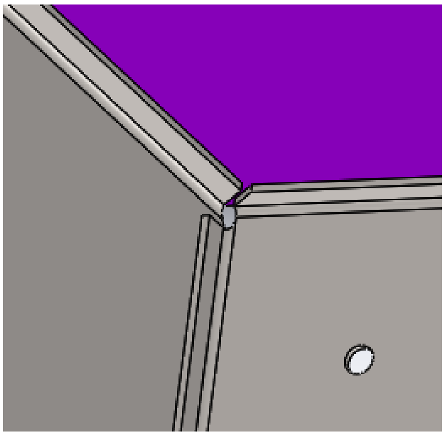

Figure 5.38: *Inside of frame*

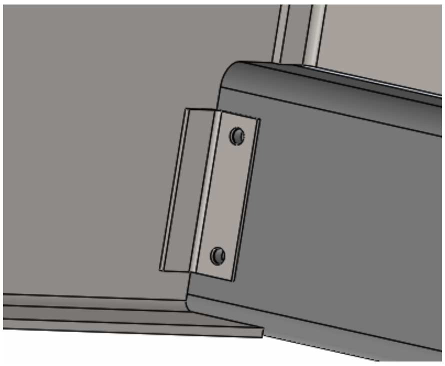

Figure 5.39: *Attachment piece to assemble frame and support beam*

Idea B: Horizontal support on underside of the frame
To add additional support to the frame, some sort of reinforcement on the underside is desired. At the original dock leveler there was three L-beams placed on either side as well as several smaller metal plates. A few different beam profiles were tested as well as the number of beams and their placement to find an optimal solution.

Idea B1: L-shaped sheet metal beams
Same as the original, easy to produce and relatively small amount of material.

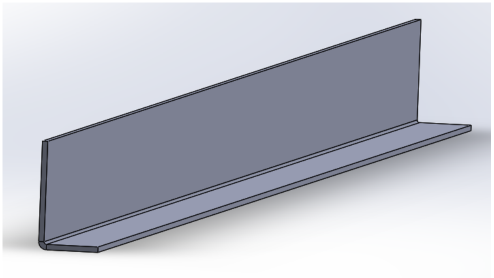

Figure 5.40: *Support beam with L-shaped cross section*

Idea B2: U-shaped sheet metal beams
Uses slightly more material but gives additional support.

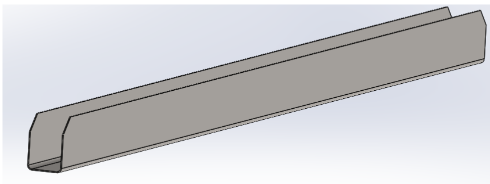

Figure 5.41: *Support beam with U-shaped cross section*

Idea C: Vertical supports on inside plate
From the pre-study it was shown how there was no significant stress on the inside plate of the frame, meaning not as much support was needed there. To still give some support to the inside plate and prevent large deformations, some U-shaped sheet metal supports were tested. These were thinner than the original C-beams and therefore both cheaper and lighter. To avoid gap corrosion the supports were placed with the open side against the inside plate. The number of supports and their placement was also evaluated. See Figure 5.42 for suggestive placement of these support beams.

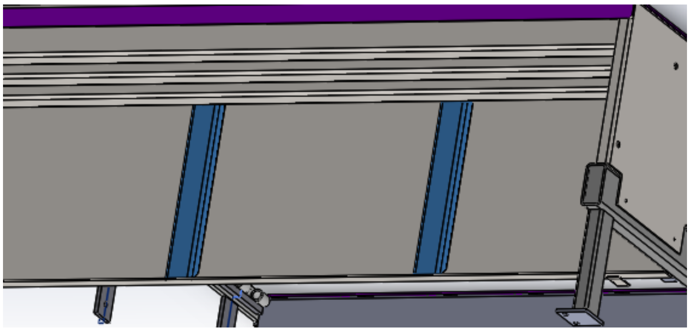

Figure 5.42: *Suggestive placement of vertical support beams with U-shaped cross section marked in blue*

5.3.6 Feet and Legs

The existing legs of the dock leveler consists of beams with a C-shaped cross section much like the original main supporting beam. The feet are constructed of metal plates with bore holes to be screwed into the ground, see Figure 5.43. To better suit the new concept of having a main supporting beam with a rectangular cross section, a new concept for the legs and feet were made.

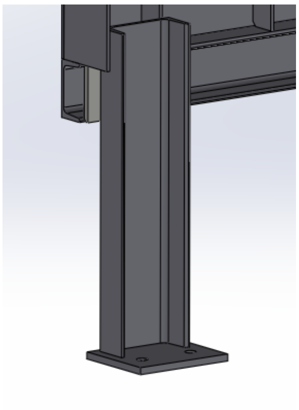

Figure 5.43: *Leg and foot of original dock leveler*

Idea A: Legs with a rectangular cross section

A beam was chosen with slightly smaller dimensions than the rectangular cross section concept of the main supporting beam described in section 5.3.3. This made it possible to attach the legs underneath the beam, see Figure 5.44. The new solution also helps with transferring applied force straight down into the leg without getting any torque. The dimensions of the feet were only adjusted to get a good fit to the legs.

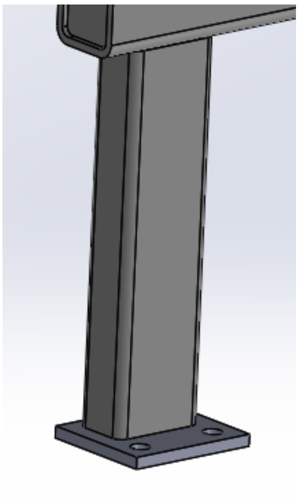

Figure 5.44: *Leg with rectangular cross section and foot with bore holes*

5.3.7 Lip Support

When the lip is stored in its vertical position, a support is needed. The current support consists of three parts which can be seen in blue in Figure 5.45. To decrease the number of parts, a new concept was created.

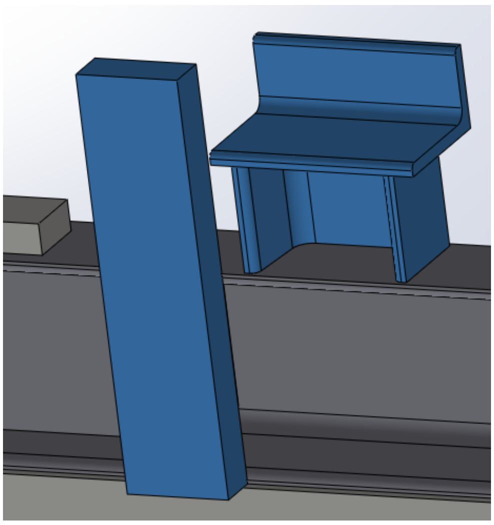

Figure 5.45: *Original lip support*

Idea A: U-shaped lip support

Limits motion of the lip both from the front and the back. The short C-beam was replaced by a beam with rectangular cross section to better fit the main supporting beam concept with a rectangular cross section as described in section 5.3.3, see Figure 5.46 for the new lip support.

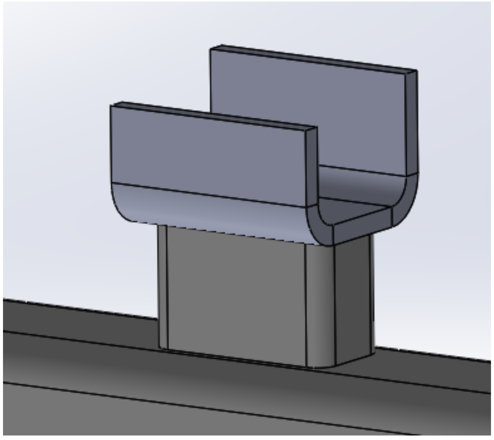

Figure 5.46: *U-shaped lip support*

6 Concept Selection

In this chapter the concept selection phase in the concept development process will be covered. After developing concepts in chapter 5 it is time to select a few concepts to move forward with, by comparing their strengths and weaknesses.

6.1 The Concept Selection Method

From Ulrich and Eppinger, the concept selection is an integral part of the product development process and is explained in this section further [5, pp. 143-147]. The stage in relation to other parts of the concept development process is shown in Figure 6.1 Concept selection is the process of evaluating the previously generated concepts with respect to the set customer needs and/or other criteria. The evaluation should compare the relative strengths and weaknesses of the concepts. The process should result in one or a few concepts to further study, investigate, test, or develop. According to the authors, concept selection is a mostly convergent step where the focus is to narrow down the set of alternatives. However, they conclude the concept selection activity is often iterative. Where combinations of concepts and further development can make the concept selection applicable for several rounds of concepts.

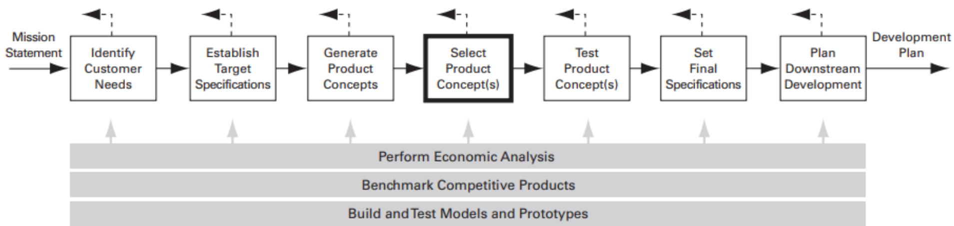

Figure 6.1: *The concept selection activity in relation to other parts of the concept development phase [5, p. 145]*

Ulrich and Eppinger propose a two step method, but clarify the first step might only be needed for simple design decisions. The first step is *concept screening* and the second stage is *concept scoring*. Both stages centers around the usage of a decision matrix which can rank and rate the concepts. Screening is a quick and simple method where the non-viable concepts are removed, whereas the second stage of concept scoring is more in depth. The concept scoring matrix is more steered towards a quantitative approach where each concept gets a score for the specific criteria [5, pp. 149-157].

6.2 Concept Selection Applied

In this project, the method of concept selection presented above was used as a basis, but some considerations and alterations to the methods were made. There were no distinct line between concept selection and generation as we got continuous feedback throughout the generation phase, proving the iterative nature of the whole concept development process. Discussions with supervisors were helpful in the process of selecting the final concepts to move further with, and their input will be reflected in the matrices.

The main alternation in our project is the use of one decision matrix for each area where concepts were developed, see the list in section 5.3. As each area only had a few concepts each, the decision was made to use either a concept screening matrix or a concept scoring matrix, depending on what the area calls for. It is crucial to note how each area can have different factors which are more or less important. This will be reflected in the matrices.

All the decision matrices can be viewed in Appendix C.

6.3 Selected Concepts

Below follows the concepts chosen from each area of the concept generation and why these were the best according to the concept screening and concept scoring.

Supporting Beams on Underside of Platform

The L-shaped support beams were chosen due to their low weight and material usage. See Figure 5.4.

Hinges

The slot hole concept for the hinge ears was chosen since it simplifies installation and reduces material at the same time, see Figure 5.8-5.10.

Main Supporting Beam

The beam with a rectangular cross section was chosen because it is easier to install, reduce number of components and is sturdier. See Figure 5.15.

Cylinder Mechanism

The concept where the cylinders are attached to the main beam was chosen both because it reduces the number of components and because installment will get easier. See Figure 5.21.

Cylinder Attachments

With the new cylinder mechanism, three attachments were to be chosen to install the cylinders.

Concept B4 which is an attachment to the main beam was chosen based on both minimized material usage, ease of manufacturing and a low number of bends. See Figure 5.25.

Concept D, an attachment to the platform was selected due to the sturdy design, ease of installment and reduced number of components. See Figure 5.33.

Concept C1 which is an attachment to connect the above two attachments to the actual cylinders was chosen due to its durability and ease of installation. See Figure 5.30 and 5.31.

Frame's Construction
The new concept with folded sheet metal was chosen for the shell since it will simplify the assembling process while also providing additional support. See Figure 5.37-5.39.

The U-shaped sheet metal beams were selected as support beams in the horizontal direction (on the underside of the frame). These were chosen for their increased durability. See Figure 5.41.

U-shaped sheet metal beams were also chosen for the vertical support beams. They are not as sturdy as the original but much lighter. See Figure 5.42.

Feet and Legs
The legs with a rectangular cross section and belonging feet were selected to fit the new main beam better and transfer force straight down instead of creating torque. See Figure 5.44.

Lip Support
The new lip support consisting of a U-shaped piece and a short rectangular beam was selected to reduce number of components while still limiting motion of the lip forward, backwards and downwards. See Figure 5.46.

7 Concept Testing & Refinement

After selecting the concepts to move forward with in the concept selection phase, it is time to test and refine them.

7.1 The Concept Testing Method

Ulrich and Eppinger sees the concept testing activity as a phase after the selection process. The testing phase in relationship to the other stages of concept development activities can be seen in Figure 7.1. They define the concept testing phase as the activity where the concepts are tested in relationship to fulfilling the customer needs/product specifications. Here, further iterations and adjustments of the concepts are preformed, improving them to meet the set needs even better. According to the authors a concept test is where the development team solicits a response from potential customers by surveying customers with description of the concepts. [5, pp. 165-167]

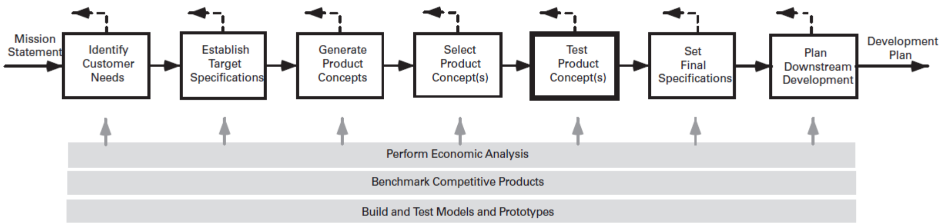

Figure 7.1: *The Concept Testing Phase in relationship to other stages of the concept development process*

7.2 Concept Testing Applied

In our case, testing will not evolve around conducting surveys for customers. Instead, concept testing will be used as a process to test the concepts in regards to the product specification list, and improving them from there. The testing phase was conducted trough FEM-simulations to study the requirements of durability and minimize stresses, while also minimizing mass. Additionally, testing was done by iterative experimentation and moving objects in the concept to improve certain aspects, such as the cylinder angles and placement of different support beams. Input from supervisors regarding important subjects such as ease of manufacturing and assembling were used to further improve the concepts. Moreover, the testing phase was in reality done more or less simultaneously as the Concept Generation Phase and the Concept Selection Phase. These three stages were all done iteratively and parallel to each other to achieve the best possible result. This section will focus on describing the concept testing of those concepts chosen from the concept selection in chapter 6. The material S355-J2GR was used for the majority of the components when testing them in Solidworks with the same setup and mesh settings as described in section 3.6. This new material has a higher yield strength which further improves the durability of the product without increasing the weight.

7.2.1 Frame Testing

When tests were made on the frame, several components and concepts were tested at the same time in a single analysis. Since the pre-study from section 3.6.2 showed very small stresses on the entire frame in the Loading load case, the tests have focused on the other two load cases described in section 3.5.

Cross Traffic

The properties of the dock leveler changed when testing different concepts, meaning the forces $R1$ and $R2$ needed to be recalculated with the same setup as described in section 3.6.3, see Appendix A for calculations. An initial analysis showed stresses mostly on the main support beam that had a thickness of 8 mm which can be seen in Figure 7.2. The stress distribution was significantly improved from the pre-study. However, the deformation seen in Figure 7.3 was about 8 mm and a thicker beam was tested to see if the issue could be resolved.

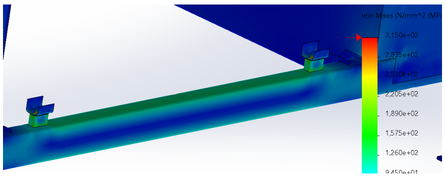

Figure 7.2: *Stresses in main support beam with thickness 8 mm*

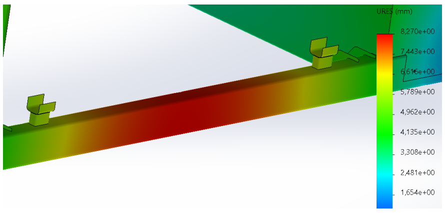

Figure 7.3: *Deformation of main support beam with thickness 8 mm*

A thicker beam with a thickness of 12 mm was tested but still showed a deformation of about 7 mm. Since the difference in deformation was miniscule and the fact that a thicker beam would both increase cost and weight to the final product, the choice was made to keep the beam with a thickness of 8 mm. See Figures 7.4 and 7.5 for the stress distribution and deformation of the thicker beam.

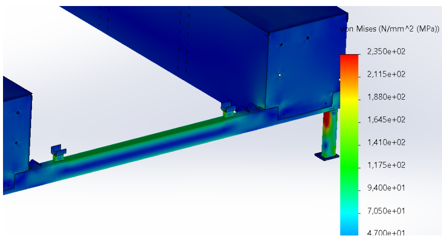

Figure 7.4: *Stresses in main support beam with 12 mm thickness*

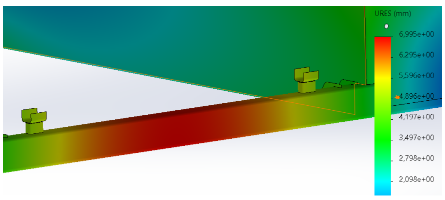

Figure 7.5: *Deformation of main support beam with 12 mm thickness*

There were also some stress concentration around the legs which can be seen in Figure 7.6. The reason is the sharp transition between the beam and the leg and will be resolved when the two are welded together and the transition becomes smoother and more rounded.

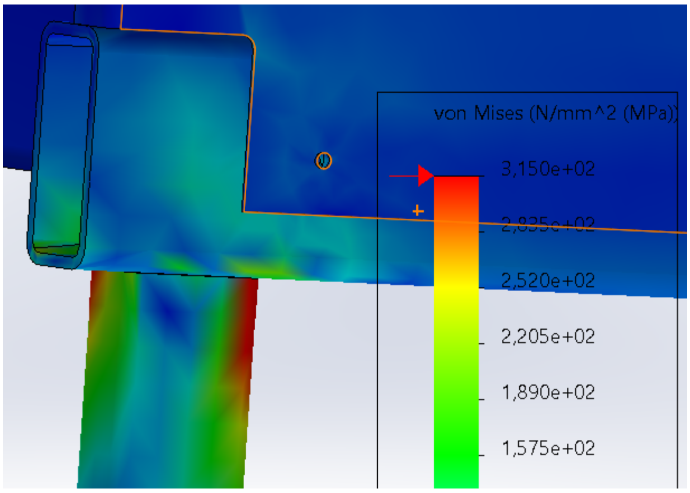

Figure 7.6: *Stress concentration around leg of frame*

On the inside of the beam, right above the legs were some minor stresses, see Figure 7.7. In accordance with advice from our supervisors, a small metal plate was placed on each end to add additional support and stability. See Figure 7.8.

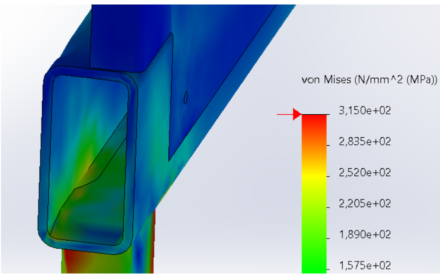

Figure 7.7: *Side view of main support beam*

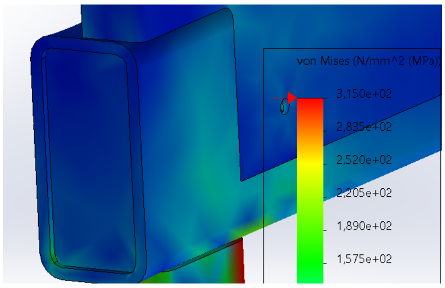

Figure 7.8: *Side view of main support beam with added metal plate*

Load only on frame

From the concept selection, the U-shaped sheet metal beams were chosen as the horizontal support beams since they are sturdier than the L-beams which the original design had. An initial analysis was made with two 3 mm thick beams on each side which is shown in Figures 7.9 and 7.10.

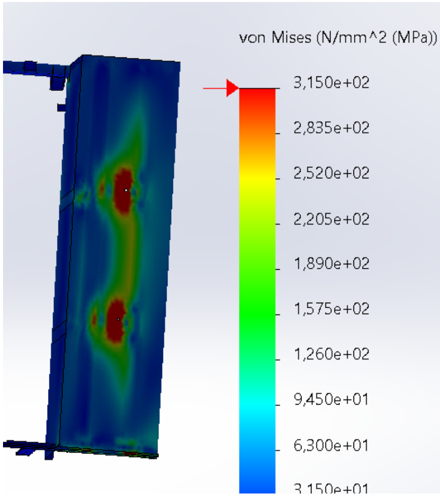

Figure 7.9: *Stress distribution on topside of frame with two support beams*

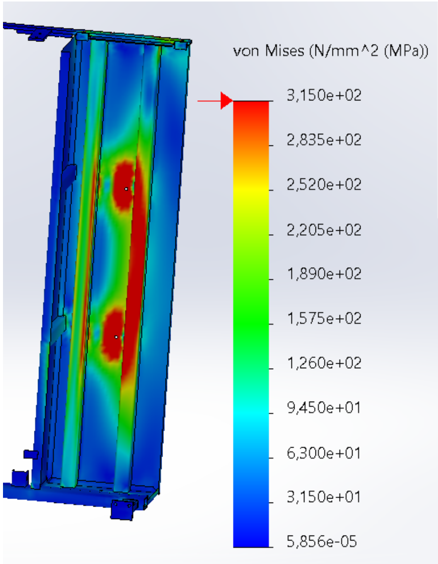

Figure 7.10: *Stress distribution on underside of frame with two support beams*

The stresses on the underside of the frame and on the support beams showed to be to quite high and the concept needed improvement. After testing to change the number of supports and their placement a solution was found where the stresses could be decreased a sufficient amount. Three support beams with the same 3 mm thickness were placed on each side of the frame. Since the load case in reality looks slightly different which is described in section 3.6.4, it is acceptable that the stresses are somewhat high in a smaller area. See Figures 7.11 and 7.12 for the final placement and stress distribution of the beams.

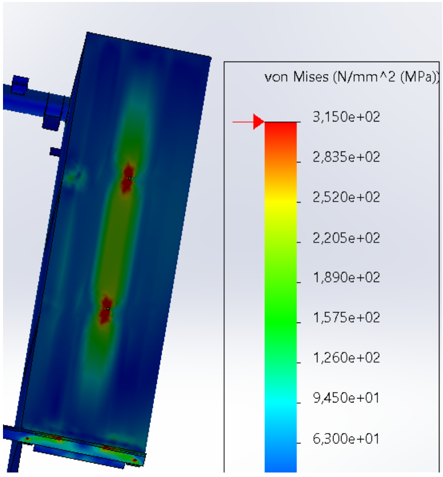

Figure 7.11: *Stress distribution on topside of frame with three support beams*

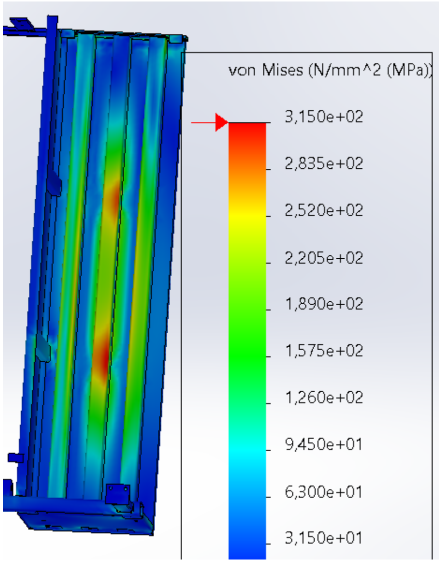

Figure 7.12: *Stress distribution on underside of frame with three support beams*

7.2.2 Platform Testing

To test the new hinge solution with the slot holes, an attempted FEM-analysis was made. This analysis only yielded poor results due to the pin connector issue described in section 3.6.1. Since the new solution was only slightly different from the original, it was estimated with the help of supervisors that the stresses would be about the same.

Cross Traffic and Loading

The analyses were set up in the same way as in the pre-study. When it comes to the overall structure of the platform and the lip, the main component which was changed was the support beams on the underside. This did not alter the stress distribution considerably, which can be seen in Figures 7.13-7.16. However, There were still some stresses in the contact area between the lip and the lip supports in the Cross Traffic Case, as well as on the underside of the lip in the Loading Case. This is reasonable due to the small contact area in the analysis which will grow larger in reality when a load is applied to the platform. Since there is a variety of lips to chose from when ordering a dock leveler, the stress distribution will look somewhat different depending on which lip is chosen.

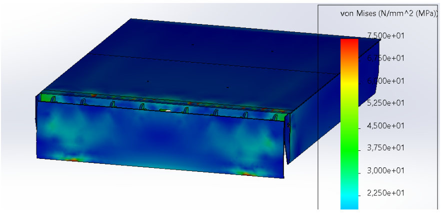

Figure 7.13: *Stress distribution on topside of platform in Cross Traffic position*

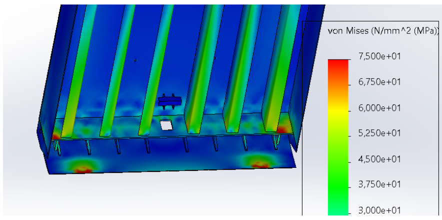

Figure 7.14: *Stress distribution on underside of platform in Cross Traffic position*

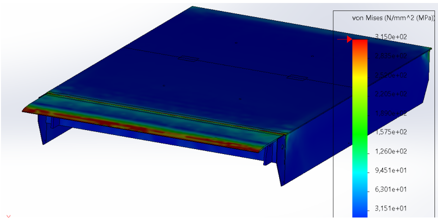

Figure 7.15: *Stress distribution on topside of platform in Loading position*

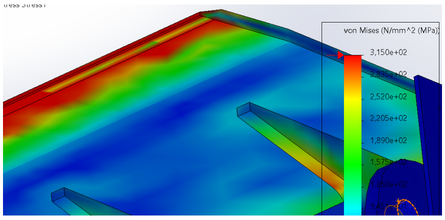

Figure 7.16: *Stress distribution on underside of lip in Loading position*

Load in the middle of platform

To test and see what happens when a load is placed in the middle of the platform, a new load case was introduced. It simulates a truck driving just ordinarily across the platform. This test also served as the basis to determine the number of support beams, their thickness and placement for the final design. The platform was placed in the Loading position and the same boundary conditions were set up. The load was placed on two rectangles in the middle of the platform which can be seen in Figure 7.17.

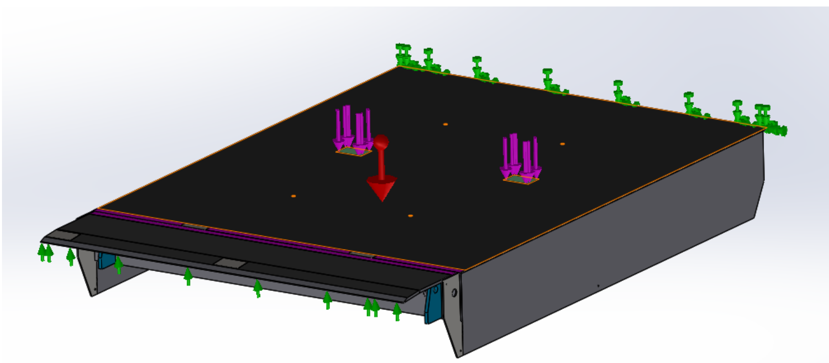

Figure 7.17: *Force application showed with purple arrows*

The first try was made with four L-beams with a thickness of 2 mm. This solution proved to be too weak and there were too much stress which can be seen in Figure 7.18. After a couple of trials of increasing the thickness and adding more beams the final concept became a platform with six support beams which had a thickness of 5 mm, see Figure 7.19. This solution gave excellent support to the platform and lowered the stresses sufficiently.

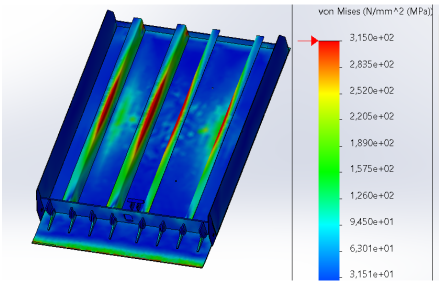

Figure 7.18: *Stress distribution on underside of platform with four support beams with a thickness of 2 mm*

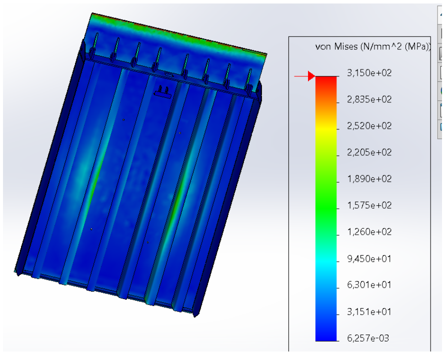

Figure 7.19: *Stress distribution on underside of platform with six support beams with a thickness of 5 mm*

Torsional flexibility

According to the product specifications in section 4, the platform needs to have a 3% torsional flexibility based on the platform width. Therefore, when the platform has a vertical deformation of 3%, there cannot be too much stress present. The platform width for the dock leveler is 2200 mm, meaning the stress distribution must be evaluated when there is a 66 mm deformation.

To simulate the scenario, a new load case was set up in the FEM-software. The backside of the platform was fixed just like in the other load cases. A small rectangular roller/slider support was placed on one corner of the lip's underside to represent the partial contact surface with a tilted lorry truck. A load was then placed on the topside of the lip on the opposite side to represent a truck. See Figure 7.20 and Figure 7.21 for a visual representation of the boundary conditions.

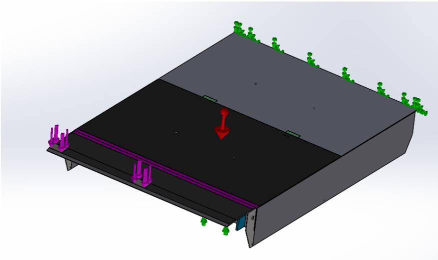

Figure 7.20: *Boundary conditions of platform for the "Torsional Flexibility" load case, purple arrows shows where the force was applied*

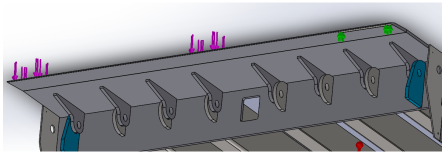

Figure 7.21: *Boundary conditions of platform for the "Torsional Flexibility" load case, green arrows shows the roller/slider support on the underside of the lip*

The next step was to figure out what load was needed to get the corresponding 66 mm deformation. After a couple of tries the following was concluded: a load of 5 kN gave about the right deformation which can be seen in Figure 7.22. The stress distribution was mostly concentrated on the lip by the contact surface and in the back corner which can be seen in Figure 7.23 and 7.24.

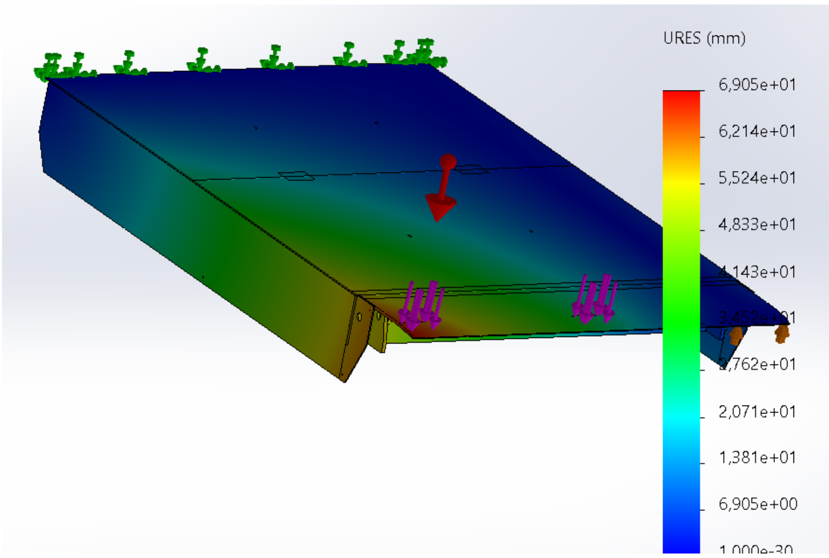

Figure 7.22: *Deformation of platform in the "Torsional Flexibility" load case*

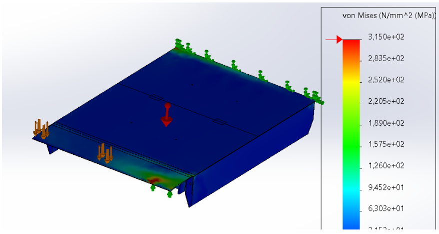

Figure 7.23: *Stress distribution on platform in the "Torsional Flexibility" load case*

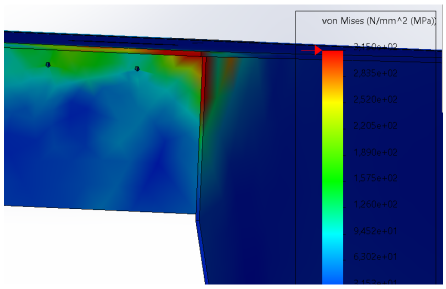

Figure 7.24: *Stress distribution on back plate of platform in the "Torsional Flexibility" load case*

The stress on the lip is nothing to worry about since it will decrease when the contact surface between the lip and the lorry bed increases. This will happen when a truck is driving on the platform.

The stress concentration in the back corner however is an issue to study further. The decided solution to use was simply shortening the height of the back plate. Doing this made the back plate more flexible in the torsional direction and the stresses were thereby lowered. See Figure 7.25 for the improved back plate.

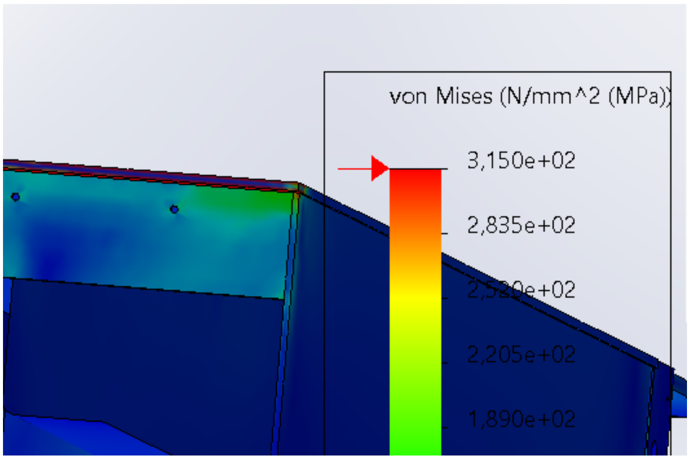

Figure 7.25: *Stress distribution on improved back plate*

7.2.3 Cylinder-Beam and Cylinder-Frame Placements

As the concept of attaching the cylinders to the main beam was chosen, the placement of the attachment points on both ends of each cylinder had to be decided. This was done by testing in CAD, using a movable model so eventual collisions would be noticed. From section 3.7.4 the conclusion was drawn that large angles are desirable, meaning the attachment to the platform should be closer towards the lip, see Figure

7.26 below.

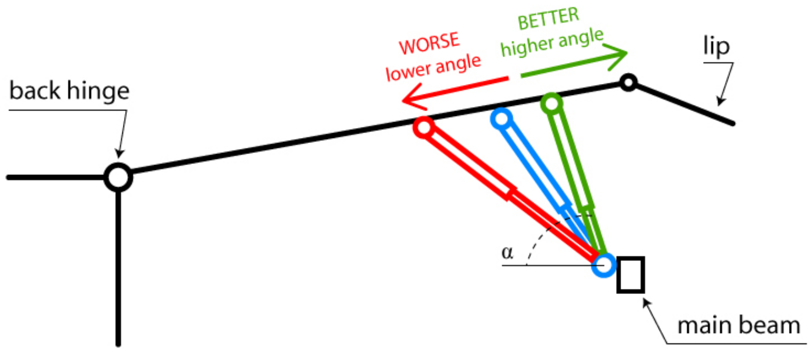

Figure 7.26: *To minimize forces, the cylinder attachment on the platform should be close to the lip.*

By incrementally moving the placement according to Figure 7.26 in the CAD-assembly, and testing it for collisions when moving the platform up and down, the right placement could be determined. Additionally, with this method the cylinder could be dimensioned to fit perfectly and allowing for the same heights A and B as before. As the working length in this new cylinder is much smaller compared to the old cylinder, mass is also lowered. The old cylinder's tube was approximately 633 mm long, whilst the new one is only 549 mm long. With the new placement, the cylinder angle span is now:

$$39,6^\circ \leq \alpha \leq 60^\circ \tag{7.1}$$

7.2.4 Cylinder-Beam Attachment

The chosen concept for the cylinder-beam attachment, B4 needed more refinements and testing. One idea was to minimize the material usage even more, by removing some material over the hole and add radii to make the part easier to handle and for the laser cutter to cut through the sheet metal, see Figures 7.27-7.28. Additionally the hole in the part must be sufficiently far away from the edge, so the cylinder ears will not collide with the beam. The thickness of the sheet metal was also tested iteratively, by conducting simple FEM-analyses and considering the standard sheet metal thicknesses available, see Appendix D. From the testing a thickness of 6 mm was chosen.

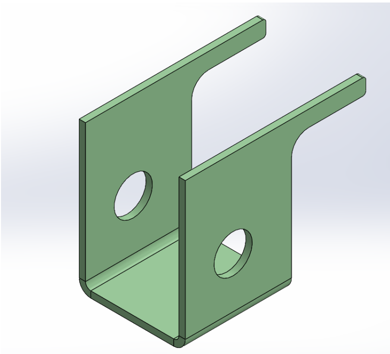

Figure 7.27: *Attachment B4 before improvements*

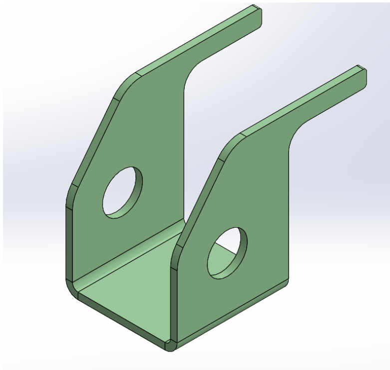

Figure 7.28: *Attachment B4 after refinements. Minimized weight and smoother edges.*

7.2.5 Cylinder Axis Refinement

After discussions about manufacturing and assembling, the cylinder axis needed refinement. To easily mount the axis in the attachments, the axis must have chamfers. With chamfers it can be inserted into the holes by tilting the axis when installing it into an attachment as the one described above in section 7.2.4. See Figures 7.29 and 7.30.

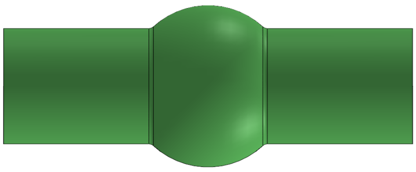

Figure 7.29: *Cylinder axis without improvements*

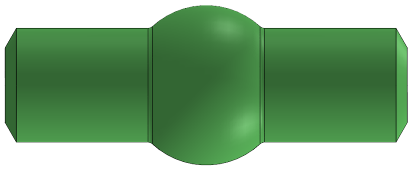

Figure 7.30: *Cylinder axis, improved with chamfers*

8 The Final Concept

After evaluating, testing, and refining all the different concepts and how they are working in different combinations with each other, a final combined concept was decided for the project. The concept was chosen based on both the concept testing described in chapter 7 and the product specifications stated in chapter 4.

The final concept has a significantly smaller number of components compared to the current model. An important source for this fact is the change of cylinder positioning to the main beam. Also, the number of beam supports on the underside of the platform as well as the underside of the frame are lowered. In the original 100 kN model, there were two main beams, whilst this new concept has one sturdier beam. Having a lower amount of components also lowered the amount of weld needed. An evaluation of the decrease in meters of weld needed is presented below in Table 8.1.

Table 8.1: *Meters of weld needed*

Model	**Final Concept 100kN**	**Original 100 kN**
Meters of weld	75.117 m	127.907 m
Decrease in percent	41.3 %	

With less components, the overall weight of the dock leveler is also lowered. Removing several of the long beams on the underside of the platform contributed significantly. By checking the mass properties in Solidworks on the new model with cylinders, pins and screws removed it could be compared to the weight of the current model (with corresponding parts removed). The mass for the new concept and the original is presented below in Table 8.2.

Table 8.2: *The calculated mass for the new 100 kN concept and the original*

Model	**Final Concept 100kN**	**Original 100 kN**
Mass	2079 kg	2109 kg

8.1 The Design

Presented below are pictures of the final concept where all the different components have been assembled with exception of electrical components and the temporary support legs which are only used during installation. The material used for the main components is structural steel (S355) with the exception of the topside components for both the platform and the frame as well as the lip which are made of S235 steel tear plates. To manufacture and assemble the dock leveler, a few different methods were used. The various support beams and majority of the frame components were created using sheet metal bending. For assembling, both welding and bolted joints were used.

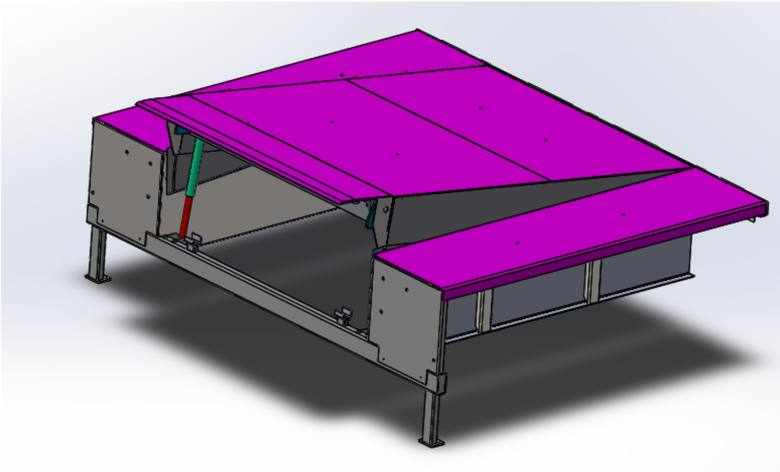

Figure 8.1: *Final design, tear plates shown in pink*

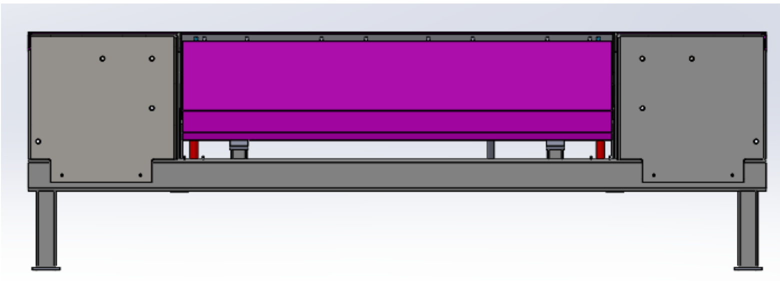

Figure 8.2: *Final design seen from the front, tear plates shown in pink*

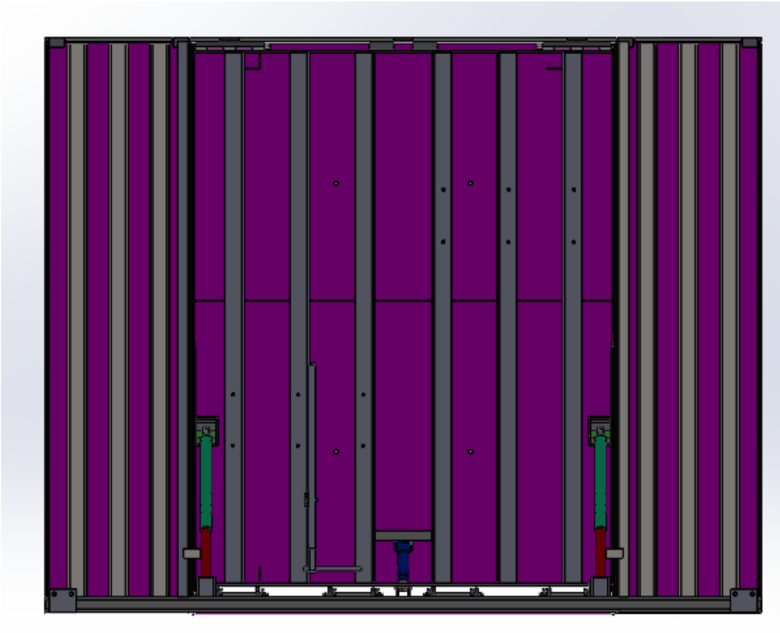

Figure 8.3: *Underside of final design, tear plats shown in pink*

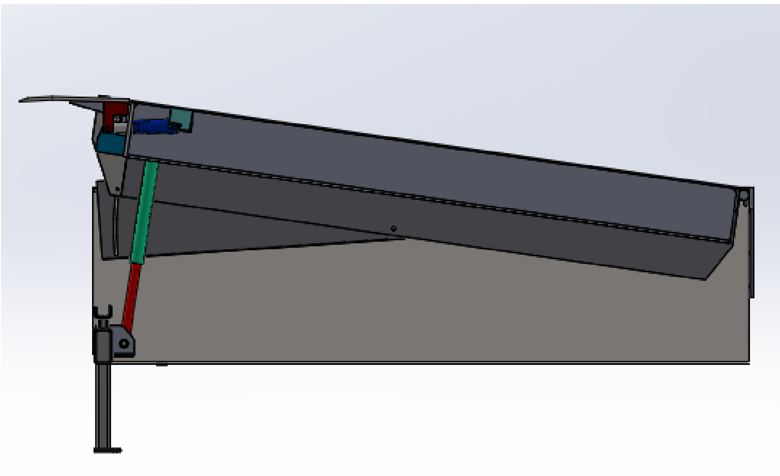

Figure 8.4: *Cross section of final design*

8.2 Technical Drawings

One aim of the project was to create a full-scale prototype in the correct materials of the new concept and if time allowed, do physical stress test with testing equipment. To be able to get a workshop to produce the prototype, technical drawings had to be made. For the assembly drawings, BOMs were made, which listed all the components used for the concept. Therefore, technical drawings constituted for a significant portion of our time spent in this project.

For the final concept, drawings of each single part had to be produced. Assembly drawings with welding annotations and how the different parts were to be put together were also made. 90 pages of drawings was produced in total. For general guidance in how technical drawings for such large assemblies are made at ASSA ABLOY, an internal document of drawings for another type of dock leveler (a telescopic lip instead of swing lip) was used. It provided useful information in how to set up large assemblies, but also the common types of welding used for much of the construction.

For overall assistance in how to make technical drawings correctly, the book *Ritteknik 2000* by Taavola, Karl [10], was referenced. Here, the overall layout and basic principles behind mechanical drawings are presented and provided a useful guide. The book *Formler och tabeller för mekanisk konstruktion* by Björk, Karl [11], was a particularly useful source on all the different types of welding annotations and how to use them correctly. In Appendix E a select few of the technical drawings are presented to give an insight into some of the work done.

9 Discussion

Within the project some different assumptions and simplifications have been made which may have affected the end result. Many of these are related to the various FEM-analyses done and provides the basis for the product development and testing taking place during the project. This chapter will also discuss more general aspects of the project and other possible sources of error.

9.1 Hinges and Pin Connectors

In the Solidworks FEM-software no ideal solution to simulate how an applied load would affect a hinge and its pin connector when they are studied together was found. This resulted in simulations where the hinge and the pin connector showed no stress or deformation at all which is unrealistic. The use of the boundary condition "pin connection" would unrealistically not allow deformations or stresses in the pin.

9.2 Boundary Conditions

In the different FEM-analyses, boundary conditions had to be set up. These consisted mainly of fixed supports on various surfaces, but also a few roller/slider supports as described in section 3.6. For some of these boundary conditions it was difficult to represent reality, causing a source of error. An example of this is on the backside of the platform where a fixed support was added for both the main load cases, even though the platform should be able to rotate around the back hinge axis.

9.3 Contact Surfaces and Application of Loads

When preforming a FEM-analysis in Solidworks with assemblies which contain many components, a global contact is used to resemble the contact between the components. Meaning, if two components are touching, the software will see them as bonded which not always is the case in reality. Several parts are connected by welds in the physical product, but in the 3D-models and FEM-calculations these were absent. Welds will in reality often contain defects and provide high stresses around cracks. At the same time a weld gives a smoother transition between parts which can also prevent stress concentration. The lack of welds in the analyses is consequently a source of error which should not be disregarded.

When it comes to *where* the various loads were applied, different rectangular surfaces and extrudes were made to be able to add a force to a smaller surface which better fit the load case. Some of these provided an accurate representation of reality. For instance, the thin rectangles on the lip supports which represent the contact surface when the lip rests on the lip support in the cross traffic load case described in section 3.6.3. However, some of these extrudes had to be simplified from reality to be able to run the analysis in accordance to the torque equations set up. One example is the back hinges on the frame. To be able to add a force there needed to be a flat surface. This meant the hinges consisting of both hollow and solid cylinders were replaced with flat rectangles where the force could be placed.

Another simplification made was positioning the platform horizontally while doing FEM-studies (except for when studying the cylinders). For an example, in the Loading case the platform could be tilted up or down to accommodate the different heights of lorry trucks. This can be seen as a slight source of error. However, as the angles for the platform are small, it should not have a considerable effect.

9.4 Cylinder Case

Only the static load cases were studied in the FEM-analysis and load calculations of the cylinders and their attachments. This case represent forces the cylinders have to withstand when the platform is in its highest and lowest position. The only load here was the weight of the platform and the lip itself.

In reality, the worst case scenario would be if the lorry vehicle drives away and the dock leveler is maximally loaded meaning the cylinders would have to support an extremely heavy weight. Since the cylinders in this case would start to compress and ultimately break in their current state you would have to consider time and velocity when calculating what kind of forces are present. This is a very complicated task without making actual tests on a real dock leveler, as described in section 3.7.4. Because of time limitations and how unusual the load case is, the cylinders and their attachments have not been developed and tested to withstand this extreme case.

9.5 Concept Generation

Since the dock leveler consists of a high number of components, it also means there are many parts and areas to study and try to improve. Because of the time limitation, only some areas with the most need for improvements were studied. Parts like the platform in general have not gone through any more concept development than on the supports on the underside described in section 5.3.1 and a dimension change to the back plate.

For many of the components which were studied, only one or two new concepts were developed and tested. To be sure that these were in fact the best concepts a few more could have been developed to have a wider test range, if more time was provided.

9.6 FEM-results

When studying the FEM-results, stress and deformations were the two aspects mainly studied. The supervisors recommended these aspects as buckling, vibrations and other factors were not of importance, according to their experience.

10 Conclusion

In this chapter, the whole master thesis will be summarized. Furthermore, several conclusions will be drawn from the entire project, and the question whether the aims of the projects were fulfilled will be answered. A discussion of further developments and recommendations will also be included.

From the research part of the thesis, several conclusions could be summarized. Here both theoretical information (standards, product data sheets, installation guides etc) and FEM-simulation were used. As a complement, verbal knowledge from the supervisors were used in all the steps.

From the standards, a list of requirements was deduced, see section 3.3. The main points from the standard was the different loading cases and the safety factors needed. These conditions provided to be vital when setting up the product specifications in chapter 4. After studying the product data sheets and the installation manual, we could further conclude how the product actually functioned and was installed. An example could be the fact that the frame is delivered in the left, right, and the beam part to later be assembled. This provided additional guidelines in the product specifications list.

In the FEM pre-study in section 3.6, the main lessons were the locations of the high-stress areas in different scenarios. Some noticed were on the main beams, the hinges and the back side of frame. Another important aspect of this section was learning how to set up the FEM-analyses and understanding the loading cases. There, an understanding of the main differences between the 100 kN vs 60 kN models were also provided. This knowledge was later applied in the concept testing phase to compare the iterations efficiently.

Another important aspect of the dock leveler is the cylinders. In section 3.7, a deep dive into cylinders was conducted. To summarize there were three crucial conclusions from the current cylinders:

- Larger cylinder angles are preferred
- Remove the possibility of radial forces
- Sturdier attachments are needed

The study of movement and forces provided useful when developing new concept for the cylinders and their attachment.

In the concept development phases of the project, new concepts were iterated and tested. Concepts for each area of interests were generated and with the help of concept selection and later refinements and testing, a complete finished product was presented. The main features of the final design is a focus on bent sheet metal parts, ready-made profiles and the cylinders on the opposite side from before. The significant issue of radial forces in the cylinders was eliminated.

ASSA ABLOY is content with the project and sees it as a basis for further development to be able to update their range of dock levelers, using the ideas presented in this thesis. Therefore, the company has great use of this project. For the broader mechanical engineering community, we hope this project and the small concepts developed can be used in other applications besides dock levelers.

To conclude the whole project in general,the usage of established methods like Ulrich and Eppinger's with slight alterations, proved to be successful. With a new concept with less components, a modernized robust design, a decrease in weld-usage and a lower mass, the main goals of the project are met.

10.1 Further Development

Although the accomplishment of the set goals of the project, there are several aspects where further development is recommended. With such a large product with a high number of components and parts in combination with the time constraints of the project, more time would be needed to fully realize a final concept.

Overall, all areas could use more concepts to guarantee better solutions. In particular, more new concepts for both the back hinges and the lip hinges would be preferred. We suggest further testing and concept generation on these hinges, as they were identified in the research part of the project as a significant problem area. The construction of the platform was not subject to much in depth concept generation, only the support beams. More development on the platform as a whole would be advised for the future.

The cylinder loading cases, when the safety vault is activated is still a mystery and how to effectively simulate it in a FEM-software. Here, additional real-life testing would be of interest. Due to the time constraints, physical testing of the new concept was not made. However, we recommend doing tests like these with a robust array of testing equipment to see how accurate the FEM-simulations in the Concept Testing Phase in section 7.2 were. Moreover, the trouble with simulating pin connections would also lead to a preference for live testing.

As the final concept is for the 100 kN, additional work is required to down-size the design to fit the other versions such as the 60 kN one. To achieve this, many components could be made thinner, but the overall design should be the same. This concept is also for swing lips, therefore an adaption could be made to fit telescopic lip versions.

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[10] Taavola, Karl. (2009). *Ritteknik 2000 faktabok.* (4^{th} ed.). Sweden: Athena lär. ISBN: 9789188816214.

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Appendix A: Force Calculations

Loading	100 kN	60 kN	100 kN (NY)
m_platt	977,00237	585,01	
m_lip	139,43864	128,32	
m_led	9,66418	0	
m (kg)	**1126,10519**	**713,33**	974,42
F (N)	140000	84000	140000
g (m/s^2)	9,81	9,81	9,81
l1 (m)	0,4992	0,49735	0,499
l2 (m)	1,64981	1,13406	1,52
l3 (m)	3,33292	3,417	3,313
R2 (kraft som överförs från plattform till ram)	26437,35905	14548,81123	25472,31256

Cross Traffic	100 kN	60 kN	100 kN (NY)
l1 (m)	1,66589	1,751	1,777
l2 (m)	2,33	2,87	2,814
l3 (m)	2,97627	2,95088	2,933
m (kg)	1126,10519	713,33	974,42
g (m/s^2)	9,81	9,81	9,81
F (N)	140000	84000	140000
R1 (N)	115783,5949	85850,01442	140111,3024
R2 (N)	35263,49703	5147,752883	9447,757788

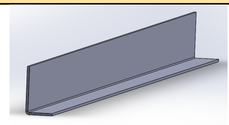
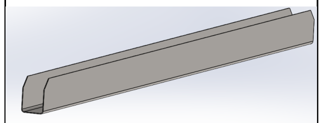
Appendix B: Matlab Code of Cylinder Analysis

```
pl = 3300; %Platform total length
cl = 1758.45; %Length from hinges to cylinder fastening
A = 410;
B = 300;

%The fixed point where the cylinder is fastened to the frame.
x_2 = 1060;
y_2 = -738;

% CASE A, PLATFORM GOES UP
theta_A= asin(A/pl);
theta_a_deg = rad2deg(theta_A);
x_a1 = cl*cos(theta_A);
y_a1 = cl*sin(theta_A);
ple = pl*cos(theta_A);
pld = pl*cos(theta_A);
c = y_a1-y_2;
d = x_a1-x_2;

alpha_a = atan(c/d); %Maximum angle for cylinder rad
alpha_a_deg = rad2deg(alpha_a);

% CASE B, PLATFORM GOES DOWN
theta_B = asin(B/pl);
theta_b_deg = rad2deg(theta_B);
x_b1 = cl*cos(theta_B);
y_b1 = -1*cl*sin(theta_B); %negative!

e = y_b1-y_2;
f = x_b1-x_2;

alpha_b = atan(e/f); %Minimum angle for cylinder in rad
alpha_b_deg = rad2deg(alpha_b);
y3= tan(theta_B)*2976.89;
%R_cyl magnitude
p = 17500000; %175 bar
r= 0.0225;
A = pi*r^2;
Rcyl = p * A;


% RCYL IN NORMAL CASE!
m = 1126.10519; %mass in kg
g = 9.81;
%Rcyl in normal case, for A (going up)
l = 1.74345; %hypotenusan till cylaxeln n r plattformen
l1_a = l*cos(theta_A); %horisontal length to cyl fast
l2_a = 1.65662; %horisontal length to center of mass in A
Rcyl_normal_a = (m*g*l2_a)/(l1_a*sin(alpha_a));
Rcyl_normal_a_one = Rcyl_normal_a/2;

%Rcyl in normal case for B (going down)
l1_b = l*cos(theta_B);
l2_b = 1.65175;
Rcyl_normal_b = (m*g*l2_b)/(l1_b*sin(alpha_b));
Rcyl_normal_b_one = Rcyl_normal_b/2;
```

Appendix C: Concept Selection Matrices

Ratings 1-5

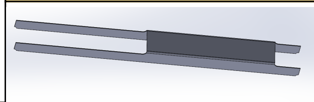
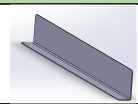
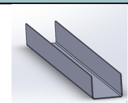
Concept scoring for support beams on underside of frame

		Concept B1: L-shaped sheet metal beams 80x150x3		Concept B2: U-shaped sheet metal beams 150x100x3	
					
Selection Criteria	Weight	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Minimized material usage*	15%	5	0,75	3	0,45
Minimize amount of bends	20%	5	1,00	4	0,80
Ease of installation	35%	5	1,75	5	1,75
Durability	30%	3	0,90	5	1,50
Total Score			4,40		4,50
Rank		**2**		**1**	
	100%				

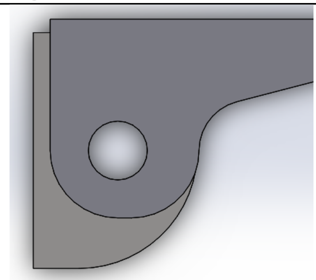
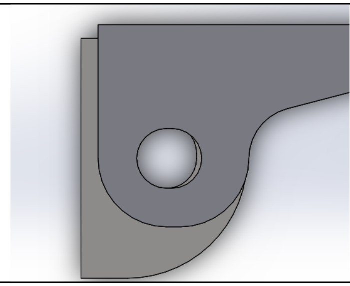
* Measured by volume in Solidworks, same sheet metal thickness for all

Ratings 1-5

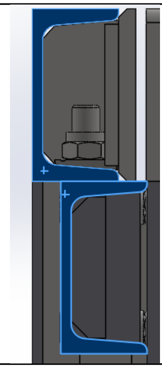
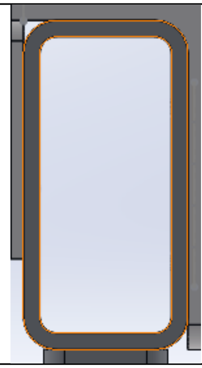
Concept scoring for support beams on underside of platform

Selection Criteria	Weight	Concept A: Folded sheet metal		Concept B: Sheet metal with L-shaped cross section		Concept C: Sheet metal with U-shaped cross section	
							
		Rating	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Minimized material usage*	15%	4	0,60	5	0,75	3	0,45
Minimize amount of bends	20%	4	0,80	5	1,00	4	0,80
Ease of installation	35%	5	1,75	5	1,75	5	1,75
Durability	30%	3	0,90	4	1,20	5	1,50
Total Score			4,05		4,70		4,50
Rank		**3**		**1**		**3**	
	100%						

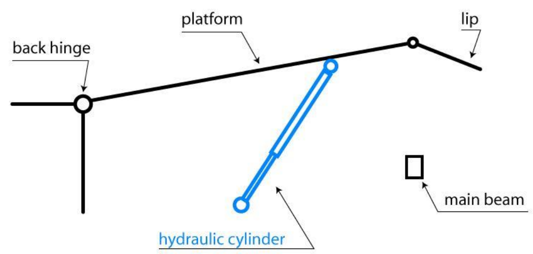
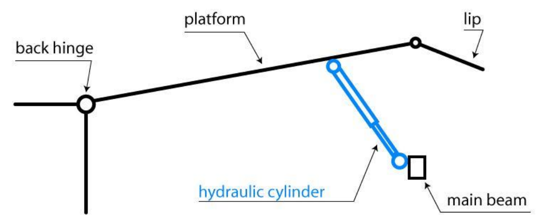
* Measured by volume in Solidworks, same sheet metal thickness for all

	Hinges	
	Original (reference) Round holes	**Slot holes**
Selection criteria		
Minimize material	0	+
Durability	0	0
Ease of manufacturing	0	0
Ease of installation	0	+
Net score	0	+2
Continue?	No	Yes

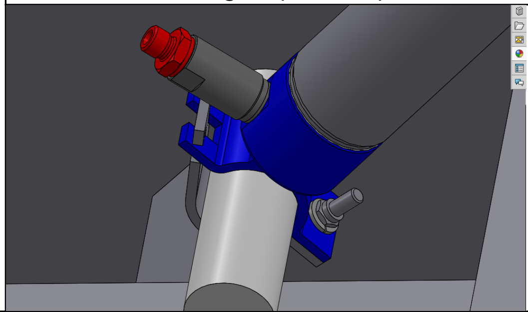
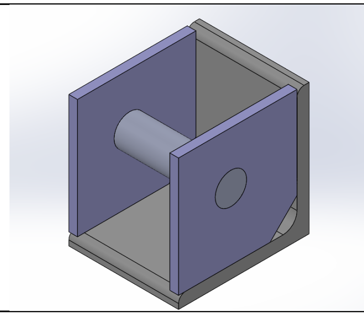
Main support beam

Selection criteria	Original (reference) Two C-beams 100x50x6 mm	Single beam with rectangular cross section 160x80x8 mm
		
Minimize no of components	0	+
Durability	0	+
Ease of manufacturing	0	0
Ease of installation	0	+
Net score	0	+3
Continue?	No	Yes

Cylinder original or fastened to main beam

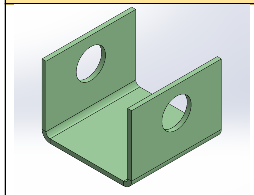
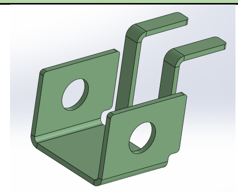
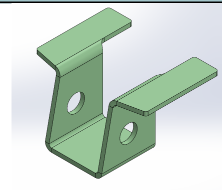
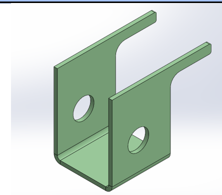
Selection criteria	Original (reference)	On main beam
		
Minimize no of components	0	+
Durability	0	0
Ease of manufacturing	0	+
Ease of installation	0	+
Net score	0	+3
Continue?	No	Yes

Cylinder - platform attachment

Selection criteria	Original (reference)	Idea D
		
Minimize no of components	0	+
Durability	0	+
Ease of manufacturing	0	0
Ease of installation	0	+
Net score	0	+3
Continue?	No	Yes

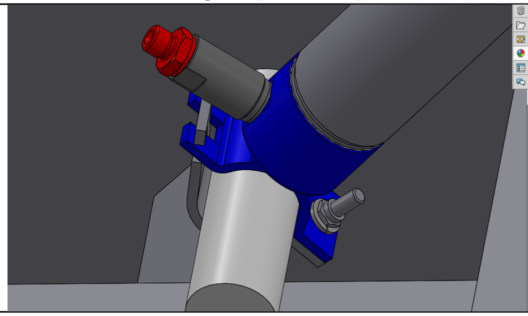
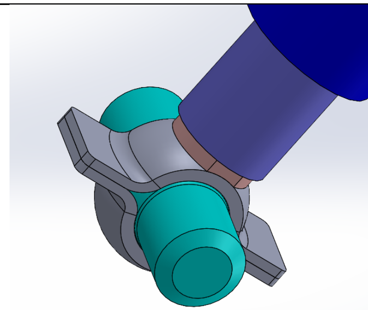
Ratings 1-5

Concept scoring for cylinder attachments on main beam

		Concept B1		Concept B2		Concept B3		Concept B4	
									
Selection Criteria	Weight	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Minimized material usage*	15%	5	0,75	4	0,60	1	0,15	3	0,45
Minimize amount of bends	20%	5	1,00	2	0,40	2	0,40	5	1,00
Ease of installation	35%	2	0,70	4	1,40	5	1,75	5	1,75
Durability	30%	2	0,60	4	1,20	5	1,50	5	1,50
Total Score			3,05		3,60		3,80		4,70
Rank		**4**		**3**		**2**		**1**	
	100%								

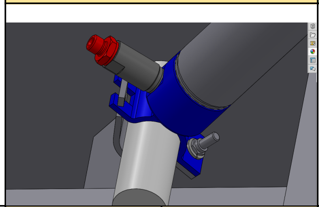
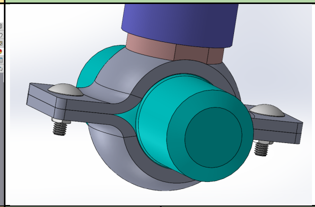
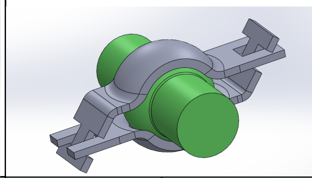
* Measured by volume in Solidworks, same sheet metal thickness for all

Original vs. Self-centering cylinder attachments

Selection criteria	Original (reference)	On main beam
		
Minimize no of components	0	0
Durability	0	+
Ease of manufacturing	0	0
Minimize radial forces	0	+
Ease of installation	0	+
Net score	0	+3
Continue?	No	Yes

Ratings 1-5

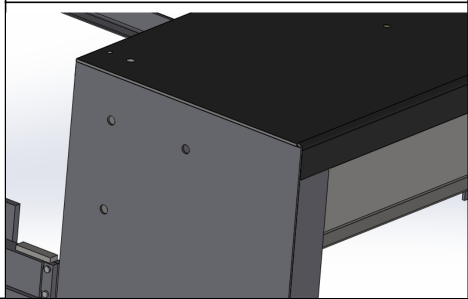
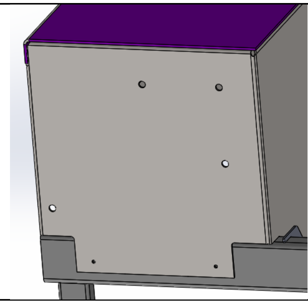
Ear attachment design

Selection Criteria	Weight	Concept A: Original solution – Rating	Concept A: Original solution – Weighted Score	Concept B: Ears with holes – Rating	Concept B: Ears with holes – Weighted Score	Concept C: Ears with cut-outs – Rating	Concept C: Ears with cut-outs – Weighted Score
Minimized material usage*	15%	4	0,60	5	0,75	3	0,45
Ease of installation	35%	4	1,40	5	1,75	0	0,00
Minimize no of unique parts	30%	3	0,90	4	1,20	5	1,50
Durability	20%	5	1,00	5	1,00	0	0,00
Total Score			3,90		4,70		1,95
Rank		**2**		**1**		**3**	
	100%						

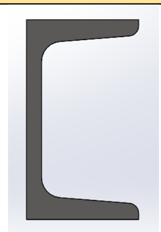
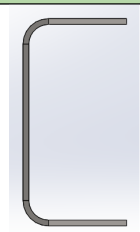
* Measured by volume in Solidworks, same sheet metal thickness for all

Frame shell

Selection criteria	Original (reference) Mainly plat sheet metal	Folded sheet metal shell
		
Minimize no of components	0	+
Durability	0	+
Ease of manufacturing	0	+
Ease of installation	0	+
Net score	0	+4
Continue?	No	Yes

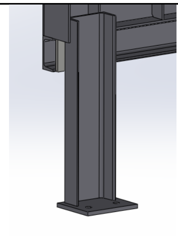
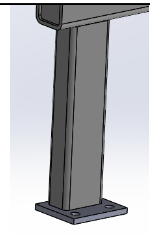
Ratings 1-5

Concept scoring for vertical supports on frame

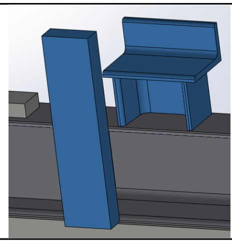
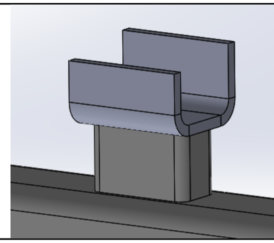
		Original (reference) C-beam 80x45x6 mm		Concept A: Sheet metal with U-shaped cross section 50x100x3 mm	
					
Selection Criteria	Weight	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Minimized material usage*	40%	3	1,20	5	2,00
Ease of installation	30%	5	1,50	5	1,50
Durability	30%	5	1,50	4	1,20
Total Score			4,20		4,70
Rank		**2**		**1**	
	100%				

* Measured by volume in Solidworks

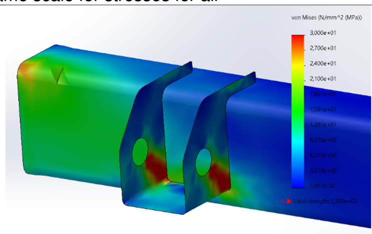
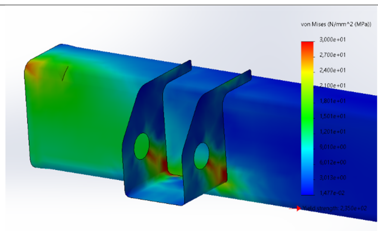
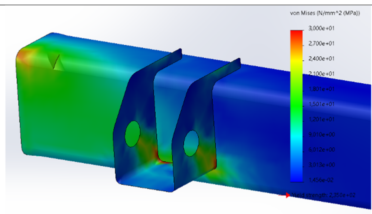
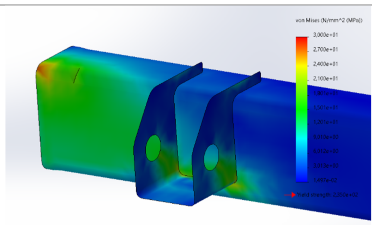
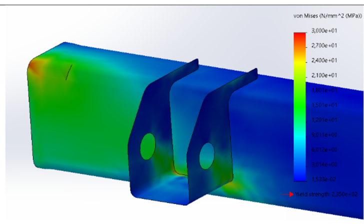
Legs and feet

Selection criteria	Original (reference) C-beam with metal plate feet	Beam with rectangular cross section with metal plate feet
		
Minimize no of components	0	0
Durability	0	+
Ease of manufacturing	0	0
Ease of installation	0	+
Net score	0	+2
Continue?	No	Yes

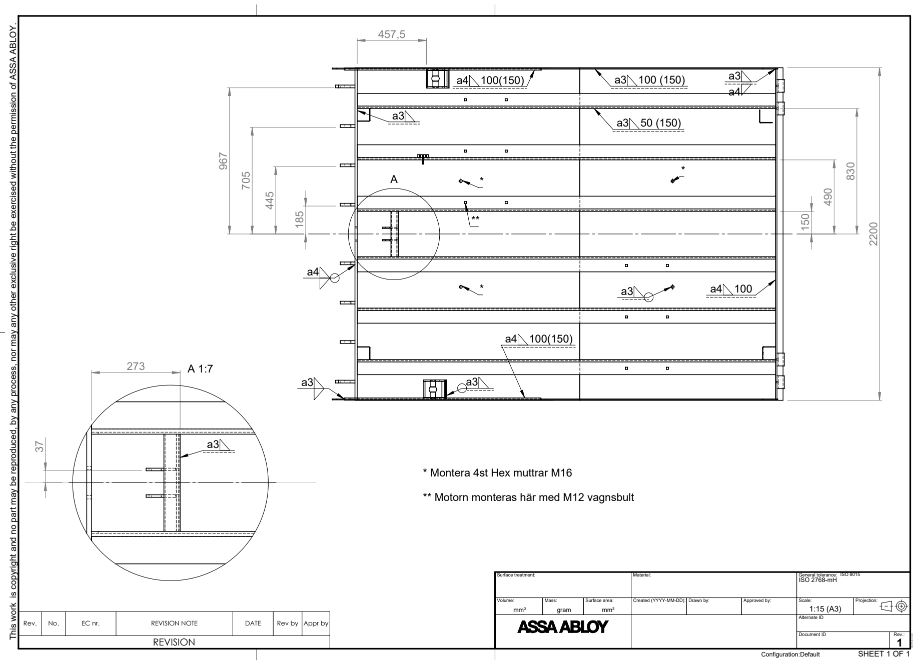
Hinges

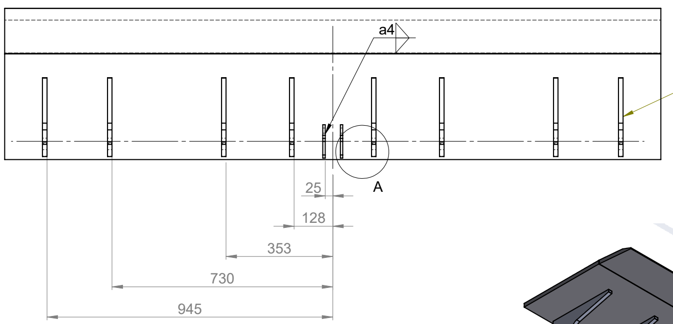
Selection criteria	Original (reference) Three-part solution	U-shaped support
		
Minimize no components	0	+
Durability	0	0
Ease of manufacturing	0	0
Ease of installation	0	+
Net score	0	+2
Continue?	No	Yes

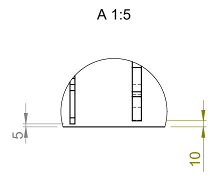
Appendix D: Thickness of Attachment

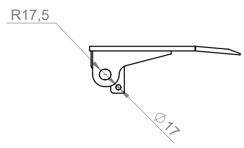
Thickness *same scale for stresses for all	
3 mm	
4 mm	
5 mm	
6 mm	
7 mm	

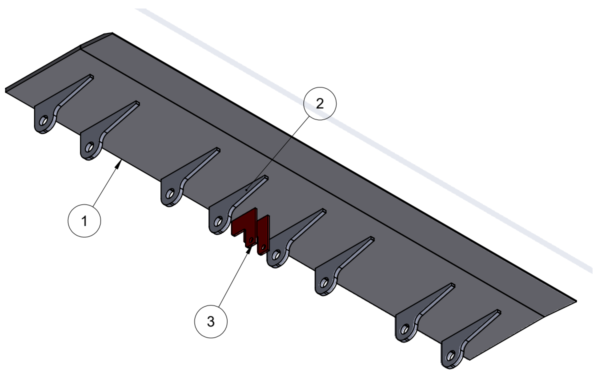
Appendix E: Selection of Drawings











ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TP_Lip		1
2	öron_lip_ovala hål		8
3	20200666 - PLATE 8X110-L=140		2

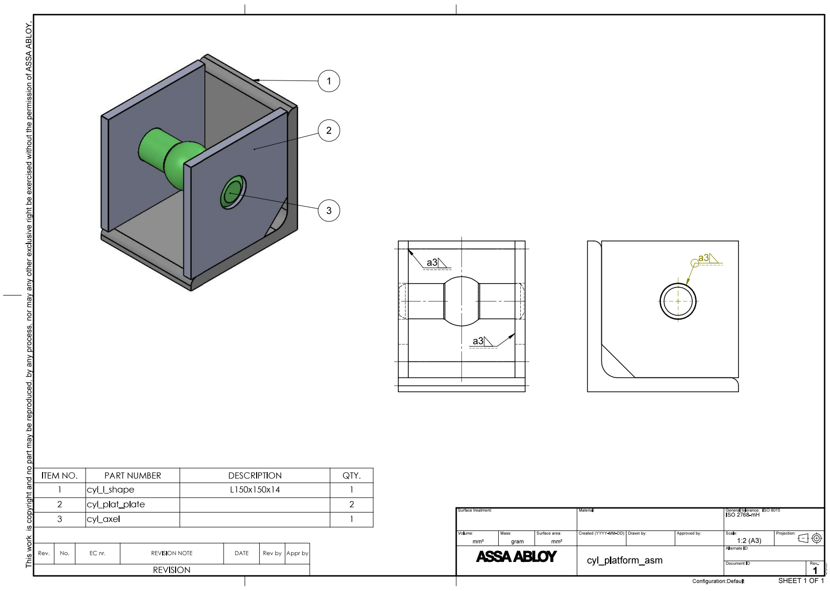
Rev.	No.	EC nr.	REVISION NOTE	DATE	Rev by	Appr by

REVISION

Surface treatment:	Material:			General tolerance: ISO 8015 ISO 2768-mH
Volume: mm³ / Mass: gram / Surface area: mm²	Created (YYYY-MM-DD)	Drawn by:	Approved by:	Scale: 1:10 (A3) / Projection:
ASSA ABLOY	lip_assembly			Alternate ID / Document ID / Rev.: 1

Configuration:Default

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	cyl_l_shape	L150x150x14	1
2	cyl_plat_plate		2
3	cyl_axell		1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	infästning_lång plattstång		1
2	infästning_vertikal platta med hål		3
3	infästning_småplatta		4
4	gångjärn_fyrkantsbit		2
5	gångjärn_rörbit		6
6	gångjärn_rundstång		2

Rev.	No.	EC nr.	REVISION NOTE	DATE	Rev by	Appr by
REVISION						

Surface treatment:			Material:			General tolerance: ISO 8015 ISO 2768-mH	
Volume: mm³	Mass: gram	Surface area: mm²	Created (YYYY-MM-DD):	Drawn by:	Approved by:	Scale: 1:10 (A3)	Projection:
ASSA ABLOY			Subassembly gångjärn och infästning			Alternate ID	
						Document ID	Rev.: 1

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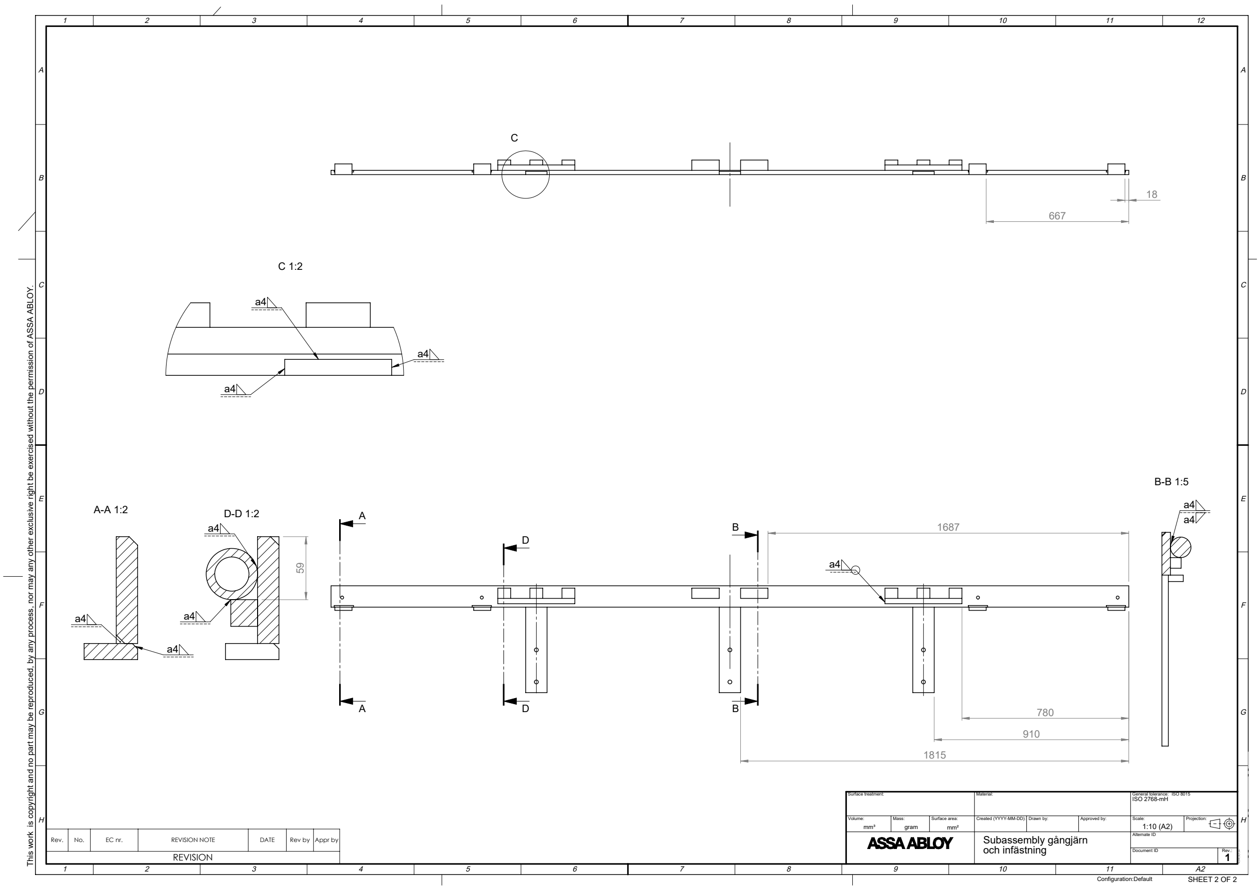
SHEET 1 OF 2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D-D 1:2
B-B 1:5
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667
1687
780
910
1815
Rev.
No.
EC nr.
REVISION NOTE
DATE
Rev by
Appr by
REVISION
ISO 2768-mH
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ASSA ABLOY
Subassembly gångjärn
och infästning
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A2
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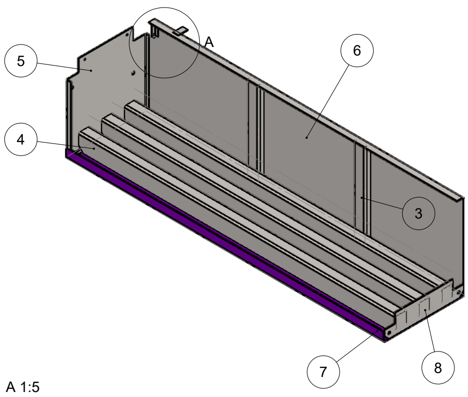
SHEET 2 OF 2



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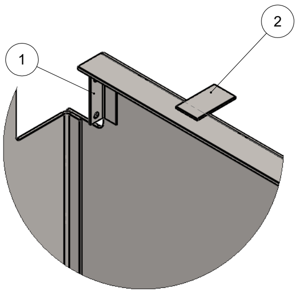


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	frame_fixeringsbit		1
2	frame_stöd_skyddsplåt		1
3	frame_U-balk vertikal		2
4	frame_U-balk_horisontell		3
5	frame_bockad_plåt_framsida		1
6	frame_bockad_plåt_insida		1
7	frame_tear plate		1
8	frame_infästningsplatta		1

Rev.	No.	EC nr.	REVISION NOTE	DATE	Rev by	Appr by
REVISION						

Surface treatment: | Material: | General tolerance: ISO 8015 ISO 2768-mH

Volume: mm³ | Mass: gram | Surface area: mm³ | Created (YYYY-MM-DD) | Drawn by: | Approved by: | Scale: 1:20 (A3) | Projection:

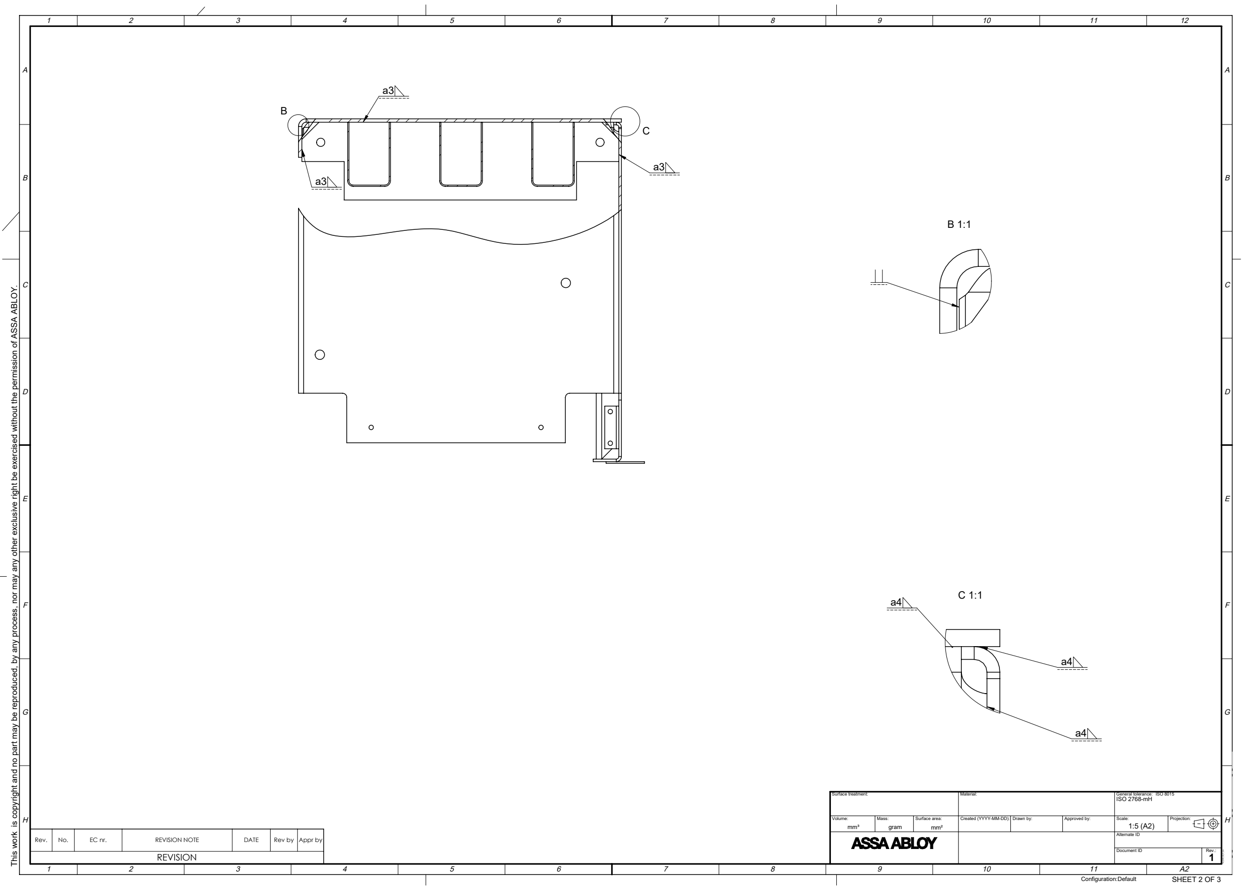
Alternate ID

ASSA ABLOY

frame vänster sida subassembly

Document ID | Rev.: 1

Configuration:Default SHEET 1 OF 3



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C
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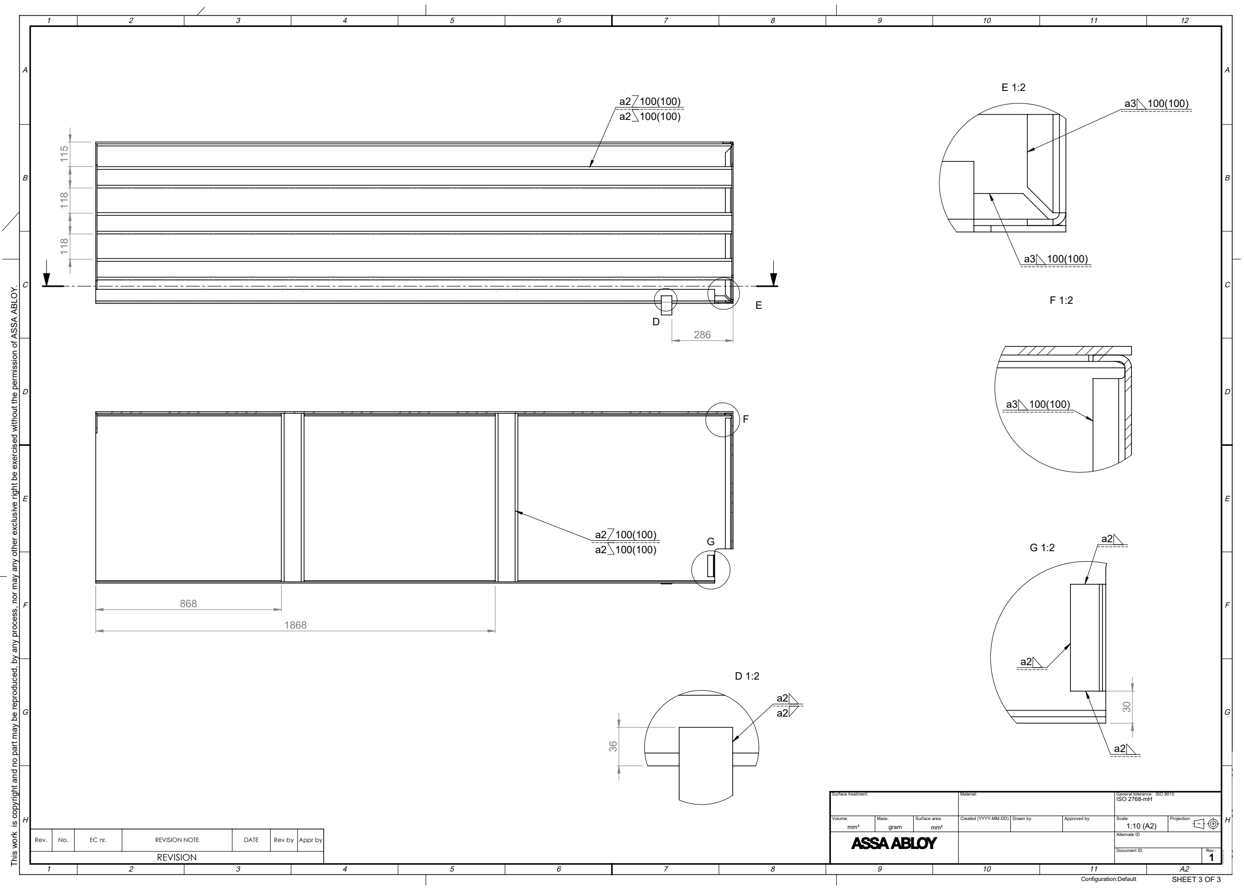
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F
G
868
1868
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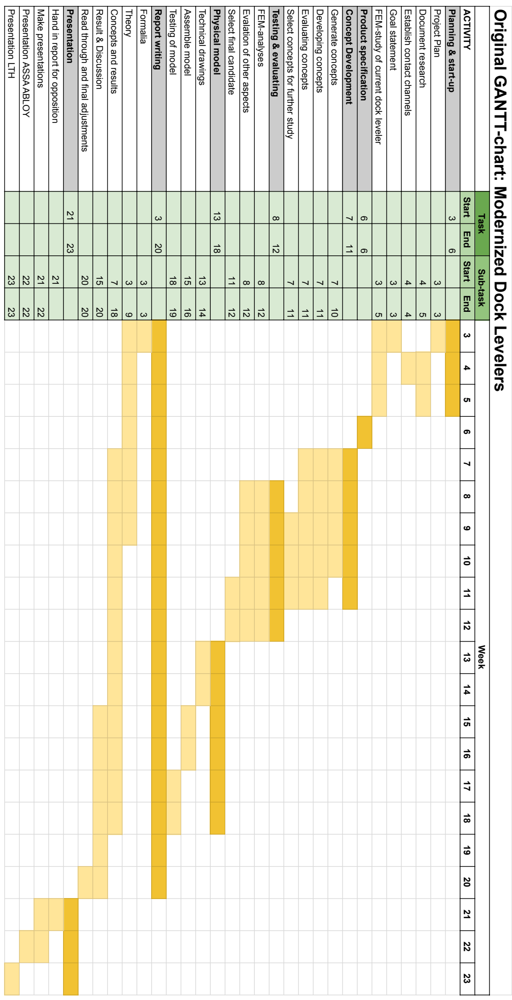
SHEET 3 OF 3

Appendix F: Gantt-charts

During the whole process, we worked simultaneously on the same things. When analysing the current models, Rebecka studied the 60 kN model, while Viola studied the 100 kN model as well as preformed most of the cylinder study. For the development of new concepts, Rebecka mainly worked with the components of the frame and platform while Viola worked with the cylinders and their attachments. For the writing and documenting process, Viola wrote a diary for each day spent working on the project. The report-writing was divided equally. Viola made the illustrations.



Actual GANTT-chart: Modernized Dock Levelers

	Task		Sub-task		Week																				
ACTIVITY	Start	End	Start	End	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Planning & start-up	3	9																							
Project Plan			3	3																					
Document research			4	5																					
Establish contact channels			3	3																					
Goal statement			3	3																					
FEM-study of current dock leveler			4	9																					
Product specification	6	6																							
Concept Development	9	14																							
Generate concepts			9	13																					
Developing concepts			9	14																					
Evaluating concepts			9	14																					
Select concepts for further study			12	14																					
Testing & evaluating	10	14																							
FEM-analyses			10	14																					
Evalation of other aspects			10	14																					
Select final candidate			11	14																					
Physical model	15	17																							
Technical drawings			15	17																					
Assemble model																									
Testing of model																									
Report writing	3	20																							
Formalia			3	3																					
Theory			3	8																					
Concepts and results			7	20																					
Result & Discussion			15	20																					
Read through and final adjustments			20	20																					
Presentation	20	23																							
Hand in report for opposition			20																						
Make presentations			21	22																					
Presentation ASSA ABLOY			22	22																					
Presentation LTH			23	23																					