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Design of Access Platforms for Pre-Fabrication of Offshore Wind Turbine Generator Foundations

Graduate thesis in Mechanical Engineering
Supervisor: Håkon Jarand Dugstad Johnson
May 2024

Graduate thesis

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REPORT BACHELOR THESIS

Title (Both in Norwegian and English):

Design of Access Platforms for Pre-Fabrication of Offshore Wind Turbine Generator Foundations.

Design av tilkomstplattform for pre-fabrikasjon av fundamentene til offshore vindturbin generatorer.

Project number:

MTP-K-2024-14

Author(s):

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Company (external):

Aker Solutions, Verdal

Supervisor NTNU:

Håkon Jarand Dugstad Johnson

Report is **OPEN**

Date submitted:

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Short abstract (Both in Norwegian and English)

English:
This project involved proposing a platform design for Aker Solutions' Wind Turbine Generator (WTG) foundation production to replace traditional scaffolding, aiming to save time and reduce costs. The design ensures a safe work environment, complies with relevant standards, and enhances production efficiency.

The platform was developed using an iterative design method with components designed in item24's engineering tool and SolidWorks. Steel tubes enhance stability by connecting upper and lower framework, with customized plastic bushings. Aluminium flooring dimensions were based on existing producer measurements. Work benches provide jacket accessibility, while safety measures like toe boards and knee rails reduce fall risks. Stairs incorporate parts from item24 and custom SolidWorks designs. The stairway includes a movable section for continuous access to the platform floor, adjusting with platform elevation.

The new platform offers personnel savings of 65,537 NOK per platform and an additional 23,375 NOK from increased efficiency. With a total cost of 464,078 NOK, the platform becomes profitable after 5.5 projects, or less than 17 months.

Norsk:
Dette prosjektet innebar å foreslå et plattformdesign for Aker Solutions' produksjon av fundamenter for vindturbin-generatorer. Den nåværende prosessen med stillas skal erstattes med plattformen, med mål om å spare tid og redusere kostnader. Plattformdesignet bidrar til et trygt arbeidsmiljø, overholder relevante standarder og forbedrer produksjonseffektiviteten.

Plattformen ble utviklet ved hjelp av en iterativ designmetode med komponenter designet i item24 sitt «engineering tool» og SolidWorks. Stålrør forbedrer stabiliteten ved å koble øvre og nedre ramme, med tilpassede plastdeler (bøssinger). Aluminiums gulvet er dimensjonert basert på eksisterende produsentmål. Arbeidsbenkene gir tilgang til jacketen, mens sikkerhetstiltak som tåbrett og rekkverk i knehøyde reduserer fallrisikoen. Trappene inneholder deler fra item24 og tilpassede SolidWorks-design. De inkluderer en bevegelig del, for kontinuerlig tilgang til plattformgulvet, som justeres med plattformhøyden.

De estimerte besparelsene i personalkostnader per prosjekt ved å bytte til plattformer er 65,537 NOK, med en ytterligere besparelse på 23,375 NOK takket være økt prosjekteffektivitet. Med de totale materialkostnadene for den designede plattformen estimert til 464,078 NOK, vil den bli lønnsom etter å ha fullført omtrent 5.5 prosjekter, eller mindre enn 17 måneder.

Stikkord:	Keywords:
Vindturbiner	**Wind-turbines**
Stillas	**Scaffolding**
Tidsoptimalisering	**Time optimization**
Aker Solution	**Aker Solution**
Styrkeberegninger	**Strength calculations**
3D-modellering	**3D-modeling**
Design	**Design**

Preface

This thesis is written by three students and submitted as part of the bachelor degree program in mechanical engineering at Norwegian University of Science and Technology.

The focus of the thesis is to carry out an actual mechanical engineering design for real-life industrial use, confronting challenges such as developing the design itself, and understanding and determining compliance with regulatory requirements. It involves conducting engineering calculations to validate strenght and safety requirements, conducting simulations in SolidWorks, and developing a risk management plan. Further, we determine the financial profitability of the project and prepare some of the neceessary manufacturing documentation. Due to time constraints, the project focused on core mechanical engineering aspects, while certain electrical and other details were left for the client to complete according to their preferences.

Throughout our bachelor's degree program, we have studied a wide range of subjects such as material science, 3D modeling and simulations, physics, strenght calculations, project management and more. The thesis team felt that engaging in a real-life industrial design project would not only pose a challenge but also offer a valuable learning experience. It provided an opportunity to combine and use the knowledge gained from these subjects in a practial setting. Futhermore, it will enhance our future careers by affording us a unique opportunity to independently manage a real-life project on our own.

Trondheim
20.05.2024

Marte Sjursen | Ingrid Marie Suphellen | Helene Waage Eikill

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We also want to thank our family members for reading our thesis, giving us feedback, and for their constant support through the entire bachelor degree program.

We would also like to extend our thanks to Aker Solutions in Verdal for the opportunity to collaborate on this project. Special thanks go to our contact, Anders Salberg Strand, for his invaluable time and support throughout the process. We are also grateful to Magnus Hardbak Nordvik, a Method Engineer at Aker, for allowing us to use his initial design as a foundation for our development. His assistance and insights on design have been crucial to our progress and success.

Abstract

This project involved proposing a platform design for Aker Solutions' Wind Turbine Generator (WTG) foundation production. The current procedure, traditional scaffolding, is time-consuming and costly due to extensive setup times and the need for repeated approvals for each scaffold. The objective of the thesis is to offer a design proposal for a platform to replace this current solution. This suggestion should provide a safe work environment, comply to relevant standards, reduce costs over time and enhance production efficiency.

The finalized 3D model of the platform has been developed following an iterative design method, ensuring compliance with standards. The main aluminium components were designed in item24's engineering tool. These models were then uploaded to SolidWorks, where missing components were designed and integrated into the assembly. To connect the upper and lower framework, steel tubes were selected and fitted inside the aluminium profiles, enhancing stability and safety. Plastic parts (bushings) were customized to shield the steel tubes from the aluminium profile. The aluminium flooring was dimensioned based off measurements from a specific producer already used by Aker. The stairs are composed of parts both from item24 and self-made designs in SolidWorks. Work benches are designed to provide accessibility to the jackets for the workers. Safety measures, such as toe boards and knee rails, are implemented to reduce risk of falls and promote a safer workplace. The stairway consists of a static and movable section, with the latter rising from 2.5m to 4m in line with the elevation of the platform. The movable stairs ensure continuous access to the platform floor.

The estimated savings in personnel costs per project from switching to platforms is 67,238 NOK, with an additional 23,375 NOK saved by the increased project efficiency. With the total material cost of the designed platform being estimated to 464,078 NOK, it will become profitable after completing approximately 5.5 projects. Assuming the client undertakes similar projects, each lasting three months, this amounts to less than 17 months in time.

Sammendrag

Dette prosjektet omfatter å foreslå et plattformdesign for Aker Solutions' produksjon av fundamenter for vindturbin-generatorer. Den nåværende prosessen med stillasoppsett er både tids- og kostnadskrevende, grunnet langvarige oppsettsprosesser og kravet om gjentatte godkjenninger for hvert enkelt stillas. Målet med oppgaven er å presentere et designforslag for en plattform som skal kunne erstatte den nåværende løsningen. Forslaget bør gi et trygt arbeidsmiljø, overholde relevante standarder, redusere kostnader over tid og forbedre produksjonseffektiviteten.

Den endelige 3D-modellen av plattformen er utviklet ved hjelp av en iterativ designprosess, som sikrer at standardene blir overholdt. De viktigste aluminiumkomponentene ble designet i item24 sitt ingeniørverktøy. Disse modellene ble deretter lastet opp i SolidWorks, der manglende komponenter ble designet og integrert i sammenstillingen. For å koble den øvre og nedre rammen ble stålrør valgt og montert inne i aluminiumsprofilene, noe som øker stabiliteten og sikkerheten. Plastdeler (bøssinger) ble tilpasset for å beskytte stålrørene mot aluminiumsprofilene. Aluminiumsgulvet ble dimensjonert basert på målinger fra en spesifikk produsent allerede brukt av Aker. Arbeidsbenker er designet for å gi arbeiderene lettere tilgjengelighet til fundamentdelen. Sikkerhetstiltak, som tåbrett langs kanten på plattformen og et rekkverk i knehøyde, er implementert for å redusere risikoen for fall og dermed fremme et tryggere arbeidsmiljø. Trappene består av deler både fra item24 og egenproduserte design i SolidWorks. De består av både en statisk og bevegelig seksjon, der sistnevnte stiger fra 2.5 m til 4 m i takt med plattformens høyde. De bevegelige trappene sikrer kontinuerlig tilgang til plattformgulvet.

De estimerte besparelsene i personalkostnader per prosjekt ved å bytte til plattformer er 67,238 NOK, med en ytterligere besparelse på 23,375 NOK takket være økt prosjekteffektivitet. Med de totale materialkostnadene for den designede plattformen estimert til 464,078 NOK, vil den bli lønnsom etter å ha fullført omtrent 5.5 prosjekter. Hvis klienten gjennomfører lignende prosjekter, hver med en varighet på tre måneder, vil dette tilsvare mindre enn 17 måneder.

Definitions

Terminology

Chassis: The foundational component of the platform that ensures stability, that can be pushed, pulled or stationary.

Totally Manually Powered MEWP: A MEWP that operates solely through manual effort for movement.

Personal Fall Protection System: Safety setup including harnesses, lanyards, anchors, and connectors to prevent falls and minimize injury.

Jacket: Refers to the main cylindrical structure in Wind Turbine Generators(WTG)-foundations.

Leg: A structural component of a WTG jacket. Each leg is part of a junction point that connects to the jacket.

Notation

, - Indicates thousands separator, as in 10,400 for ten thousand four hundred.

. - Indicates decimal separator, as in 10.400 for ten and four hundredths.

N - Newton

m/s2 - Acceleration in meters per sqare second

m/s - Velocity in meters per second

NOK - Norwegian kroners

g - grams

kg - kilograms

m - meters

cm - centimeters

mm - millimeters

RPM - Rounds per Minute

N/mm^2 - Newtons per square millimeter

°C - Degree celsius

Acronyms and Abbreviations

Aker - Aker Solutions - Aker Solutions Verdal

MEWP - Mobile Elevating Work Platform

WTG - Wind Turbine Generator

AC - Alternating current

DC - Direct current

BLDC - Brushless DC motor

STP - Stepper motor

POM - Polyoxymethylene (technical thermoplastic type)

A2 - A specific working hall at Aker

VPL - Another specific working hall at Aker

CoM - Center of Mass

FEM - Finite Element Method

FEA - Finite Element Analysis

CAD - Computer-Aided Design

UN - United Nations

SDG - Sustainable Development Goals

PDE - Partial Differential Equation

ESTRN - Engineering Strain

SF - Safety Factor

DL - Distributed load

PL - Point load

BOM - Bill of Materials

Contents

1 Introduction

This report outlines the development of a specialized work platform designed to enhance the efficiency and cost-effectiveness of assembling Wind Turbine Generator (WTG) jackets. Initiated by Aker Solutions, the project seeks to optimize construction methods, reduce operational costs, and improve productivity in jacket assembly processes.

1.1 Background

The initiative for this thesis was provided by Aker Solutions with the goal to develop a platform more efficient than the conventional scaffolding currently used in the production of WTG jackets.

Currently, the scaffolding process at Aker involves constructing new scaffolds or reassembling old ones for each production stage. This process starts for each jacket entering the facility and requires partial dismantling for rotations, leading to high resource consumption, increased expenses, and a significant cost burden for Aker, as these costs are not covered by production buyers. Implementing a movable platform could provide a more efficient and cost-effective solution.

Figure 1: Current scaffolding setup in working hall A2 at Aker Solutions, with jackets lying horizontally.

WTG jackets, the primary focus of this platform, are cylindrical structures that stand several meters tall. Workers frequently operate at heights between three and four meters above the ground. Given the significant height at which workers operate, ensuring safety on these platforms is critical. The diameters of these jackets vary from one project to another, emphasizing the need for a platform that can adjust to different sizes.

The assembly process of WTG jackets includes welding junction points, each made up of two legs, onto the cylindrical structure. The junction points are illustrated in Figure 2, to the left, showing a jacket with one junction point (two legs). Workers perform their tasks atop the jackets, and as the second leg of a junction is welded, rotation of the structure may lead to one of the legs obstructing the platform, as depicted in Figure 2 to the right. Consequently, a significant aspect will be to create a platform that not only supports varying jacket sizes but also accommodates their rotation, thereby increasing efficiency of the workflow and enhancing the production.

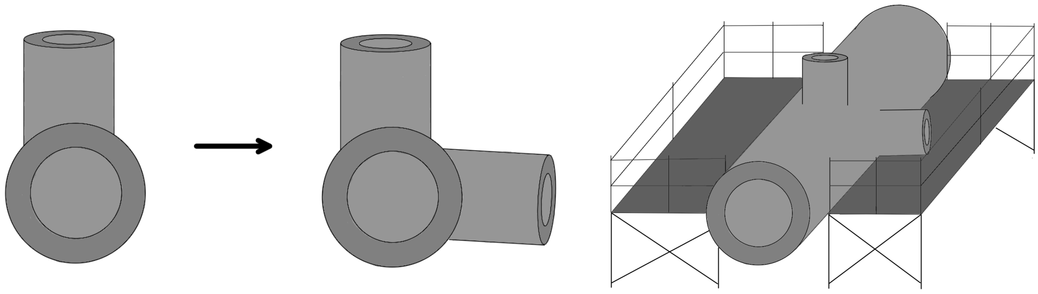

Figure 2: To the left; WTG jacket with one junction point, in reality there will be two of these welded onto the jacket. To the right: Two platforms on each side of WTG-jacket.

To provide a clearer understanding of how the work on the jacket is conducted, a flow chart has been developed, shown in Figure 3. This flow chart illustrates the process for constructing a jacket with a single rotation.

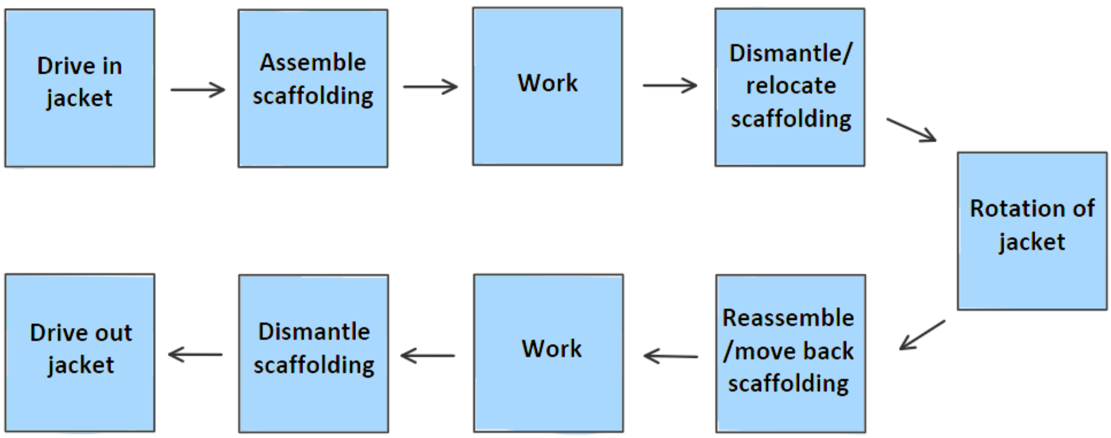

Figure 3: Flow chart of traditional scaffolding with one rotation.

1.2 Problem Formulation

Propose a design for access platforms for pre-fabricating offshore WTG foundations.

Considerations to be made:

- Logistics within the workshop

- Transport of the structures
- Size
- Adjustability
- Functionality requirements (weight allowance, equipment etc.)
- Cost
- Production process
- Safety
- Regulatory compliance
- Adaptability to future projects
- Durability
- Sustainability

1.3 Objectives

Traditional scaffolding methods are deemed inadequate due to their slow pace, requiring platforms that are easier to move and integrate into the established process. The main objective is to develop platforms that enable safe and efficient access for various disciplines involved in installation, welding, pre-heating, dimensional control, and Non-Destructive Testing of WTG jackets.

1.3.1 Outcome Goals

The *main objective* of the project is:

- **To design an access platform for the production WTG jackets that can replace the existing scaffolding currently used by Aker.**

This should result in a reduction in setup time, thereby reducing labor cost and increasing production efficiency. The saved labor allows Aker to complete the production in less time, thus leading to lower costs and higher profits or better ability to compete for future orders.

Additional goals that need to be successfully accomplished in order to achieve the main objectives are:

- Ensure that the structure provides a safe work environment that follows relevant regulations and standards.
- Develop a solution that is cost-effective both in terms of initial setup and long-term maintenance when compared to traditional scaffolding.
- Aiming for simplicity and efficiency in construction and deconstruction of the structure, thus reducing downtime.
- Consider the environmental impact and aim for eco-friendly materials.
- Durable design that is capable of withstanding various work environments, especially the work conditions special to plating and welding.
- Satisfaction among all stakeholders, including workers and project managers.

1.3.2 Effect Goals

In this project the focus extends beyond the technical outcomes to include personal and professional development goals. These "effect goals" encompass the acquisition of specific skills and knowledge that will enhance our capabilities and understanding of the engineering field. Here, it is detailed which experiences and insights we aim to acquire throughout the project.

- Gain experience of the design processes used in professional settings, particularly focusing on how complex engineering projects like the adjustable access platform are conceptualized and executed at Aker Solutions.
- Gain expertise in 3D modeling and simulation by developing a detailed model of the access platform, which will include simulations to test design integrity and functionality.
- Gain insights into the dynamics within the professional work environment through collaborative efforts across departments, observation, meetings, and interviews with Aker personnel.

1.4 Limitations

While the specialized work platform aims to address challenges associated with current scaffolding procedures for WTG jackets, certain limitations are present:

- Constructing and testing a physical prototype within the timeline of the study is not feasible. Therefore, in designing the access platforms, feedback from individuals at Aker we will be incorporated to create a concept that is believed to perform well. If the design gets further developed, the resulting protoype will have to be tested by Aker.

- The tailored platform design to the specific requirements may not be universally applicable. Modifications may be necessary for different project specifications.
- Limitations in available materials, manufacturing processes, and budgetary constraints may restrict the final design of access platforms.

1.5 Structure of the Report

The report starts with preliminary sections such as the Preface and Acknowledgements. It then transitions into the Introduction, which covers the Background, Objectives, and Theoretical Basis, including topics like Newton's Laws and the Finite Element Method. Subsequent sections provide detailed discussions on Methods, Compliance with Standards, Results, Budgeting and Risk Assessment. The report wraps up with a Conclusion that summarizes the findings and Appendices that offer additional details.

2 Theoretical Basis

This section outlines the fundamental theories used in the design of the access platform. It covers key concepts including stress, strain, and the mechanics of motion, supported by relevant equations and principles from established sources. These basic theories help us understand and analyze the structure of the platform and it's mechanics.

2.1 Stresses

Stress is a quantity that describes the amount of forces causing deformation in a material when it is subjected to external forces [2]. Stress is often defined as force per unit area, as shown in Equation 1 below. The force (F) is the applied force acting perpendicular to the area (A). The area is the cross sectional area over which the force is distributed [77].

$$\sigma = \frac{F}{A} \tag{1}$$

Bending stress, σ_b, is a measurement of the initial forces that occurs in a beam when it is bent by a load. This is calculated using Formula 2 given under. When a beam is subjected to a bending moment, it will deform and take on a curvature. This results in tension on the underside of the beam, while the top side gets compressed, as Figure 4 illustrates. Inside the beam, there is a transition from tension to compression, and in this transition zone there is no elongation, only curvature [49].

$$\sigma_b = \frac{M}{I} \cdot z \tag{2}$$

M = The bending moment acting on the cross-section

z = distance from the neutral axis

I = The moment of inertia of the beam‘s cross section

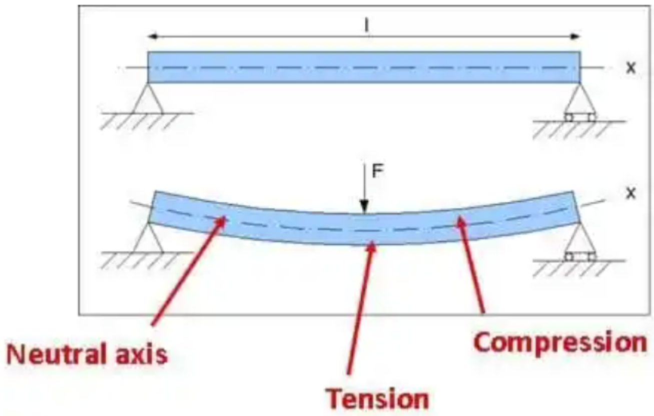

Figure 4: Tension and compression in a beam exposed to a load [13].

The amount of stress a material can withstand before permanent deformation occurs is called yield strength. Factors like material composition, temperature and processing will influence the yield strength of the material, making it different for every material *yield strength*. For the material to be able to withstand permanent formation, the acting forces have to result in a lower stress than the yield strength of the material. This is the basis for Equation 3.

$$\sigma < \text{Yield Strength} \tag{3}$$

2.2 Strain

Strain, also known as relative elongation, is the deformation or alteration in the shape of a material that occurs due to an applied force. Strain occurs by the fractional change in length (tensile-strain), volume (bulk-strain) or geometry (shear-strain), and can be related to stress with Equation 4.

$$\sigma = E \cdot \epsilon \tag{4}$$

σ = Stress

E = Young's Modulus for tensile stress, Bulk Modulus for bulk stress or Shear Modulus for shear stress

ϵ = Strain, which is defined as the proportion of the change in length of a material relative to its initial length [82].

Strain is a dimensionless quantity that can be both elastic and plastic. Elastic strain implies that the materials return to their original shape when the force is removed, while plastic strain results in permanent deformation [50].

2.3 Displacement

Displacement refers to the distance one specific particle in an oscillating system is from its usual position [31]. In a beam, displacement describes how much a point on the beam moves away from where it would normally be if no external forces were acting upon it [31].

2.4 Trigonometry

The three basic trigonometric functions are; sine (sin), cosine (cos) and tangent (tan) [75], expressed below Figure 5.

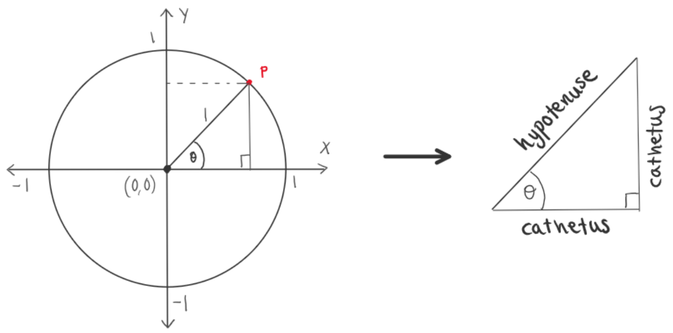

Figure 5: Geometric illustration of cathetus, hypotenuse and cathetus [75].

$$\cos\theta = \frac{\text{Length of the adjacent cathetus}}{\text{Length of the hypotenuse}}$$

$$\sin\theta = \frac{\text{Length of the opposite cathetus}}{\text{Length of the hypotenuse}}$$

$$\tan\theta = \frac{\sin\theta}{\cos\theta} = \frac{\frac{\text{Length of the opposite cathetus}}{\text{Length of the hypotenuse}}}{\frac{\text{Length of the adjacent cathetus}}{\text{Length of the hypotenuse}}} = \frac{\text{Length of the opposite cathetus}}{\text{Length of the adjacent cathetus}}$$

2.5 Finite Element Method

The Finite Element Method (FEM) is a numerical technique used to perform a Finite Element Analysis (FEA) to predict the behavior of a structure concerning any specific physical phenomen [84].

For many geometries and problems, Partial Differential Equations (PDE) cannot be solved analytically, and the alternative is using numerical methods with discretization. Therefore, the solutions obtained are approximations to the real solutions to the PDEs. The FEM is a method that subdivides a complex space or domain into smaller, finite pieces, described by simpler Equations [84].

FEM can analyze different aspects, like the structural mechanics of parts under various loads, heat flow in engine components, or electromagnetic radiation distribution from antennas. An important aspect of FEM involves the preparation and subdivision of the Computer-Aided Design (CAD) model during meshing, where it is discretized into smaller elements as shown in Figure 6 [84].

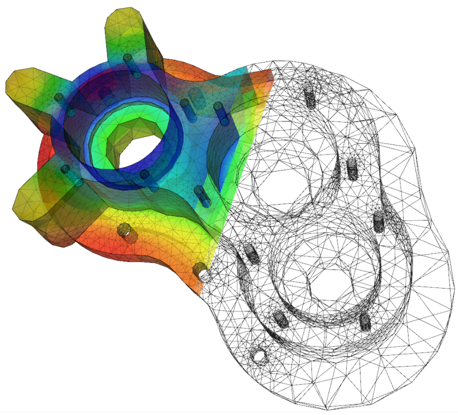

Figure 6: Example of Finite Element Mesh [84]

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2.6 Newton's Laws

2.6.1 Newtons 1. Law

Newton's First Law, also known as the law of inertia, states that an object will stay at rest or move at a constant velocity unless acted upon by a net external force [53]. This is expressed in Equation 5:

$$\sum \vec{F} = 0 \implies v = constant \tag{5}$$

$\sum$F = sum of all external forces

v = velocity of the object.

If the sum of the forces equals zero, the object's velocity does not change.

2.6.2 Newtons 2. Law

Newton's second law, shown in Equation 6, is a fundamental principle in physics that offers a precise understanding of how forces influence the motion of objects. It claims that the rate of change of momentum of an object is directly proportional to the force acting upon it, and occurs in the same direction. Since momentum is a vector, a quantity with both magnitude and direction, any force applied to an object can alter its momentum by changing its speed, direction, or both [53].

$$\vec{F} = m \cdot \vec{a} \tag{6}$$

$\vec{F}$ = force

$\vec{a}$ = acceleration

m = mass

2.6.3 Newtons 3. Law

$$\vec{F}_{AB} = -\vec{F}_{BA} \tag{7}$$

Newton's third law, Equation 7, which is often referred to as the law of action and reaction, states that interacting bodies exert forces on each other that are equal in magnitude and opposite in direction. This law applies to both static and dynamic scenarios. For example, an apple resting on a table exerts a downward force equal to its weight, and in response, the table exerts an upward force of equal magnitude but opposite direction. If a body is not accelerating, it indicates that the acting forces are balanced or absent, thus not resulting in any net force [53].

2.7 Moment

A moment is a measurement for a force's tendency to cause rotation of an object, about a point or axis. Moments occur when the force applied does not pass through the centroid of the object.

Equation 8 defines the magnitude of the moment [90].

$$M = F \cdot \text{Lever Arm} \tag{8}$$

M = Moment

F = Force

Lever Arm = The perpendicular distance from the action line for the force and the center of moments

2.8 Friction

When attempting to move an object along a surface, like a table, resistance is encountered. The table applies a force to the object in the opposite direction of the motion. This occurrence is termed frictional force. Two types of friction forces exist: kinetic friction and static friction [56].

2.8.1 Kinetic Friction

Figure 7 shows an object affected by two horizontal forces. A force F is applied to the right, causing the object to slide in that direction. Consequently, a frictional force R acts to the left [56].

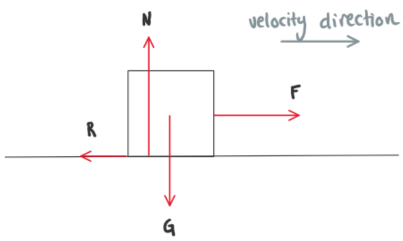


Figure 7: Illustration of friction with different forces [56].

Frictional forces always oppose motion, and are always perpendicular to the contact surface. Since the normal force (N), which is the force exerted on the block by the surface, is always perpendicular to the contact surface, the frictional force (R) is always proportional to the normal force. The proportionality constant μ is known as the coefficient of friction and is a dimensionless number. The formula is shown in Equation 9 [56]:

$$\vec{R} = \mu \cdot \vec{N} \tag{9}$$

$\vec{R}$ = frictonal force

μ = coefficient of friction

$\vec{N}$ = normal force

2.8.2 Static Friction

If an object cannot be moved when pulled, it indicates that the frictional force is sufficient to prevent motion. According to Newton's first Law, the frictional force must then be bigger than the applied force (R > F). Typically, the coefficient of static friction μ_s is greater than that of kinetic fricton. Static friction follows the same law as Equation 9 for kinetic friction [56].

2.8.3 Rolling Friction

During rolling of a circular object, for example a wheel, the friction work in a similar manner as for the kinetic and static frictions. The forces working on the wheel can be positioned as in Figure 8, where the friction works opposite to the force applied. In this case, the friction force can be obtained by multiplying the friction coefficient by the normal force of the object. However, the friction coefficient will be significantly lower for a rolling object than for a static one [32].

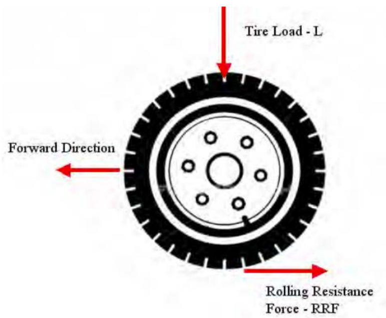


Figure 8: The forces a wheel is subjected to during rolling [51].

2.9 Tipping

Tipping, in this project, is defined as when a object is tilted at such an angle that gravity alone would cause it to overturn.

There are several ways of defining when tipping will occur. One of which is to compare tipping moment with the stabilizing moment of the object [4]. Another is to look at the Center of Mass (CoM) and determine at what point its vertical projection travels outside the objects tipping lines, where the tipping lines are the vertical lines from the outer contact point as depicted in Figure 9 [1].

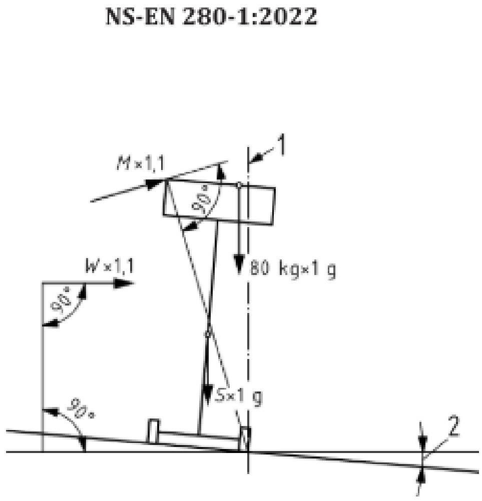


Figure 9: A descriptive picture of an example platform with it's corresponding tipping line (1) taken from the standard NS-EN 280-1:2022.

Tipping occurs when the CoM passes the tipping lines [1]. At this point gravity will cause rotation of the object, because of the change in the direction of the normal force for the object, resulting in tipping.

The tipping moment of an object is defined as the moment equal to the stabilizing moment of the same object as written in Equation 10.

$$M_{tipping} = M_{stabilizing} \tag{10}$$

The stabilizing moment is the moment caused by the structure‘s own mass, which prevents it from tipping.

$$M_{stabilizing} = N \cdot \text{Distance from CoM to critical tipping line} \tag{11}$$

The stabilizing moment can be found by multiplying the normal force (N) of the object by the arm from CoM to the critical tipping line as shown in Equation 11.

2.10 Buckling

Buckling is defined as the critical value at which a sudden deformation of an object subjected to compression occurs. This is a sudden phenomenon categorized as a failure mode because of the permanent damage it does to the object. This is especially common for vertically mounted columns [87].

2.10.1 Effective Length Factor

To account for the restraint at the ends of the columns, the length of the columns will be multiplied by a factor (Effective Length Factor) that represents the degree of restraint. This is because of the different shapes that each end condition results in. The different factors and their correlated conditions are depicted in Figure 10:

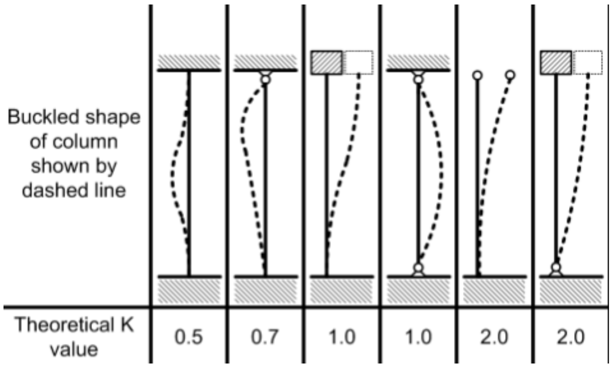


Figure 10: Different effective length factors for buckling and their corresponding restrain-types [24].

2.10.2 Euler's Buckling Formula

Euler's buckling formula, Equation 12, helps find the critical axial load (F_{CR}) which leads to buckling of the column [87].

$$F_{CR} = \frac{\pi^2 EI}{KL^2} \tag{12}$$

E = Young's modulus

I = Second moment of inertia

K = Effective length factor

L = Length of the column

2.10.3 Slenderness Ratio

To define how slender columns are, Equation 13 compares the cloumn's length with how thin it is. By looking at Equation 12, it can be determined that a longer column would have a smaller critical load, therefore a higher slenderness ratio would imply a higher risk of buckling.

$$\lambda = \frac{KL}{\sqrt{\frac{I}{A}}} \tag{13}$$

λ = Slenderness Ratio

A = Cross-sectional area

By combining Euler's buckling formula and slenderness ratio, the Euler critical buckling stress can be found. The formula for this buckling stress is shown in Equation 14.

$$\sigma_{CR} = \frac{\pi^2 EI}{(KL)^2 A} \tag{14}$$

The critical buckling stress (σ_{CR}) expresses the critical stress at which buckling occurs [87].

A column or member can be categorized as either "short", "long" or "intermediate" based on its slenderness ratio. A short member would not be prone to buckling, but rather to the material yielding, whereas a long member will most likely buckle before the material's yield strength is reached. The intermediate members should be checked for both to ensure safety.

Based on "A Guide to Unbraced Lengths, Effective Length Factor (K), and Slenderness" [5] the lengths of a steel member is categorized as "short" when its slenderness ratio is below 50, "intermediate" when its between 50 and 200, and "long" when the slenderness is above 200. For concrete the limit is 10 between "short" and "long" members. As for aluminium, which is closer to steel than concrete in material properties, the categories are assumed to be approximately:

Short = < 30

Long = > 100

Intermediate = $\in [30, 100]$

2.11 Motors

The motor's role in this thesis is to supply energy to the actutators, which then convert this energy into movement for adjusting the platform's height. The relevant motor types for this thesis are electrical and combustion.

Electrical motors convert electrical energy into mechanical energy through rotation and are used in various applications. They harness magnetic force to generate motion, categorized into DC and AC motors [20, 12]. AC motors, simpler in construction, are favored in industrial automation[12]. Universal motors can operate with both AC and DC power [88].

Internal combustion engines convert fuel energy into mechanical work through internal combustion, driving either a turbine wheel or a piston [14].

Alternatively, energy could be supplied directly from the AC mains to the platform.

2.12 Actuators

An actuator is a device used to move or control a mechanism or system. It works by using a source of energy, such as electric current, hydraulic fluid pressure, or pneumatic pressure, and transforms this energy into motion. Essentially, it is the component through which a control system interacts with its environment. Control systems using actuators can vary from simple mechanical or electronic configurations to more intricate software-based systems [7]. In this project, actuators are used as part of the system to move the platform vertically.

2.12.1 Hydraulic Cylinder

Hydraulic cylinders are devices that use fluid power to generate force and motion. They consist of a cylinder filled with hydraulic fluid, usually oil, and a piston that moves back and forth inside it [40]. Figure 11 illustrates its composition, while the enumeration below describes its functionality.

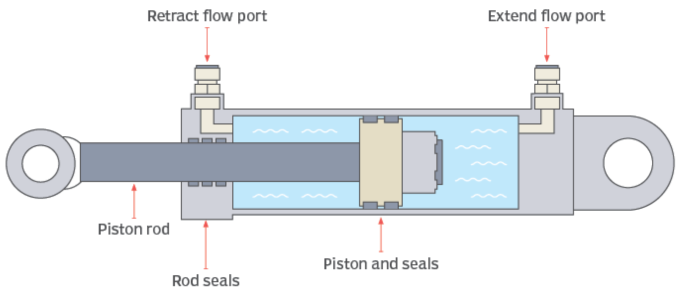


Figure 11: How a hydraulic piston works [91].

Hydraulic fluid is pumped into the cylinder, creating pressure that moves the piston, extending or retracting the rod. The fluid's volume and pressure determine the force exerted by the piston. Valves control the flow and direction of the hydraulic fluid, ensuring it reaches the correct chamber to produce the desired movement. A reservoir holds the fluid before it is pumped into the cylinder and returns it after use [40].

In short, hydraulic cylinders convert the potential energy stored in hydraulic fluid into mechanical movement, making them essential components in various industries for tasks requiring heavy lifting, precise motion control or both [40].

2.12.2 Pneumatic Cylinders

Pneumatic cylinders, or pneumatic actuators, are devices used to provide linear or rotary motion and force in various automated systems and machines. They operate by utilizing compressed air to move a piston inside the cylinder, which in turn performs the desired mechanical action, such as lifting or clamping [89]. Figure 12 illustrates the pneumatic process.

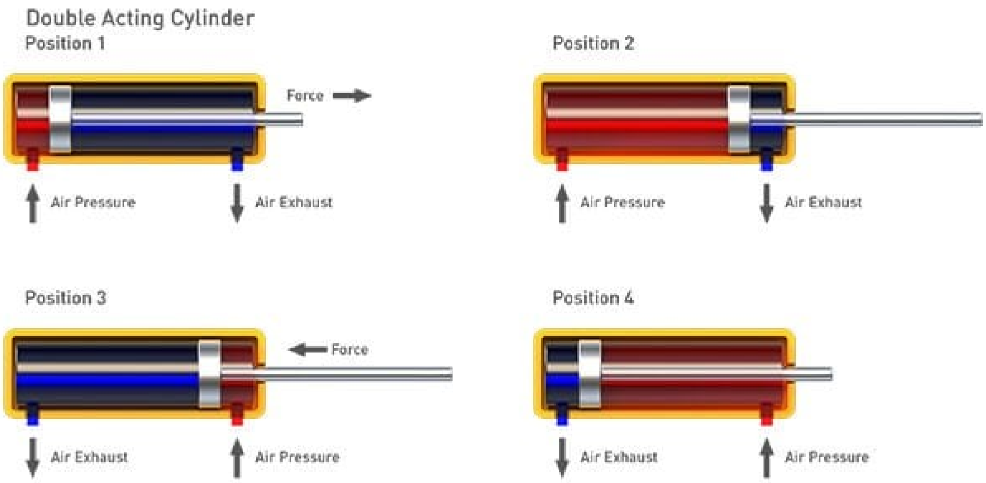


Figure 12: How double acting pneumatic cylinders works [16].

The main difference between hydraulic and pneumatic cylinders is the medium they use to generate motion. Hydraulic cylinders use hydraulic fluid (oil), while pneumatic cylinders use compressed air. Hydraulic systems offer higher force output and are suited for heavy-duty applications, while pneumatic systems provide faster response times and simpler control mechanisms [44].

2.12.3 Electric Cylinders

Electric cylinders are powered by an electric motor that actuates gears, which in turn either turn a screw or drive a belt to move the load [92]. Electric cylinders offer precise control over movements and positions, which is essential for ensuring stability and synchronization. This precision allows for exact adjustments and consistent operations across multiple actuators [17].

Electric cylinders do not require the complex and space-consuming infrastructure that hydraulic and pneumatic systems need, such as pumps, compressors, and fluid reservoirs, reducing installation complexities and operational costs. Electric cylinders are quieter and cleaner, as they avoid fluid leaks and air system contaminants. Hydraulic and pneumatic systems have higher costs associated with the maintenance of additional components like pumps and compressors [17].

2.12.4 Jack Screw Actuator

An electric motor rotates a lead screw that makes a bolt rise. The translation of motion from motor to linear motion is achieved through a mechanical linkage system. The rotation of the screw is converted to linear motion by engaging with a threaded nut. The interaction between these components translates rotational motion into linear movement [47].

These actuators are known for their strength and stability, allowing them to lift heavy loads. They are easy to integrate into various products, usually requiring only a power source to operate, and are used in applications from adjustable desks to medical equipment [74]. To ensure reliability in industrial environments, they need protection from dust and debris [73].

2.13 Materials

2.13.1 Aluminium

Aluminium is a lightweight metal with a melting point of 660.1 °C, and a density of 2.699 g/cm^3. It is easy to shape and process through methods such as rolling, pressing, and extrusion. Pure aluminum offers good corrosion resistance and workability, to enhance its mechanical properties, aluminum is commonly alloyed with other metals [8].

Relevant Aluminum Types for This Thesis:

- **EN AW-5754 (H111) Aluminum [83]:**

  Density at 20 °C : 2.66 kg/dm^3.

Thickness: 4 mm

Tensile Strength : 190-240 MPa

Yield Strength : 80 MPa

- **Aluminium from item24 [45]:**

  Yield strength : 195 MPa.

  Young's modulus: E = 70,000 MPa

2.13.2 Steel

Steel is an alloy of iron and carbon, with a maximum of two weight percent carbon. Steel can also contain other alloying elements. Different types of steel have a diverse range of properties that can be tailored to various applications, making it highly versatile as a construction material.

The properties of steel depend on factors such as composition, forming process, and heat treatment. This allows steel to be customized with properties such as strength, hardness, toughness, fatigue resistance and corrosion resistance, according to specific requirements and applications. As a result, steel is used in a wide range of applications in construction, transportation, manufacturing, and many other fields [79].

The relevant steel type for this thesis is:

- **S355J2H steel**. A non-alloy structural steel.

  Yield strength : 355 MPa.

  Tensile strength : between 470-630 MPa.

  Despite steel's susceptibility to corrosion, its strength and cost-effectiveness make it an optimal choice for structural applications [71].

2.13.3 POM - Polyoxymethylene

POM, also known as polyacetal, maintains high levels of strength, stiffness, and abrasion resistance across a wide range of temperatures. This material typically exhibits a crystalline content of 70-80%. It has a melting point of 166 °C for copolymers, and 178 °C for homopolymers [58]. The dimensional stability, fatigue strength, and machinability of POM make it highly adaptable for engineering purposes, especially in the design of mechanical components [59]. Known as a self-lubricating material, POM has low friction, making it resistant to wear and tear [6].

Tensile strength : 71.5 MPa, according to the SolidWorks material database.

2.14 Lifting Mechanisms

Lifting mechanisms consists of components working together to lift vertically. These mechanisms are important in the industrial sector, enabling effective vertical lifting. They are designed to lower, lift, or move heavy objects in a safe and effective manner [23].

2.14.1 Jack Mechanism

A jack is a tool used to lift heavier objects, and is divided into two main types, mechanical jacks and hydraulic jacks [46, 43]. Mechanical jacks transfer forces through gears or screw mechanisms. Hydraulic jacks are constructed with lifting cylinders and hydraulic pumps [43].

For this thesis, the focus is on mechanical scissor jacks.

Mechanical Scissor Jacks:

Characterized by their distinctive 'X' or scissor-like mechanism, scissor jacks are operated by turning a screw which expands or contracts the mechanism. This design allows for considerable force amplification with minimal effort, making them particularly useful for lifting vehicles during tire changes or undercarriage repairs [72].

The mechanism works through a lead screw interacting with the scissor arms, turning the screw in one direction causes the arms to extend and lift the load. Reversing the direction of the screw movement causes the arms to contract, and lowering the load. This design maximizes mechanical advantage, and allows the jack to collapse down into a compact form for easy storage and transport [72].

Advantages:

- Compact Storage: When not in use, scissor jacks collapse into a flat, compact shape [72].
- Ease of Use: Typically equipped with a simple winding mechanism that requires minimal physical effort to operate [15].

Disadvantages:

- Limited Lift Height and Weight: Scissor jacks have a restricted range of lift height and are often rated for lighter loads, which limits their use to specific scenarios [15].

- Safety: Due to the scissor action, scissor jacks pose a serious pinching/crushing/cutting danger.

2.14.2 Static Lifting Columns

Static lifting columns, inspired from car lifts, offer a robust and trustworthy method of elevating vehicles safely. When a car is lifted into the air, it is crucial that the lifting mechanism is both strong and stable to prevent accidents. The columns function as support structures, maintaining a static position with predetermined height, while the platform moves in relation to them. The columns distribute the weight of the vehicle across the entire lift. This distribution helps reduce stress on the lift components, contributing to improve safety [3].

A solid support construction is essential for ensuring the safety of everyone using the lift, and static columns play a significant role in reducing the risk of accidents. The floor of the platform have a relative movement in relation to the columns, ensuring adaptibility during lifting operations [3].

Figure 13: Static lifting columns [3]

Advantages:

- High Stability: Static lifting columns provide stability, which is crucial when lifting heavy [3].
- Even Weight Distribution: These columns are designed to distribute the weight of the load evenly. This not only enhances safety by reducing the likelihood of tipping but also prolongs the life of the lift by minimizing wear and tear on its components.

- Safety: With a design that emphasizes strength and stability, static lifting columns significantly reduce the risk of accidents. In addition to the typically hydraulic lifting cylinders, static lifting columns include mechanical detents to ensure safety even if the hydraulics should fail.
- Low Maintenance: Due to their simpler mechanical design compared to hydraulic or pneumatic lifts, static lifting columns generally require less maintenance.

Disadvantages:

- Space Requirements: Because they are static, these columns can occupy fixed vertical space within a facility, which could be a disadvantage.
- Adaptability Limitations: While they offer great stability, static columns may not be as adaptable to different types of lifting tasks as some more modern lifting systems.

2.15 Wheels

In terms of wheels, materials such as cast iron, steel, polyurethane, and rubber are recognized for their ability to withstand heavy loads while maintaining strong resistance to wear [76]. Machines with wheels made from harder materials are easier to get moving, thanks to their reduced starting and rolling resistance. This means that less force is required to both initiate and maintain the wheels in steady motion, especially when they are carrying heavy loads, [86]. Generally, fixed wheels provide enhanced stability and straight-line motion, however swivel wheels contribute to increased manoeuvrability [76].

2.16 Standards

Standards are established criteria designed to ensure safety, reliability, and efficiency in products and processes [80]. Compliance with standards is essential not only for quality assurance but also for meeting legal and safety requirements [42].

This project adhered to NS-EN 280-1:2022, which covers Mobile Elevating Work Platforms. This standard is crucial for ensuring the stability and safety of mobile elevating work platforms [54]. Additionally, the Machinery Directive was followed, providing guidelines for the design and construction of machinery to ensure required safety [30].

2.17 Workplace Risks

In industrial workplaces, various accidents can occur, potentially leading to serious consequences. Some of these accidents are listed below:

- Pinch points: where body parts can get caught between moving parts or between a moving and a stationary object, pose serious risks in the workplace [57].
- Tipping: can occur due to various factors such as an uneven surface, shock loading on one side, a person hanging from the railing, or a sudden drop of one wheel [25]
- Fall hazard: when working at heights, fall accidents are among the most frequent causes of injuries at Norwegian workplaces [11].
- Falling objects: Struck byy falling objects is a frequent hazard in all industry sectors, leading to numerous workplace injuries. Objects falling from hights can hit induviduals on the head, resulting in sever or even fatal injuries [28].
- Electrical shock: Poses a risk due to improper insulation, incorrect installation, or overloading. All electrical equipment can present dangers, including burns, fires, explosions, and even death [19].

Prioritizing safety in industrial workplaces is crucial due to risks. By implementing safety measures injuries can be reduced [11].

The risks are studied in detail in Section 7.

3 Method

The bachelor thesis began with an initial outreach to Aker, seeking information on possible assignments open for development. A mail containing various projects was received. Afterwards, a meeting was scheduled to discuss the proposed projects and meet with the potential supervisor. After careful consideration, an assignment was chosen, and contracts were formalized. In January, the first visit to Aker Verdal took place.

3.1 Interviews

In the initial stages of our project, interviews were conducted with personnel from Aker to gather information and insights. They were conducted with welders, sheet metal workers, the scaffolding foreman, the structure foreman, and others. These interviews provided valuable information that was incorporated into the design phase.

Based on the interviews, the following requests have been identified for the new platform design:

1. **Platform Size and Capacity:**

   Source: Welders/Platers.

   Request: The platform should measure 2 meters by 6 meters to accommodate two workers and necessary space for tools.

2. **Adjustable Height:**

   Source: Welders/Platers.

   Request: The platform should be able to reach a maximum height of 5 meters and a minimum of 2 meters.

3. **Stability:**

   Source: Welders/Platers.

   Request: Stability is crucial to ensure safety and high-quality welding results.

4. **Material:**

   Source: Scaffolding Foreman.

   Request: The platform should be constructed with steel, although traditional scaffolds are typically made of aluminum.

5. **Assembly and Disassembly Time:**

   Source: Scaffolding Foreman.

   Request: Reduce the time required to assemble and dismantle the scaffold, currently needing a six-person team and significant time. It typically takes one-third of the time to dismantle the scaffold compared to building it. The frequency of assembly and disassembly depends on the number of rotations. The standard size of a traditional scaffold is 2x1.5m.

6. **Mobility:**

   Source: Various personnel.

   Request: Consider adding a motor for horizontal movement and hydraulic systems for adjusting height.

7. **Static vs. Mobile Platform:**

   Source: Various personnel.

   Request: Evaluate whether the platform should be stationary, and only lowered during jacket rotation, or equipped for mobility.

8. **Compliance with Regulations:**

   Source: Scaffolding Foreman.

   Request: Ensure compliance with local Aker regulations, safety standards, and building codes. Structures must be tagged with a green label to indicate readiness and safety compliance.

9. **Smoke Management:**

   Source: Personnel discussing welding operations.

   Request: Implement a smoke suction system to manage smoke dispersion effectively.

These requests were taken into consideration during the design phase, with efforts made to uphold as many as possible.

3.2 Survey

Following the interviews with Aker personnel, a survey was distributed to all participants and others involved, presenting various design options. The survey included different movement mechanisms, motors, actuators, and railings considered to be the most suitable for the platform design. These options are shown in Appendix N.

The survey did not turn out as comprehensive as had been hoped for. The response rate was low, resulting in a limited scope of information. The outcome from the survey was taken into consideration during the design phase, although the final decision regarding the design was made independently.

3.3 Design Process

3.3.1 The Initial Phase

At the start of the design phase, a mind map was crafted to incorporate all brainstormed ideas gathered from interviews and surveys. The mind map, illustrated in Figure 14, covered everything from railing to how the platform could move across the floor.

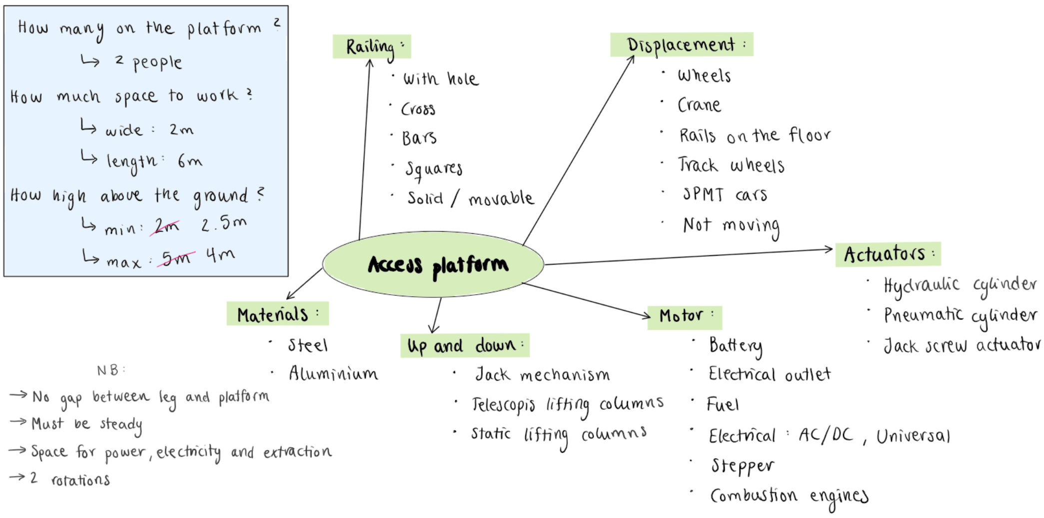


Figure 14: Mind map

Following this, each individually started sketching different design ideas for how the platform and its components could look together. This helped to visualize the final product might look like. Below in Figure 15, some of the various designs people drew are illustrated.

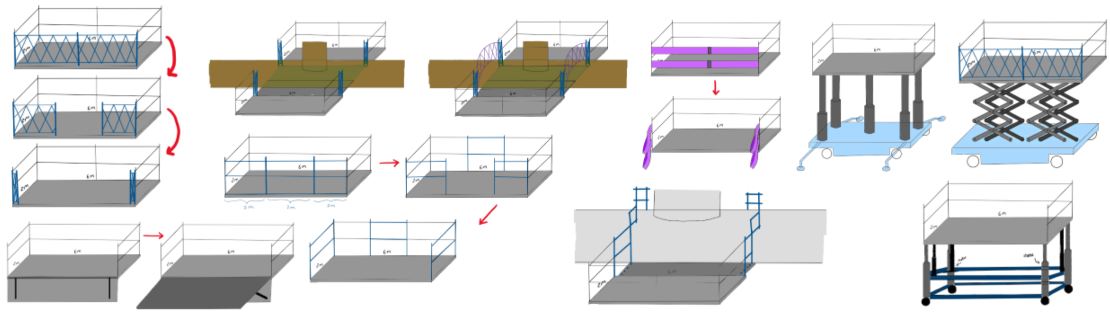


Figure 15: Diverse design ideas for the platform.

After the sketching phase, it was necessary to determine which design worked best. Through discussion, presentation with feedback, and insights from the survey, an initial design proposal was settled upon.

3.3.2 Selected Materials

Based on recommendations from interviews, steel was suggested as the main material. However, Aker encountered issues when attempting to construct a platform using steel, because it became too heavy.

Considering this, aluminum was chosen for the main components of the platform. However, steel will be used in components where stresses and loads deem it necessary. This approach allows the platform to maintain a substantial weight capacity while employing the necessary safety precautions. The specific types of materials employed in the design are listed below:

- Aluminium, EN AW-5754 [22]. An aluminium alloy with high corrosion resistance, moderate strength and good weldability and anodizing properties [9]. Used in the platform flooring.
- Aluminium, anodized. Standard for item24 aluminium-profiles [45].
- Steel, S355 [41]. Used to make the tubes located inside the aluminium profiles for stabilized lifting.
- POM (polyoxymethylene). A thermoplastic with high strength, rigidity, sliding properties and good wear resistance [59]. Used as a protection between the aluminium profile and the steel tubes.

To make the platform design as detailed as possible and ensure easier production for Aker, the materials were sourced from standard product lists from various suppliers. This approach allows the Bill of Materials (BOM), in Appendix A, to be detailed and precise, facilitating easy purchasing and production of a potential prototype. The components were identified through contact with different producers and by utilizing digital tools.

3.3.3 3D-modelling and Simulations

Due to the broad task description, the project started with a simplified model to establish a foundation. This simplified model served as the initial step in the project, providing a start point of the design for further exploration and development.

Simplified Model

At the beginning of the project, the initial platform design featured four lifting screws and a jack mechanism. A simplified model of this platform was initially assembled in SolidWorks as shown in Figure 16. The components were deliberately simplified to facilitate an iterative approach, which helped identify the designs' potential. This model then served to evaluate whether this approach was viable or not. The simplified components included:

- **Lifing Screws**

  The threads on the screw were not considered in this part of the project since the primary objective was to determine the feasibility of the design.

- **Platform Base - Chassis**

  To simplify the 3D model, the base, at this stage, was designed merely as a box with predetermined height and length. In reality the base would also be equipped with a motor and a control panel.

- **Assembly**

  The assembly between the components was also simplified. The platform floor was directly connected to the lifting screws, and the screws were connected to the base as a single-bodied element. Although this does not align with the actual assembly in real life, it will help determine its potential.

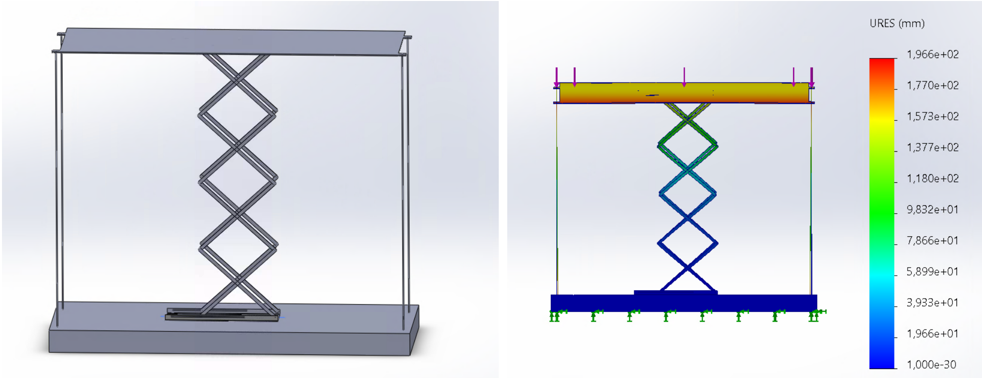


Figure 16: Assembly of simplified model to the right, and displacement of simplified model under maximum load to the left.

Even though the stress levels of the platform were well within acceptable limits, this design solution led to significant displacement under maximum load, as illustrated in Figure 16. It was also obvious that the platform was prone to buckling and did not offer the necessary stability. It was clear that this design solution would not result in a functional platform. Therefore, the decision was made to develop a more robust "framework" design, effectively resetting the design process. The revised approach included using resources from the site item24, recommended by Aker, to create a stable framework, incorporating components that could be easily sourced from the manufacturer.

Item24

During a meeting with Magnus Hardbak Nordvik, a Method Engineer at Aker, the site item24 was presented as a potential supplier of components for the platform. Since item24 had been used in the design of another platform, currently in operation in another working hall, it was concluded that engaging the same supplier could result in cost savings for Aker through bulk purchasing. Additionally, purchasing from item24 would be easier as the supplier is already known to Aker. This decision will also enhance the efficiency of the assembly process, as item24 produces parts that are readily compatible. The profiles selected for the various components are detailed in Appendix B.

Engineeringtool

Upon introduction to item24, it was also mentioned that an online tool called "Engineering tool" is integrated into the website. Within the Engineering tool, the bottom and top of the platform, corner platform and base for the stairs were designed and assembled. After completion of the design, it was downloaded as a CAD format and then transferred to SolidWorks for further 3D modeling.

However, not all required profiles and components were available for use in the Engineering tool. Some were only available in CAD format. These were downloaded and transferred to SolidWorks for futher editing and eventually the entire platform was assembled within SolidWorks.

After the designs were finalized in the Engineering tool, the online site automatically generated project documentation. This documentation included cover sheets, parts lists, isometric views, assembly guides, and additional elements. For Aker, this feature simplifies and speeds up the process of creating a physical platform by ensuring that all necessary documents are readily available and well-organized. For the components not developed within the Engineering tool, a separate "bill of materials" was developed.

Complete Model

With the Engineering tool the framework for the bottom and top of the platform was assembled, shown in Figure 17. These models were subsequently uploaded into SolidWorks, where the other remaining components were designed and integrated into the assembly.

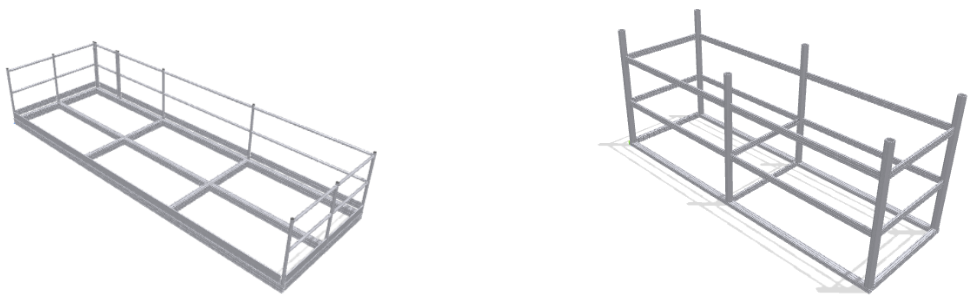


Figure 17: Bottom and top of the platform designed in item24.

To connect the upper and lower framework of the platform, six steel tubes were designed in SolidWorks, matching the dimensions of the "KKR S355J2H" Steel Tubes from Tibnor as shown in Figure 18. These tubes have an outer diameter (D) of 76.1 mm and a thickness (T) of 5 mm [41]. As these tubes are manufactured in 12-meter lengths, they need to be cut into eight 1.5-meter segments. Six of these segments will be utilized for one platform.

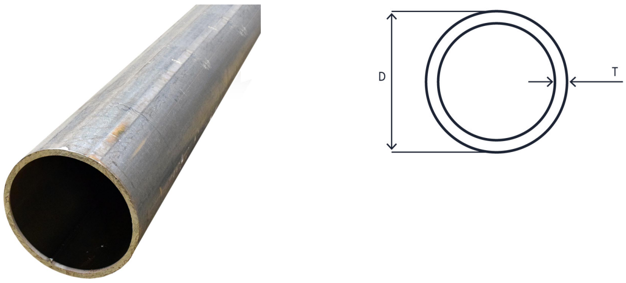


Figure 18: Steel tubes from Tibnor with an outer diameter of 76.1mm and a thickness of 5mm [41].

The POM parts, designed to allow the steel tubes to slide inside the aluminium profiles, were tailored to fit onto the steel tubes and inside the aluminium profile 8 120x120-45° used in the platform's base. As these parts are 3D-printable, their designs were customized as needed.

The aluminium flooring for the platform was designed in SolidWorks to match the dimensions of the EN AW-5754 aluminium plates from the Alumeco group [22]. These plates, measuring 2x1 meters, will be precisely cut to accommodate the circular poles that make up the railing on the sides of the platform. The plates will then be securely screwed into the framework, ensuring stable attachment on the side without railing.

All these parts were then assemblied as shown below in Figure 19:

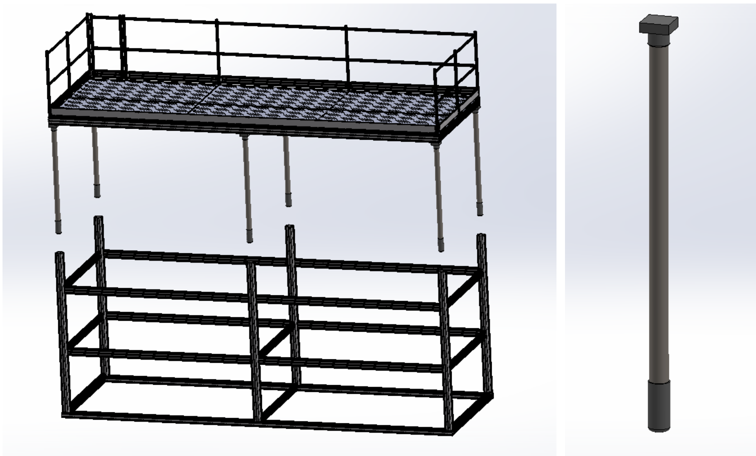


Figure 19: Platform framework and steel tubes connecting top to bottom.

The next step involved designing the static stairs, which was carried out in SolidWorks. The same profiles used in the platform framework were applied to construct the stairs. Profile 8 120x40, measuring 2.5 meters in length, served as connectors for the stair steps. These were positioned at a 45-degree angle, aligning the total height of the static stairs with the platform's height of 2.5 meters when fully lowered. The railings were then assembled to the profiles as shown in Figure 20. The railings were first assembled with the Engineering tool at item24's site and then integrated into the assembly.

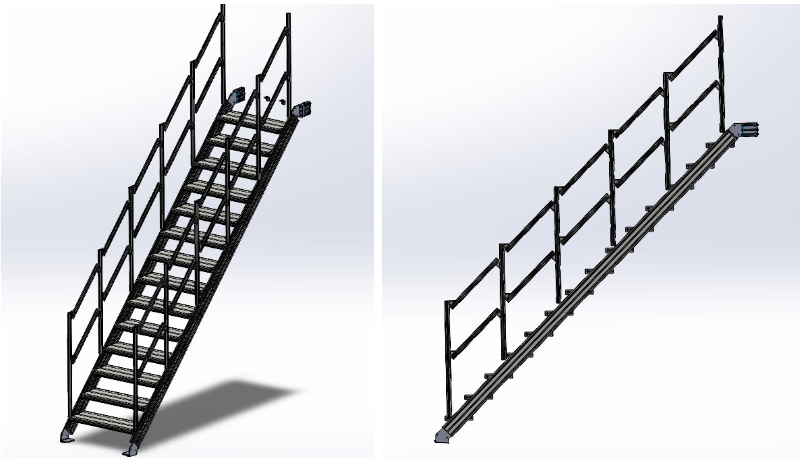


Figure 20: Static stairs with railing, seen from an angle and from the side.

Then the movable stairs were assembled. They were designed in CAD by securing seven short stair-steps onto a steel frame shaped like a 45-degree stairway as shown in Figure 21. At the end of each short step, a POM closure was fastened to function as a lifting device when it comes into contact with the long steps resting on top of the static stair frame. Subsequently, two POM closures were fastened to the long steps resting on the stair frame, aligning with the pattern of the other closures.

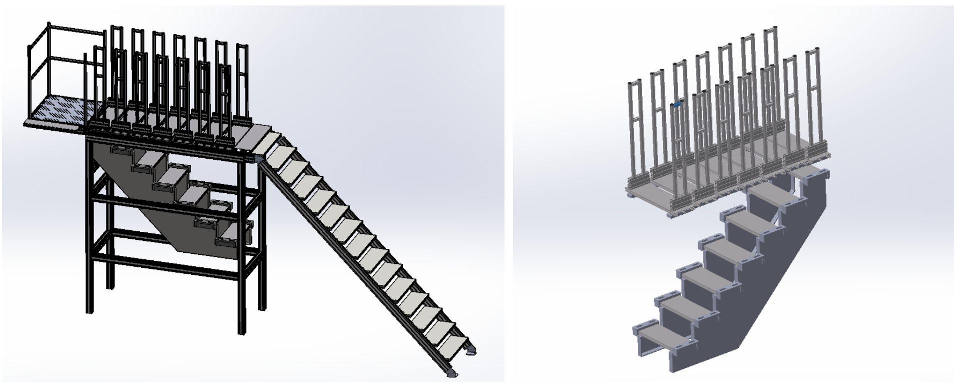


Figure 21: Both stairs assembled and movable stairs on lifting frame.

To prevent the steps from shifting horizontally on the stair base, plastic closures were designed. These ensure that the steps remain stable while resting on the frame. The plastic closures are depicted in Figure 22. It is assumed that horizontal movement will not occur during lifting, as the closures on the steps and the lifting frame are designed to interlock.

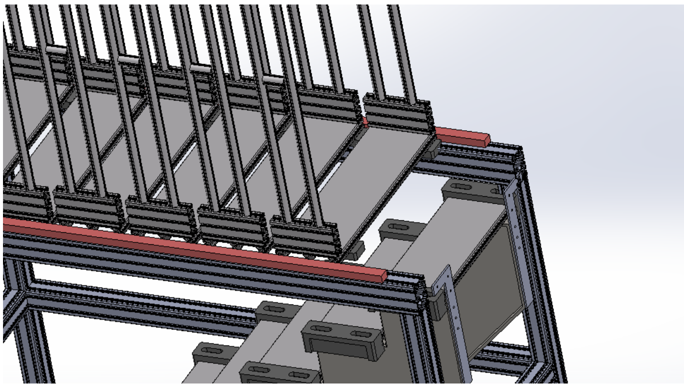


Figure 22: The plastic closures, in red, attached to the stair base to prevent the resting steps from moving horizontally.

To connect the stairs and the platform, a corner piece of a staircase was created using item24, as shown to the left in Figure 21. An aluminum plate for flooring was also added, similar to the platform's floor. The complete corner part was designed to be fastened to the steel frame that supports the movable stairs. This fastening was achieved by attaching two steel plates, dimensioned as shown in Figure 23. These steel plates were then secured between the corner part and the lifting frame, ensuring synchronized movement during the lifting and lowering of the platform.

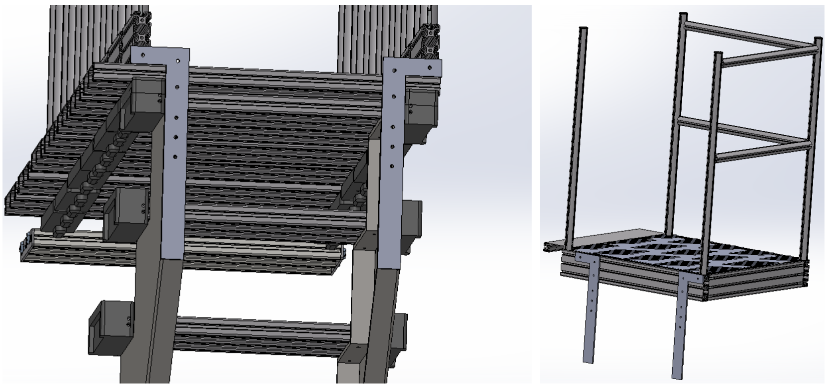


Figure 23: Fastening between corner platform and movable stairs.

To create a gap between the staircase and the static framework at the base of the platform, a 160 mm step is placed between the platform frame and the corner of the stairs as depicted in Figure 24. The step creates a 160 mm space between the platform and the stairs, preventing potential collisions during the lifting and lowering of the platform. This step will be secured with a steel plate on the underside, ensuring that a strong material holds the platform and stair-section together. The plate is shown in Figure 25.

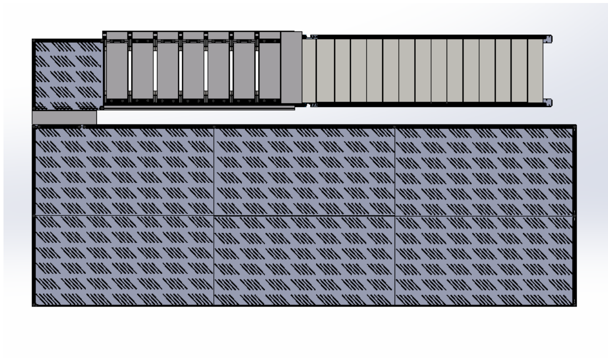


Figure 24: Platform and stairs connected, view from above.

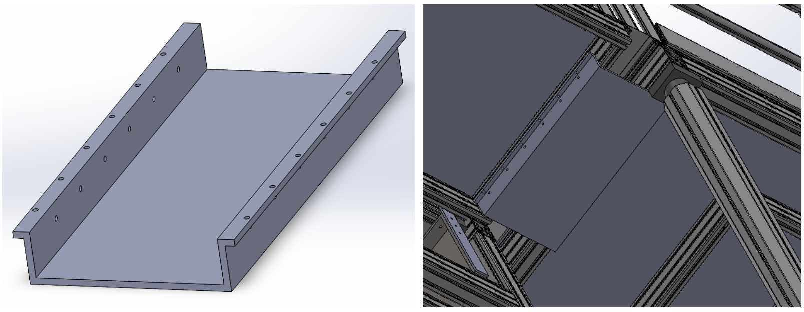


Figure 25: To the left, securing steel plate part. To the right, the plate connected to the bottom of the platform and stairs.

The assembled platform is shown in Figure 26.

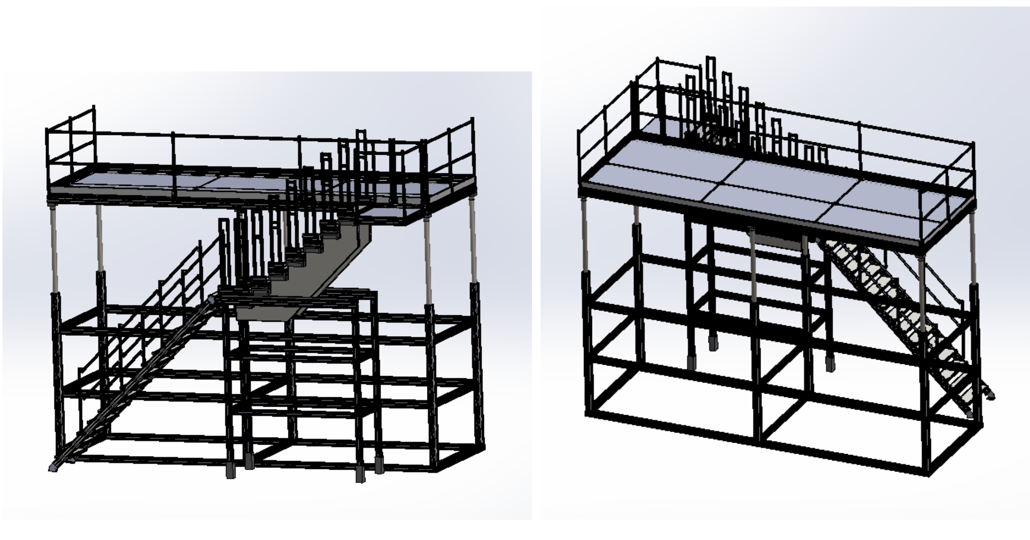


Figure 26: Finished simplified 3D-model from two angles.

When designing the platform for Hall A2, it was important to consider that it needs to function effectively within the available space. It was agreed that a platform design with a total width not exceeding 3 m would be a sufficient constraint to secure that two platforms would fit side by side. This constraint had to be factored into the design.

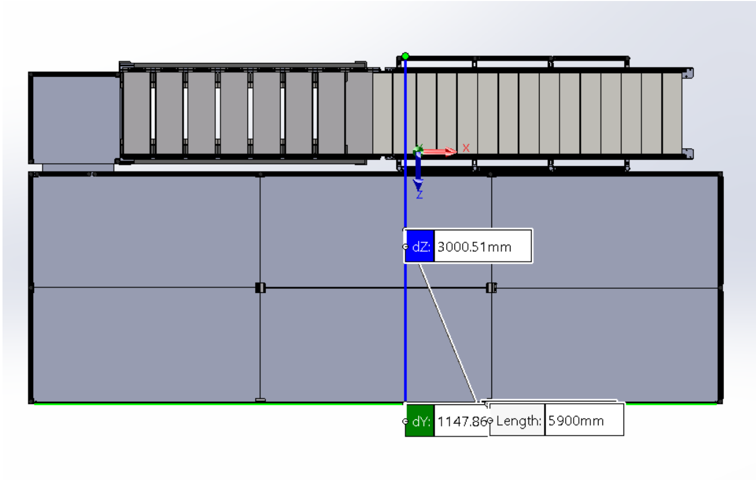


Figure 27: The total width of the platform.

The finished design firstly had a width of 3000.5 mm as shown in Figure 27. This was reduced by removing the step between the platform and the corner and by changing the railing on the static stairs.

The railing on the static stairs was exchanged with a railing fastened on top of the stairframe as opposed to on the side. The total distance from the stairs to the platform was reduced by changing the parameters of the securing steel plate so that the corner platform was directly fastened to the platform top, leaving no gap (or step) between them. Figure 28 shows the reduced dimensions of the securing plate.

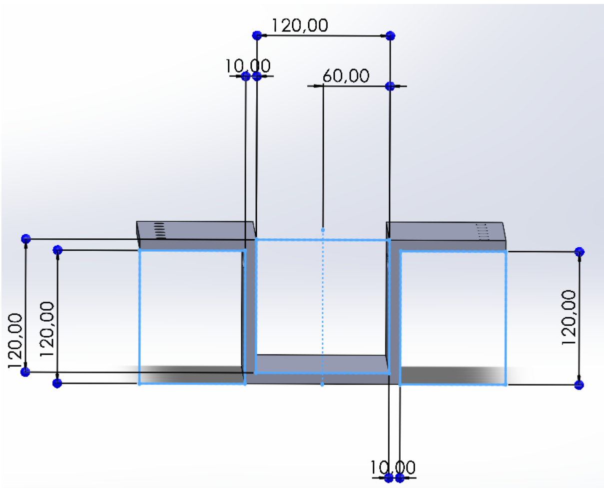


Figure 28: The renewed dimensions of the securing plate.

This resulted in a more compact platform design as depicted in Figure 29. The total length of the finished platform measures 2,881.75 mm or approximately 2.882 meters, which is within the required width constraint.

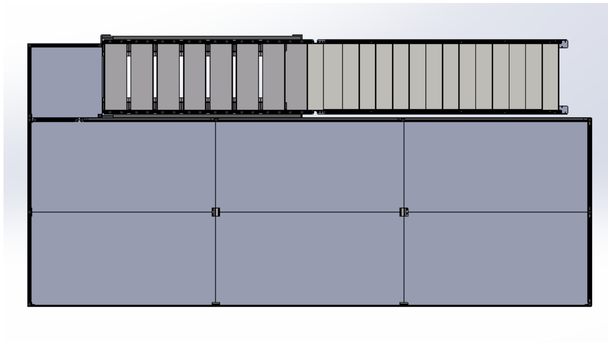


Figure 29: The finished platform design, seen from above.

The last step of assembling the platform was to fasten the wheels to the platform's vertical beams (both base and stairs). The resulting platform design is presented in Section 5

Workbench

As previously described, workers need to have access to the top of the jacket, even when a junction part obstructs the platform. To facilitate this, a workbench has also been designed and 3D modeled to provide a solution. The platform after a roation is shown in Figure 30 below, showing how the benches might be located beside the leg.

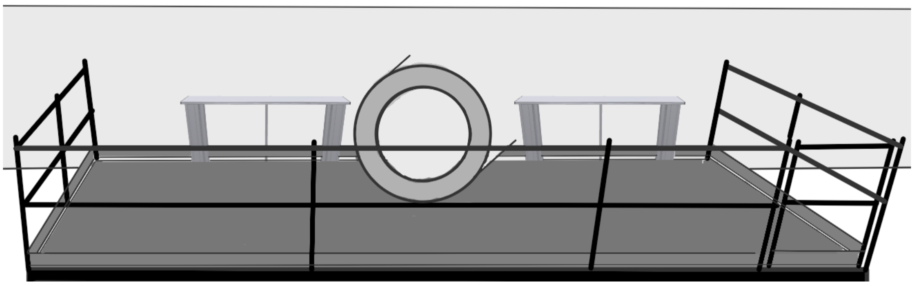


Figure 30: Work bench illustrated alongside the jacket, with a leg obstructing the platform.

Because of varying dimensions of the jackets being worked on, the height and length of the benches may vary from one project to another. Therefore a basic workbench design has been made, but the height and length can be modified to fit the projects needs.

4 Compliance with Standards and Platform Analysis

The Machinery Directive, outlined in Norway's "Forskrift om maskiner" [30], mandates safety standards for machinery to minimize injury risks. As a directive, it holds a higher level of authority and is overarching compared to standards such as NS-EN 280, making it more critical to adhere to. It provides clear guidelines for manufacturers, importers, and regulators, emphasizing safe design and hazard management [48]. Although this directive provides general rules, its requirements are less detailed compared to the specific NS-EN 280 standard. By complying with NS-EN 280, which addresses stability, fall prevention, and slip resistance, adherence to the more general safety objectives of the Machinery Directive is inherently achieved. Therefore, the platform will only be checked for adherence to NS-EN 280 in this section.

To ensure compliance with standards, it is essential to calculate the tipping angle and stabilizing moment for the platform. These calculations will be utilized to demonstrate adherence to standard requirements. The tipping angle and stabilizing moment will be determined based on a simplified model of the platform frame, excluding the stairs, as depicted in Figure 31. This approach provides conservative estimates, thereby enhancing the reliability of the safety analysis.

4.1 Tipping Angle

In these calculations the contact points of the platform with the floor in the working hall are considered to be the supports of the platform. The platform design that will be used to calculate tipping angle is shown in Figure 31.

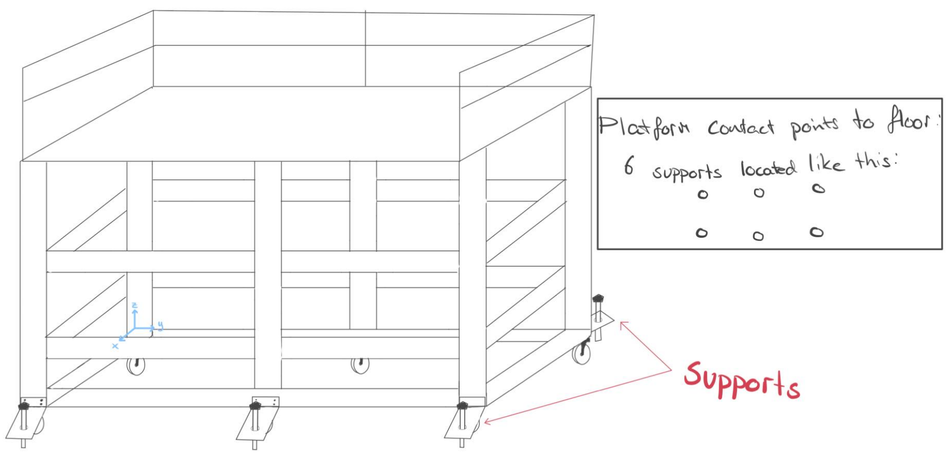


Figure 31: Hand-drawn sketch of platform model used in tipping calculations. The red arrows shows the location of the supports.

The values for the Center of Mass (CoM) were determined using SolidWorks and are displayed in Figure 33. These values are relative to the origin of the coordinate system, as shown in Figures 31 and 32. The origin of the coordinate system is set at the left side of the platform, the one with a regular railing. The positive directions are along the platform's short side in x-direction, along the long side in y-direction and upwards along the platform in z-direction.

4.1.1 Tipping Angle - Without Loads

To calculate the tipping angle, analysis will focus on the shorter side of the platform, as tipping is most likely to occur in the direction to the left as indicated in Figure 32 since this is where the CoM is closest to the tipping line. By evaluating the platform without the attached stairs, the most conservative tipping angle is determined. This approach ensures that the platform remains stable even if the stairs are later positioned differently, such as being parallel to the platform's length. Such adaptability enhances the platform's versatility for various operational setups.

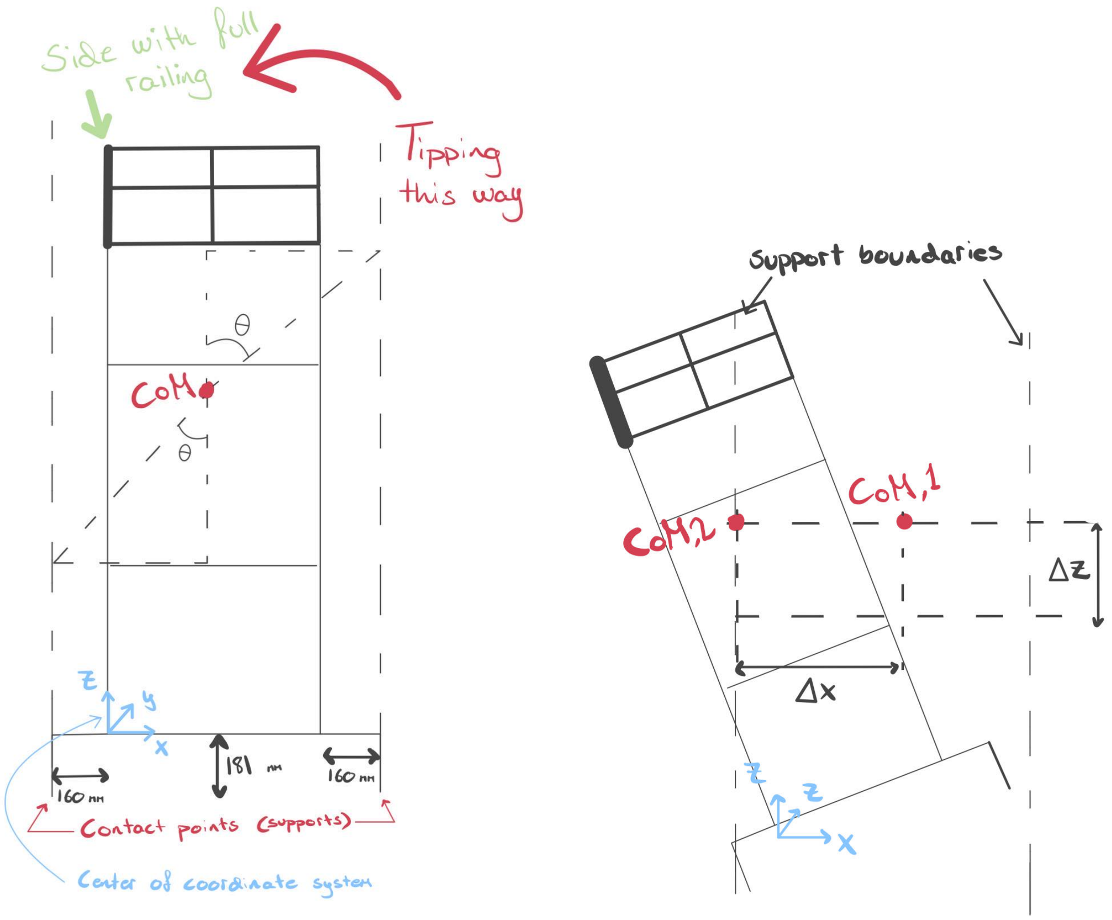


Figure 32: Short side of the platform during tipping.

Trigonometry was applied to determine the tipping angle. This involved calculating the distances between the supports and measuring the total height from the floor to the CoM. Since the supports are outside the platform base, which the coordinate system is based upon, they had to be added or subtracted from the calculations to obtain the correct calculations.

Taking the origin of the coordinate system into account:

- Distance between supports, short side (x-axis) = 2,000 mm + 320 mm = 2,320 mm
- Distance between supports, long side (y-axis) = 6000 mm - 80 mm = 5,920 mm
- Height of supports (z-axis) = 181 mm

CoM from SolidWorks:

$$x = 983 \text{ mm}$$

$$y = 3,000 \text{ mm}$$

$$z = 2,170.92 \text{ mm}$$

Because of the origin not being relative to the ground, the distances from the CoM to the ground must be found:

$$\text{x-distance} = 983 \text{ mm} + 160 \text{ mm} = 1,143 \text{ mm}$$

$$\text{z-distance} = 2170.92 \text{ mm} + 181 \text{ mm} = 2,351.92 \text{ mm}$$

These distances, relative to the CoM, can be seen in Figure 33.

The tipping angle was then calculated using the arctan of 1,143 mm / 2,351.92 mm. These calculations are depicted in Figure 33.

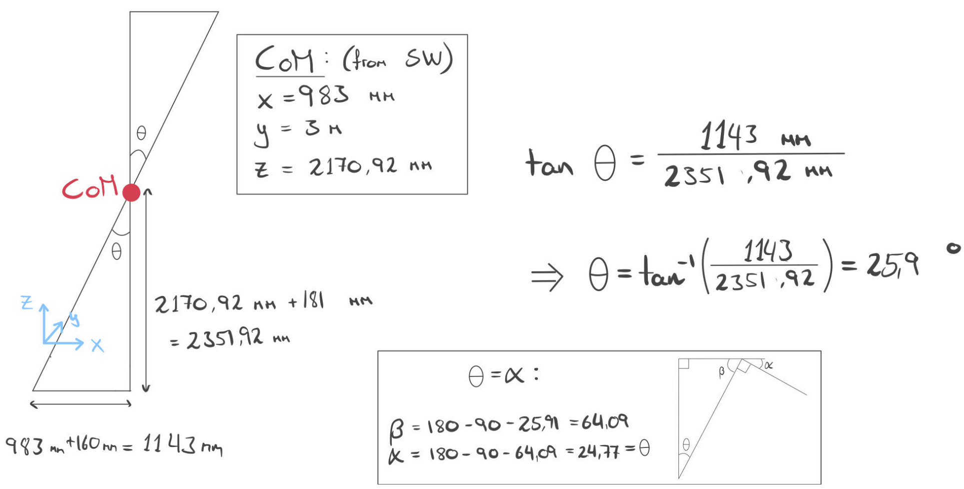


Figure 33: Trigonometry calculations for tipping.

The tipping angle for the platform is calculated as 25.9 degrees. This is quite a steep angle, indicating that the platform is more than stable enough.

The full calculation is shown in Appendix G.1.

4.1.2 Recalculated Tipping Angle - with Maximum Loads

To ensure the platform can withstand maximum loads under critical conditions without tipping, the displacement of CoM was analyzed during maximum loading. This analysis involved applying two point loads of 80 kg each on the platform floor at its critical side, complemented by an additional 440 kg distributed evenly across 50% of the platform floor. A more realistic tipping angle was recalculated using trigonometry similarily to the previous calculations.

A distributed load of 440 kg across half of the platform floor (on the side closest to the critical side because of worst case scenario), will move the CoM in x-direction closer to the critical tipping side, as shown in Figure 35. The point loads will affect the CoM only in this direction as well, since the loads are both located symmetrically in relation to the CoM's y-coordinates.

The relocated CoM was determined by multiplying position vectors by corresponding forces. This accounts for each mass's impact on the system's balance. These weighted vectors are added together to find a total moment vector for the system, and then devided by the total force. Thus considering both the position and influence of each mass.

$$\text{CoM}_{\text{Unaffected by loads}} = (0.983, 3, 2.17092)$$

The evenly distributed load across half the platform floor has an equal point load of 4400 N (approximately 600-80-80 = 440 kg) with the coordinates:

$$\text{PL}_{\text{From distributed load}} = (1.5, 3, 4)$$

The mass of the platform was found in SolidWorks and was rounded up to 1040 kg, the gravitational force of the platform was then set to be:

$$\text{G} \approx 10,400 \text{ N}$$

The new coordinates were then calculated:

$$x_{\text{CoM}} \approx \frac{(10,400 \text{ N} \cdot 0.983 \text{ m}) + (4,400 \text{ N} \cdot 1.5 \text{ m}) + 2 \cdot (800 \text{ N} \cdot 2 \text{ m})}{10,400 \text{ N} + 4,400 \text{ N} + 2 \cdot 800 \text{ N}} = 1.22093 \text{ m}$$

$$y_{\text{CoM}} = 3$$

$$z_{\text{CoM}} \approx \frac{(10,400 \text{ N} \cdot 2.17092 \text{ m}) + (4,400 \text{ N} \cdot 4 \text{ m}) + 2 \cdot (800 \text{ N} \cdot 4 \text{ m})}{10,400 \text{ N} + 4,400 \text{ N} + 2 \cdot 800 \text{ N}} = 2.8401 \text{ m}$$

Which gives:

$$\text{CoM}_{\text{Relocated}} = (1.22093, 3, 2.8401)$$

The recalculated tipping angle is then calculated similarily as the previous one, as shown in Figure 34.

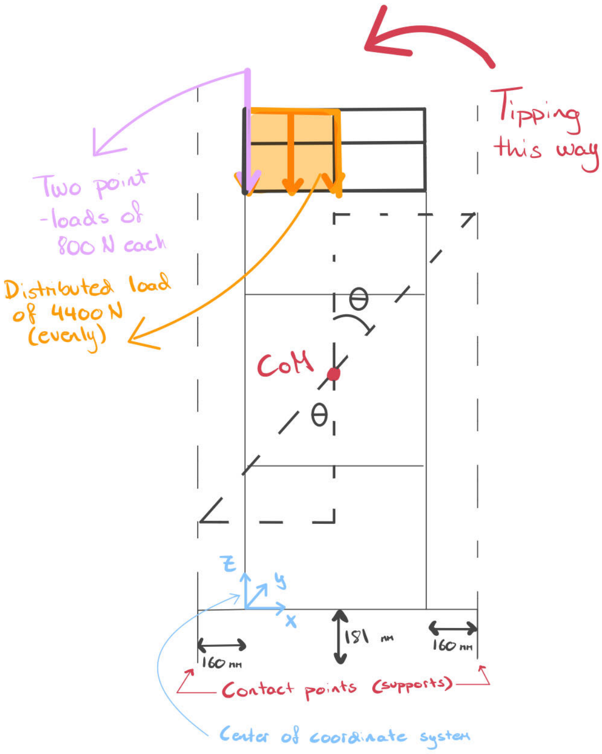


Figure 34: Sketch of platform with maximum loads applied.

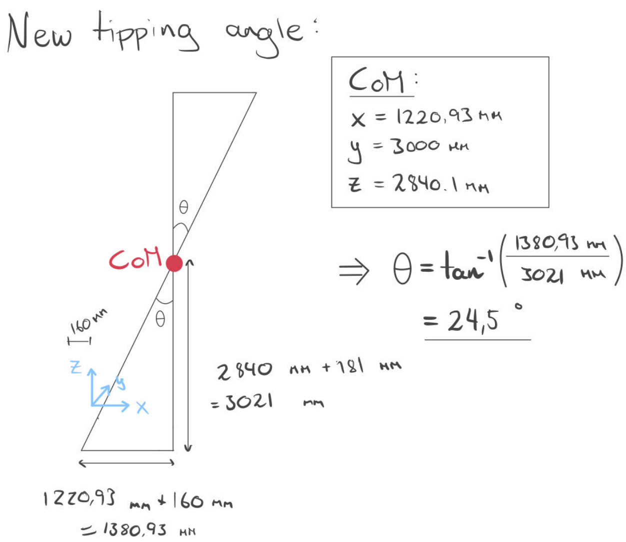


Figure 35: Calculations of new tipping angle with maximum loads applied.

The recalculated tipping angle, shown in Figure 35, is then 24.5 degrees, which is still a steep angle that is unlikely to be exceeded.

The full calculation is shown in Appendix G.2.

4.2 Stabilizing Moment

The stabilizing moment for the simplified platform can be calculated as follows:

$$M_{\text{stabilizing}} = G \cdot \text{Lever Arm From CoM to Critical Tipping Line} \cdot tan(\text{Tipping Angle})$$

For the unloaded platform, the stabilizing moment is:

$$M_{\text{stabilizing}} = 10,400 \text{ N} \cdot (2 \text{ m} + 0.16 \text{ m} - 1.22093 \text{ m}) \cdot tan(5.91°) = 4,744.3807 \text{ Nm} \approx 4,744 \text{ Nm}$$

For the maximum loaded platform, the resulting stabilizing moment is:

$$M_{\text{stabilizing}} = 10,400 \text{ N} \cdot (2 \text{ m} + 0.16 \text{ m} - 1.22093 \text{ m}) \cdot tan(24.56°) = 4,463.1293 \text{ Nm} \approx 4,463 \text{ Nm}$$

The full calculation is shown in Appendix H.

4.3 NS-EN 280-1:2022

The standard NS-EN 280-1:2022 focuses on Mobile Elevating Work Platforms (MEWPs). It outlines critical guidelines for design calculations, stability criteria, construction, and safety to ensure these platforms are built to adequate safety and performance standards. This standard is essential for minimizing the risk of accidents and enhancing the operational efficiency of MEWPs, thereby protecting both users and operators.

4.3.1 Classification

To determine the platform classification the standard states that a MEWP can be either in group A or B. Group A are "MEWPs where the vertical projection of the centre of the area of the platform in all platform configurations at the maximum chassis inclination specified by the manufacturer is always inside the tipping lines", and Group B are "All other MEWPs"[54]. Since the platform always has its CoM inside the tipping lines, it is categorized as type A.

The classification of the platform type is linked to the location of the control panels. Type 2 platforms are controlled from the chassis, whereas Type 3 platforms are controlled from the work platform itself. This design is identified as a combination of Type 2 and Type 3 MEWP, determined by the presence of control panels both at the chassis and on the platform floor. This dual-control setup enhance flexibility and safety, allowing operations to be managed from either location depending on the specific needs and circumstances of the task.

4.3.2 Number of Permissible People

For the designed platform, the following excerpt from the 4.2.3.1 section of the standard is relevant to determine the number of permissible persons on the platform at one time:

Rated Load:

$$m = n \cdot m_p + m_e \tag{15}$$

where:

- m: rated load
- n: number of permitted people
- m_p: mass of a person (this is 80 kg)
- m_e: mass of material and tools (minimum 40 kg according to the standard)

Since the maximal external load for the platform is defined to be 600 kg by Aker and has been used in all safety calculations, this formula is used to calculate how many people the platform can safely carry, given that each person weighs 80 kg and while including extra weight for equipment and materials. As given in Table 2 in the standard, the rated load should be multiplied with a partial safety factor of 1.34.

Table 2 — Partial safety factors

Clause	Loading	Partial safety factors γp	
		Load combination A	Load combination B
4.2.3.1	Rated load	1,34	1,22
4.2.3.2	Dead weights	1,22	1,16
4.2.3.3	Wind loads	–	1,22
4.2.3.4	Manual force	–	1,22

Table 1: Table from standard NS-EN280-1:2022 [54]

The material and tools weight on the platform can be estimated by combining the weight of the welding equipment—which is heavier than the plate-working tools—with the weight of a tool box, assumed to be 15 kg. The total weight of the welding equipment includes the handheld welder and the wire feeder unit. The additional weight will therefore be estimated to 50 kg.

The number of permissible persons on the platform can then be calculated from Equation 15 for rated load:

$$n = \frac{m - m_e}{m_p} = \frac{\frac{600\text{ kg}}{1.34} - 50\text{ kg}}{80\text{ kg}} = 4.972$$

The platform is designed for use by two persons at a time, yet the calculations show that it can safely accommodate over four individuals. This higher capacity is beneficial as it accounts for potential variations where individuals may exceed the assumed weight of 80 kg, and material weights might also vary. Therefore, having a capacity that surpasses the requirement for two people is a prudent safety measure. Moreover, there may be occasions when more than two individuals need to be on the platform simultaneously, underscoring the necessity of a safety margin.

4.3.3 Marking

For the platform to adhere to the standard, this information needs to be permanently and clearly marked onto the platform:

- Rated load in kilograms (600 kg).
- Rated load given as allowed number of people and mass of equipment in kilograms (four people, 50 kg or two people, 287 kg which can be calculated with Equation 15).

- Maximum allowable manual force in newtons.

  This value should be determined by Aker when the complete model has been finilized.

4.3.4 General Requirements

For the designed platform certain requirements must be met according to the standard. These are listed below, and the measures taken to meet them are listen below each point.

- **It is important to recognize that each person's weight is considered a point load, which influences the distribution of weight and could impact the platform's strength and structural integrity.**

  The platform is designed to adhere to this requirement, ensuring it can withstand the maximum load without experiencing failure. As previously stated, the maximum load is set to 600kg, which includes the weight of two persons, equipment, and a safety margin of 2.

  During the calculations of tipping angle for the platform in Section 4.1, the maximum load was distributed over 50% of the platform floor, including two point loads acting as the forces applied by two workers. This was done to adhere to this specific requirement of the standard.

  The calculations in Section 4.3.7 uses the CoM recalculated for the platform with maximum loads, taking into account the impact this load distribution has on the platform. This ensures that the platform maintains its strength and structure during use, even when subjected to point loads for the weight of a person.

- **The weight of the equipment is assumed to be evenly distributed over 25% of the platform's floor area. If this distribution results in pressure exceeding 3 kN/m², adjustments to the area's percentage will be necessary.**

  With the platform floor dimensions (6x2 m with a thickness of 4 mm), the pressure created by a 50 kg load of equipment distributed over 25% of the floor is:

  25 % of total area: 12 m^2 x 0.25 = 3 m^2

  Pressure (kN/m^2): 500 N/3 m^2 = 0.167 kN/m^2

  This pressure is significantly below the limit of 3 kN/m^2. Therefore, with this setup, the platform meets the requirement and an adjustment is not required.

- **To ensure that the platform is sufficiently robust all loads are positioned to yield the most severe outcomes.**

To meet the requirement, we identified the most severe scenarios the platform might face. As the platform is intended to be used indoors, factors such as weather and temperature variation were deemed irrelevant. Aker estimated a load of 600kg as maximum load. This is including two individuals, equipment, and a safety margin of 2. Simulations and calculations were done while the platform was in its "worst case scenario" state, to adhere to the standard and to get conservative and safe calculations. The platform's "worst case scenario" has been determined to be when the platforms maximum load is distributed over 50% of the floor, including two point loads at the outermost part of the un-railed platform side. This has been done during all calculations and simulations, for example in Section 4.1 and 4.3.7.

- **To confirm the platform's stability when stationary, the masses of the MEWP components are considered as static dead weights. This ensures the platform can safely support its own weight without movement.**

  To confirm the platform's stability when stationary, the masses of the MEWP components are treated as static dead weights. This means the component masses are considered constant and unaffected by any dynamic factors such as movement or operation. The buckling simulation, detailed in Section 4.4 of buckling, involved simulating the platform to verify it can carry the rated load with the masses as dead weights. This method is used in all static simulations and calculations to meet this requirement.

- **To ensure the platform can handle operational stresses, the masses of the MEWP components when in motion are considered as dynamic dead weights. This accounts for extra loads caused by movement, including vibrations, braking, and acceleration.**

  The current simulation of the MEWP undergoing a kerb test in SolidWorks uses constant forces for gravity and horizontal movement. To more accurately reflect real-world conditions, incorporating dynamic analysis is necessary, taking into account vibrations and impact shock. This requirement will have to be met during further motion studies by Aker.

- **The maximum overturning moments and corresponding stabilizing moments should be calculated around the least favorable tipping lines.**

  In the calculations for the tipping angle as presented in Section 4.1, the tipping lines were determined based on a simplified model. This approach ensures the derivation of the most conservative tipping angle, as the CoM for this model is positioned closest to the critical tipping line. Consequently, these calculations adhere to the requirement by focusing on the least favorable tipping scenarios in real life.

Furthermore, the calculations of both the overturning moment and the stabilizing moment, detailed in Sections 4.3.5 and 4.2, are also centered around this critical tipping line. By evaluating the maximum potential overturning force against the inherent stabilizing force due to gravity, it is confirmed that the stabilizing moments are sufficiently greater than the overturning moments. Thus, these calculations further substantiate compliance with the standard, ensuring that the platform maintains stability under all evaluated conditions.

In addition, the braking test done in Section 4.3.7 adheres to this requirement by evaluating the platform's stability under maximum applied forces relative to the least favorable tipping line, ensuring that the stabilizing moments sufficiently exceed any potential overturning moments under these conditions

- **The calculations must adhere to the laws and principles of applied mechanics and the strength of materials.**

  The simulations detailed in Section 4.4 adhere to the principle of material strength by comparing the maximum stress experienced by the components to their respective materials' yield strengths. This approach ensures that no yielding occurs. This principle is consistently applied across all stress analyses.

  Additionally, buckling calculations in Section 4.4.3 involve checking beams to ensure they can withstand the maximum rated load of 600 kg, verifying adherence to buckling principles.

  Furthermore, moment calculations performed in Sections 4.2 and 4.3.6 follows the mechanical principles related to stabilizing moment.

  In summary, all simulations and calculations have been carried out in accordance with the relevant principles of mechanics and material properties, thus meeting this requirement.

- **The level of the work platform should not exceed five degrees from the horizontal plane or the plane of the chassis, both during movements of the extending structure and under loads during operations. This should be verified in the most critical conditions, including at maximum height and weight.**

  To make sure the platform floor does not have a higher tilt than 5 degrees during movement of the extending structure, the actuators will have to be synchronized. A solution for this is suggested in Section 8.3.1 where the actuators follow a leader/follower synchronization, making sure they move simultaneously. This requirement will therefore have to be met when Aker decides what actuator they want to use.

- **MEWPs must have non-slip, evenly spaced ladders if the access height exceeds 0.4 meters.**

Although the height of the platform stairs, both movable and static, can vary due to the platform's adjustments, the overall stair design is intended to ensure safety under all conditions. This safety standard is consistently met when the platform is fully lowered and also when it is fully extended. However, when the platform height is adjusted to positions between these two extremes, the step height of the first movable step may vary from the others. This variation is necessary to accommodate the design of a movable staircase.

- **MEWPs should have properly arranged handrails to ensure safe climbing without using unsuitable supports like controls or pipes.**

  The platform is equipped with railings on both the static and movable stairs, as well as around the platform itself, ensuring safety during ascent and descent. These railings adhere to standard specifications and are strategically positioned in areas susceptible to falls or slips. However, one side facing the jacket lacks a railing, making it a potential risk. Potentially implementing a chain along the open side when the platform is not pressed against a jacket will enhance safety and better fulfill this safety requirement.

  Nevertheless, as stated in Section 5.7 regarding the intended use of the platform, only one person will occupy the platform while it is in vertical motion, specifically standing at the control panel as depicted in Figure 36. It is not intended for anyone to be on the platform when it is not pressed against a jacket, and once in the working position, the platform will have no open sides, thus posing no fall risk. Therefore, it can be determined that, when used as intended, the absence of a railing on one side does not significantly increase the risk of falls.

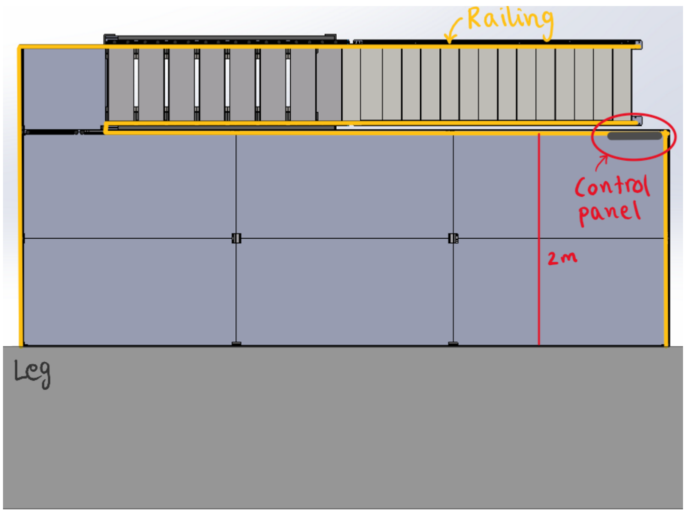


Figure 36: Platform seen from above pressed against the jacket with intended placement of control panel (in red) and railings (in yellow).

- **Vertically hinged intermediate guardrails should be capable of being held open with one hand whilst a person enters or leaves the platform.**

  The platform features one temporary railing, a swing door, designed to resemble the railing, serving as the entrance from the stairs to the platform. This is shown in Figure 37. This feature was not implementet on the simplified 3D-model of the platform, but is included in the complete model from item24 with all the fasteners.

  This door should be securely attached with a locking mechanism to ensure it remains secured when fastened, whilst also being easy to open when entering or exiting the platform. Also aligning with the requirements in the standard; the platform's entry-point is designed to only open inwards.

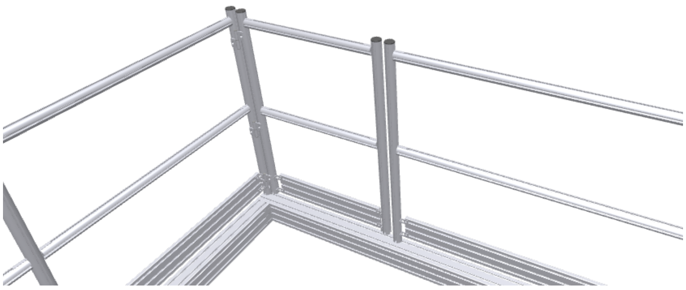


Figure 37: The intended access hatch on the platform.

- **Anchorages for personal fall protection systems must be provided on the platform.**

  The platform is designed to function without anchors since there will be no gap when the platform is fully pushed against the jacket. However, the railing facilitates easy attachment with a clamp-on, both depicted in Figure 38.

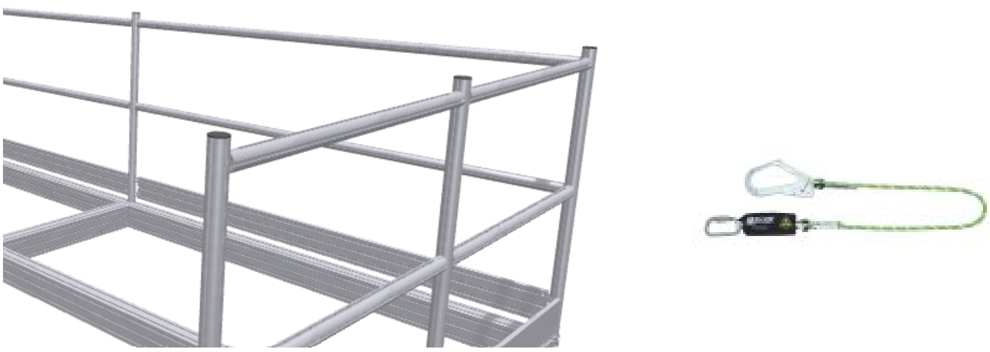


Figure 38: The designed railing and an example clamp-on [67] that can be used as anchorage.

To calculate the tugging force for the fall, the mass of a person is 80kg, the gravitational acceleration is 9.81m/s^2 $\approx$ 10 m/s^2, the lenght of the rope before extension is set to 2, and the resulting deceleration distance is then 0.5 m. These are used to find the tugging force, as shown in the equation below:

$$F = \frac{\text{Number of People} \cdot \text{Weight of a Person} \cdot \text{Gravitational Acceleration} \cdot \text{Length of Rope}}{\text{Deceleration Distance}}$$

$$= \frac{1 \cdot 80 \text{ kg} \cdot 10 \text{ m/s}^2 \cdot 2 \text{ m}}{0.5 \text{ m}} = 3,200 \text{ N}$$

This indicates that the calculated force of a fall should be set to at least 3,200 N during further calculations.

In an effort to determine the railing's capacity to withstand a person's fall, calculations of the bending stress on the shortest railing (located on the short side of the platform) with a central point force of 3,200 N have been conducted using item24's website. As illustrated in Figure 39, the resulting bending stress is lower then the material's yield strength. It can therefore be assumed that the railing can be used for anchorage points, provided that the short sides are used as anchorage points and with a maximum of one person per railing section. However, the railings on the longer sides of the platform were not capable of withstanding the required force.

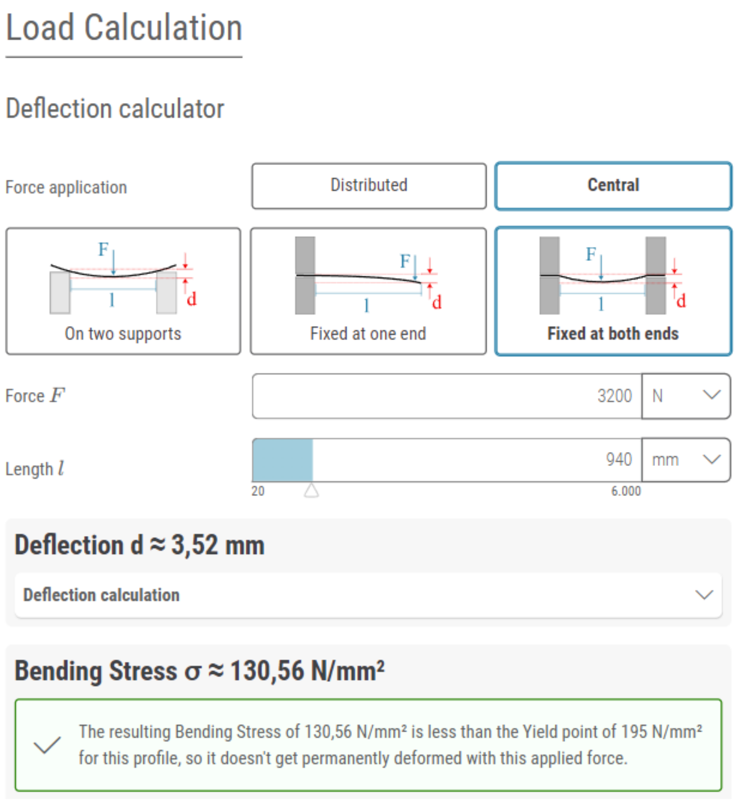


Figure 39: Central force of 3,200N on the horizontal part of the railing, on the short platform sides.

- **The direction of the movements shall be clearly stated on or near the controls with words or symbols.**

  The control panel design suggested in Section 8.3.3 meets this requirement by featuring a simple design with symbols clearly indicating directions. It is designed with only three buttons, limiting the potential for confusion and ensuring straightforward operation as depicted in Figure 40.

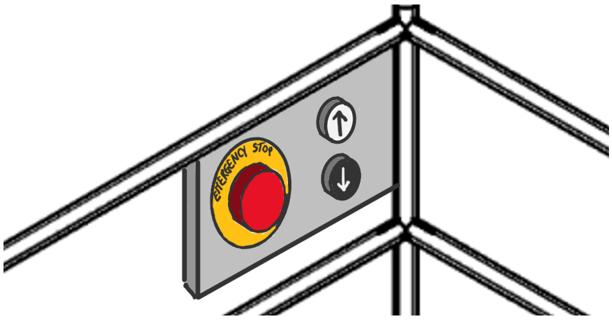


Figure 40: Illustration of the control panel design.

- **The MEWP shall be provided with an emergency stop function.**

  As described in Section 8.3.3, the suggested control panel design will be equipped, both at the platform top and chassis, with an emergency stop button. This ensures that the platform will immediately stop all operations upon pressing the button, thereby enhancing safety for the workers and adhering to this specific standard requirement. To avoid accidental emergency stop, it is suggested to apply a safety casting or a necessary rotation of the button before enabling the stop.

- **Any gaps presented in the floor, or between the floor and the railing or toe board need to ensure that an object with a diameter of 15 mm cannot pass through**

  All gaps presented in the floor, or between the floor and the railing or toe boards, are designed in compliance with this requirement.

- **Railings are required to have a minimum height of 1.1 m high, a toe board of at least 0.15 m height and intermediate guard rails not more than 0.55 m from toe board or top guard rail.**

  The railing design incorporates several features to enhance safety by preventing slips or accidental steps over the edge. Specifically, the railing includes a top guard rail positioned at 1.0 m, an knee railing at 0.5 m above the floor and 0.39 m below the top guard rail, and a toe board standing at 0.12 m in height. While this design largely aligns with safety standards, some adjustments are necessary to fully comply.

Although the intermediate guard rail satisfies the requirement, the overall height of the railing needs to be increased by at least 0.1 m, and the toe board height should be raised by at least 0.03 m. These modifications are minimal due to the slight deviations from the required measurements.

Due to the late discovery of the specific requirements and existing time constraints, no alterations will be made to the current model. If adherence to these standards becomes necessary, adjusting the railing and toe board in item24 will not pose a significant challenge. However, with changes occuring in both item24 and the 3D model, we currently lack the time to undertake these modifications.

- **Stairs providing access to the platform should be a minimum of 420 mm broad.**

  The staircase on the platform is constructed to be 700 mm wide, thus exceeding the minimum width requirement of 420 mm.

4.3.5 Manual Movement

To ensure that the platform can be easily moved, even with maximum loads applied, calculations has been done to see how big of a force (F_w) is necessary to initiate horizontal movement.

The suggested wheels for the platform have ball bearings as wheel bearings. The ball bearings will make the wheels turn and the friction force, described in Section 2.8, will usually have a coefficient between 0.001 and 0.005 for such bearings [55].

The total loads pointing downwards on the platform during maximum loads will be:

$$F_{down} = G + \text{Maximum Load} = 10,400 \text{ N} + 6,000 \text{ N} = 16,400 \text{ N}$$

The friction force, with the most conservative friction coefficient = 0.005, is:

$$F_{friction} = \mu \cdot F_{down} = 0.005 \cdot 16,400 \text{ N} = 82 \text{ N}$$

With no supports in contact with the ground, a force of at least 82 N is required to move the platform manually. In practice, this force may need to be greater due to uneven flooring or dust and dirt on the ground. However, this value suggests that relocating the platform when necessary should not pose a significant challenge.

The full calculation is shown in Appendix I.

4.3.6 Stability During Intended Use

According to section 4.2.3.4 in the standard, when calculating the platform's stability, the least amount of force that should be applied is 400 Newtons, for platforms designed to carry more than one person, applied at a height of 1.1 meters above the platform's floor. This load and maximum loads are depicted together in Figure 41. This is to account for the increased likelihood of tipping when forces are exerted higher than the platform frame. This ensures that the platform remains stable and does not tip over while in use, particularly when subjected to typical operational forces by workers.

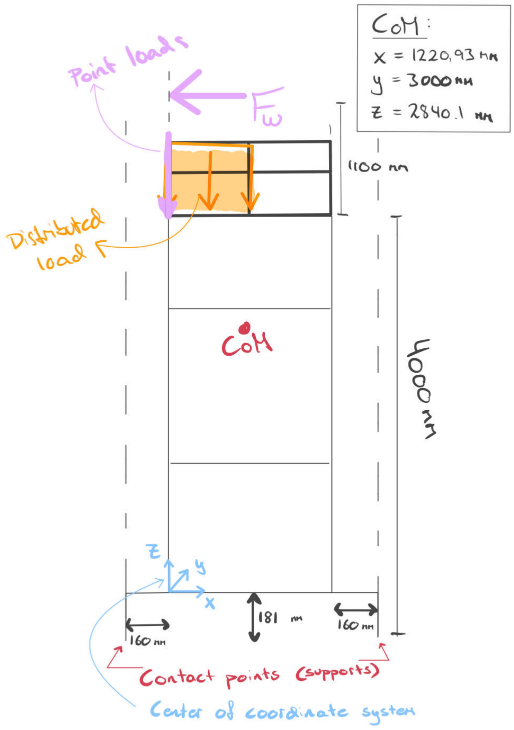


Figure 41: Sketch showing the placement of the working force on the platform with maximum load, seen from the side.

To find out if the platform will tip over during this state, the moment made by the working force is compared to the stabilizing moment calculated earlier. The calculations were done with a working force equal to 600 N, since the standard states "minimum of 400 Newtons". If the platform remains stable during this state, this part of the standard will consequently be met.

$$M_{F_w} = F_w \cdot (4 \text{ m} - 2.8401 \text{ m} + 1.1 \text{ m})$$

$$= 600 \text{ N} \cdot 2.2599 \text{ m} = 1,355.94 \text{ Nm}$$

The moments due to the maximum load, both distributed (DL) and point loads (PL) is then calculated:

$$M_{\text{DL}} = 4,400 \text{ N} \cdot (1.5 \text{ m} - 1.22093 \text{ m}) = 1,227.908 \text{ Nm}$$

$$M_{\text{PL}} = 2 \cdot 800 \text{ N} \cdot (2 \text{ m} - 1.22093 \text{ m}) = 1,246.512 \text{ Nm}$$

The total moment due to forces (M_{tot}) is then:

$$M_{\text{tot}} = M_{F_w} + M_{DL} + M_{PL} = 1,356.94 \text{ Nm} + 1,227.908 \text{ Nm} + 1,246.512 \text{ Nm} = 3,830.36 \text{ Nm}$$

M_{tot} equals 3,380.36 Nm, and the stabilizing moment, previously calculated in Section 4.2 is still 4,463 Nm. Since the stabilizing moment is greater than M_{F_w}, the platform will not tip during this state, proving that this part of the standard is met.

Full calculations are shown in Appendix J

4.3.7 Stability Tests

This section outlines the necessary stability tests according to NS-NE 280, along with their corresponding test results.

· **Kerb test:** assesses how the MEWP reacts as one or more wheels (or supports) moves over an uneven surface and how it reacts as it hits a kerb.

Uneven Surface Test:

According to the standard, the rated load should be evenly distributed on half of the platform floor during the test. However, the platform is not intended to be manually moved while loaded. Consequently, the original kerb test was conducted with an unloaded platform.

The motion study was conducted with gravitational acceleration set at 9.81 m/s^2, velocity maintained at a constant 200 mm/s, and the applied manual force focused on the middle vertical beam at the rear. The supports are removed during this test to obtain the most conservative results, simulating the condition when the supports are fully raised and not in contact with the ground.

Due to the challenges of demonstrating the platform's movement in static images, the video has been included. To see the full video one can either click on the images or see Appendix C.1.

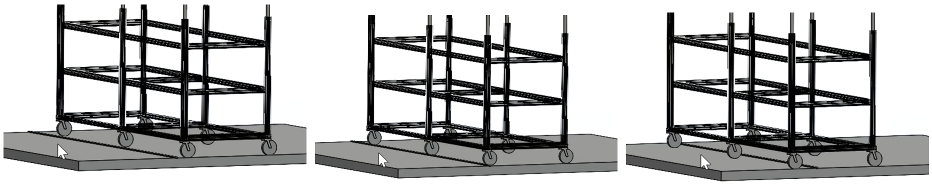


Figure 42: Pictures from video of kerb test motion study, showing the first three wheels going over a 2 cm kerb. Click here to see full video or on image.

There is almost no tilting of the platform during the first three wheels traversing over the 2 cm kerb as depicted in Figure 42. Proving that the side prone to tilting is the rear of the platform.

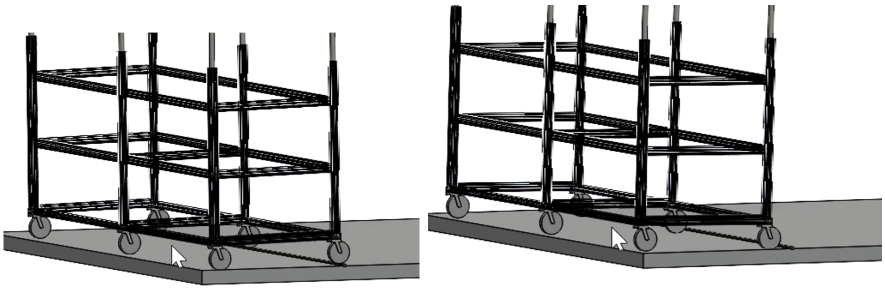


Figure 43: Images from the video of the kerb test motion study, showing the last three wheels traversing a 2 cm kerb. Click here to see full video or on image.

Figure 43 illustrates how the platform tilts slightly while and after crossing the kerb. Despite this, the platform maintains balance and does not tip over while crossing the kerb at a speed of 200 mm/s. The video demonstrates that the platform tilts toward the rear, where stairs will be attached during actual operation, effectively reducing this tilting effect. Furthermore, although the platform is not designed for manual movement while loaded, adding a load as the standard requires would nonetheless enhance its stability.

According to the standard the test should also be done with the platform facing the other way, going rear first onto the kerb. Figure 44 shows still images of how the platform rolls over the 2 cm kerb with the rear first. This way seems more stable than going front first, probably because the CoM being located closer to this side for the unloaded platform. The full video can be found in Appendix C.2 or by clicking on the image Figure 44.

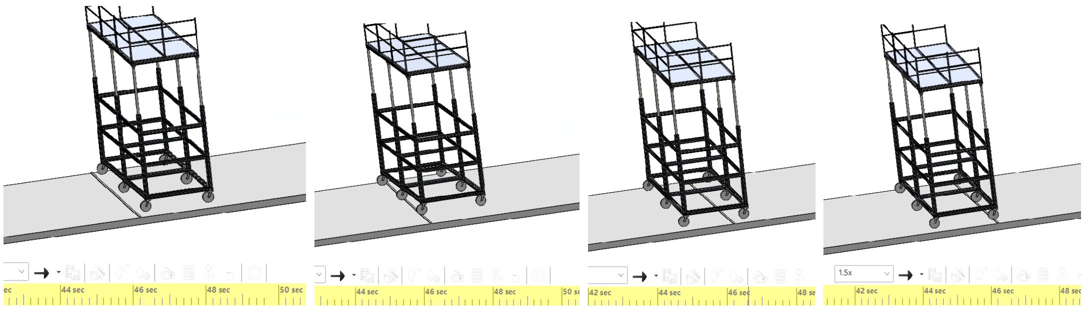


Figure 44: Static images from the motion study with the rear facing the 2 cm kerb. Click here to see full video or on image.

These observations confirm that the platform can successfully undergo this type of kerb test, maintaining stability under simulated operational conditions.

Hitting-a-Kerb Test:

The next motion study simulates how the platform will react to hitting a 15 cm tall kerb and not rolling over it. As shown in the video in Appendix C.3, the wheels of the platform will hit the kerb, and as the force continue to push the platform, it will eventually tip over. Figure 45 shows still pictures showing the platform hitting the kerb and tipping.

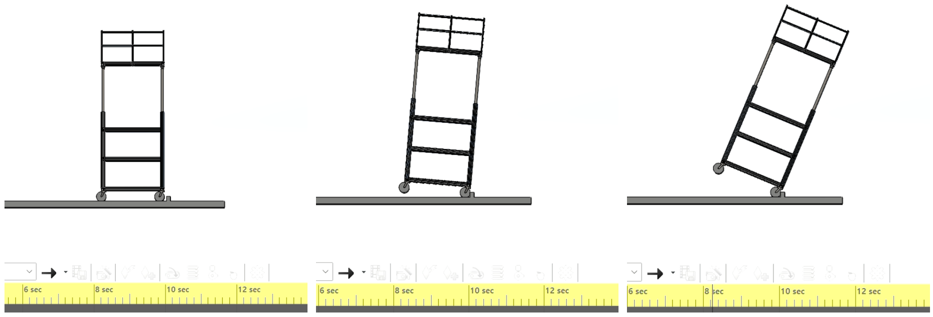


Figure 45: Still pictures from the motion study video in Appendix C.3, showing how the platform tipps when in contact with a 15 cm kerb, and with a horizontal force pushing it from the rear, middle beam. Click here to see full video or on image.

In the motion study the constant velocity is set to 200 mm/second as in the previous kerb tests. The wheels come in contact with the kerb at 2.5 seconds into the study, and by finding the time at which the platform reaches the tipping angle, the total time for tipping in this test can be found.

The tipping angle for unloaded platform will first be to be modified since the supports are removed. The mass is set as approximately the same, but the tipping lines are now even narrower than the platform base. This results in the tipping angle being smaller than:

$$\text{Tipping Angle} = arctan(\frac{0.983 \text{ m}}{2.35192 \text{ m}}) \approx 22.682^{\circ}$$

By checking the angle of the platform during tipping in this test, it can be found that the approximate time it takes from hitting the kerb to reaching 22 degrees is 5.3 seconds.

The radius of the wheel is 75 mm and the kerb is 15 mm taller than the ground. This means that the wheel will hit the kerb as depicted in Figure 46 and the resulting forces that gives moment is shown as forces (F) and frictional forces (R).

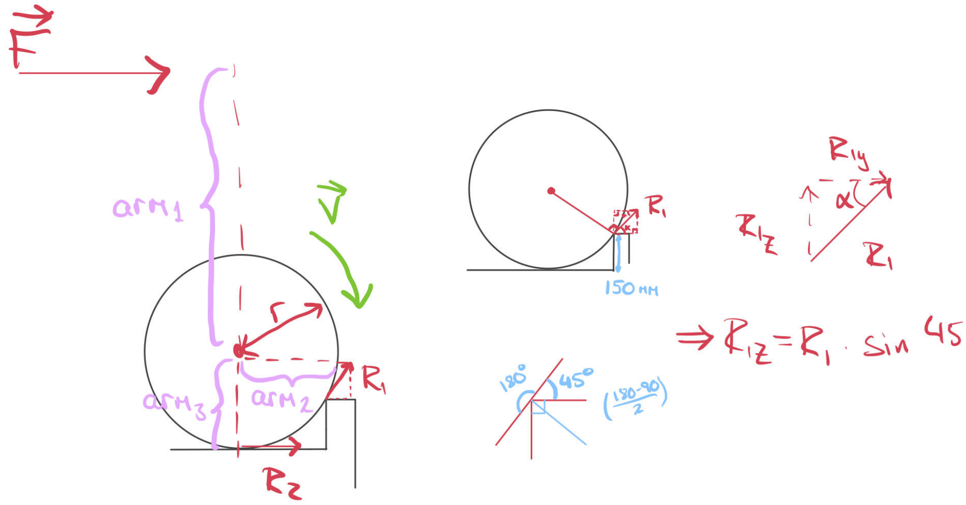


Figure 46: Sketch of how the wheel hits the 15 cm kerb, with resulting, moment inducing, forces. Pushing force is named F and the two friction forces are named R_1 and R_2.

To find out the magnitude of the force that will tip a platform under these conditions, the sum of moments on the wheel can be calculated:

$$\sum M = F \cdot arm_1 - R_1 \cdot arm_2 - R_2 \cdot arm_3$$

The distance between the applied moving force (F) and the center of the wheel was set to half the distance of the vertical beams on the base plus the radius of the wheel. This results in the forces arm being 2,420 mm/2 + 75 mm= 1,285 mm. The frictional forces has arms equal to the radius of the wheel. Since the frictional force R_1 affects the wheel at an angle and not perpendicular to its radius, the component of the force that will affect the moment is the one depicted in Figure 46 which equals R_1 sin(45°). The sum of moments can then be written as:

$$\sum M = F \cdot 1,285 \text{ mm} - R_1 \cdot sin(45°) \cdot r - R_2 \cdot r$$

The frictional forces can be found by using Equation 9, and when these are put into the equation above the result is:

$$\sum M = F \cdot 1,285 \text{ mm} - N \cdot \mu_S \cdot sin(45°) \cdot r - N \cdot \mu_S \cdot r$$

The normal force will be equal to the normal force used earlier at 10,400 N and the static friction coefficient for polyurethane on concrete has been tested to be approximately 0.634 by Kristian Hansen at UiT [52]. With these properties the sum of moments can be written as:

$$\sum M = F \cdot 1,285 \text{ mm} - 10,400 \text{ N} \cdot 0.634 \cdot sin(45°) \cdot 75 \text{ mm} - 10,400 \text{ N} \cdot 0.634 \cdot 75 \text{ mm}$$

$$= F \cdot 1,285 \text{ mm} - 8,441.9 \text{ Nm}$$

The platform will tip over when the sum of the moments are greater than zero as described in the theoretical basis for tipping. To find the maximum force that has to be employed, on the middle vertical beam of the platform, during this state, this equation has been solved:

$$\sum M = 0 \implies F \cdot 1,285 \text{ mm} = 8,441.9 \text{ Nm} \implies F = \frac{8,441.9 \text{ Nm}}{1.285 \text{ m}} = 6,976.7 \text{ N}$$

Any force greater than 6,976.7 N will result in the platform tipping while in contact with the 15 cm kerb.

The full calculation can be found in Appendix L.

· **Depression test:** assesses how the MEWP reacts when one or more wheels (or supports) are in a depressed area or on an uneven surface while standing still.

This test was conducted manually with a depression of 2 cm on two of the supports, mirroring the conditions observed in A2. The maximum depression height was also calculated using the previously determined tipping angle, both without and with maximum loads. This was done using trigonometry to find the vertical difference that appears when an angle close to tipping angle is present.

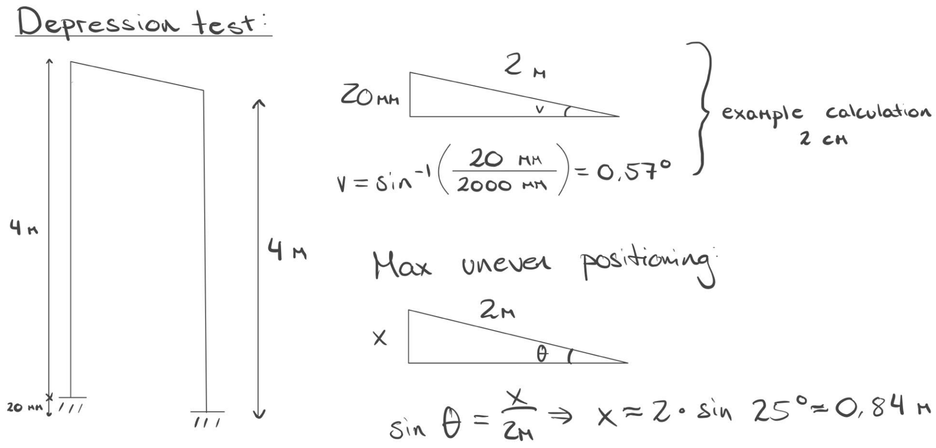


Figure 47: Depression calculations on platform without any loads.

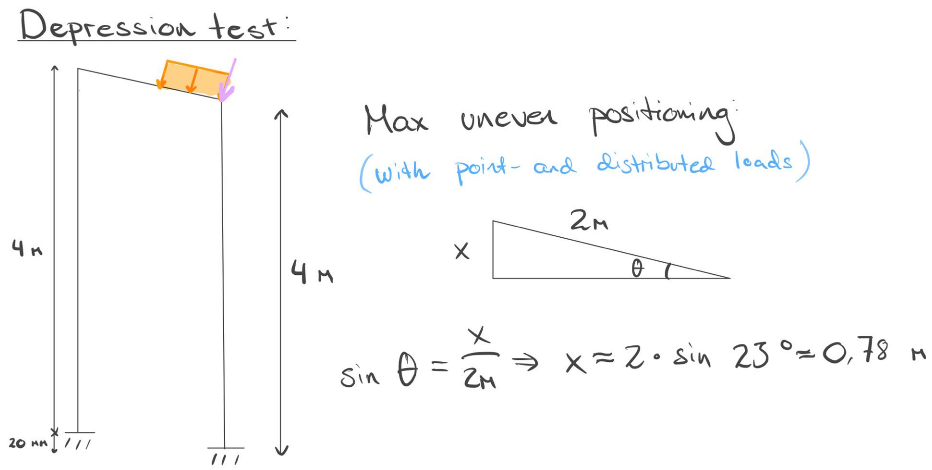


Figure 48: Depression calculations on platform with maximum loads.

The calculations indicate that a 2 cm depression results in a floor angle of 0.57 degrees on the platform without loads as shown in Figure 47. Furthermore, Figure 48 displays the calculation of the maximum depression limit on the platform during maximum loads, determined to be 0.78 meters. However, such an angle is highly unlikely to occur as components within the platform are expected to fail before achieving this extreme. Nonetheless, this test demonstrates that the structural integrity of the platform itself will not be the limiting factor under such conditions.

· **Braking test:** evaluates the platform's stability when subjected to the greatest human force applied to stop or push it forward during manual movement. The goal is to ensure that the platform does not tip over under these conditions. In this test the rated load should be distributed evenly on half of the platform floor.

To simulate a worst case scenario, the height of the force was set to be applied 1.1 m above the ground. According to LoadMoverINC [10] an estimate for the greatest force a human can push or pull can be set equal to the force of moving 100 lbs along a horizontal ground. This is approximately the same as 450 Newtons. In worst case scenario there might be three people pushing or pulling the platform along the long side at the same time, one on each vertical beam, so there will be three of the 450 N forces, spaced evenly along the long side.

By using the CoM of the platform that has been calculated in Section 4.1.2 while taking into consideration all the forces acting on the platform, then the tipping stability of the platform can be calculated by considering only the external push/pull forces.

To evaluate the tipping, the stabilizing moment is compared to the moment applied on the platform from the push/pull forces. These moments are calculated by using Equation 8.

The perpendicular distance from the CoM to the force is:

$$\text{Distance from CoM to PF} = 2.84 \text{ m} - (1.1 \text{ m} - 0.3 \text{ m}) = 2.04 \text{ m}$$

The moment per force is then:

$$\text{Moment per force} = 450 \text{ N} \cdot 2.04 \text{ m} = 918 \text{ Nm}$$

The total moment for all 5 forces is therefore:

$$\text{Total moment} = 3 \cdot 918 \text{ Nm} = 2,754 \text{ Nm}$$

Comparing this with the stabilizing moment already calculated in Section 4.2, the forces excerted by pushing or pulling the platform will not lead to tipping because:

$$\text{Total moment} = 2,754 \text{ Nm} \not> 4,463.1293 \text{ Nm} = \text{M}_{stabilizing}$$

Since the push and pull forces are set to be 450 N at max, the direction of the force will not affect the moment value. In addition, the perpendicular distance from CoM to the force will be the same for each computation as shown in Figure 49, which in turn means that the moment will be the same for each one as well.

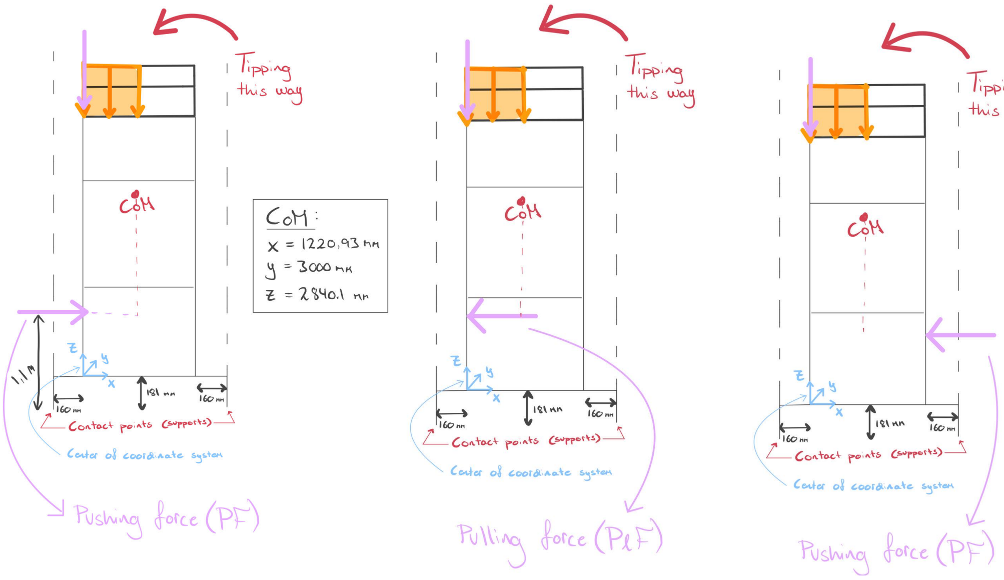


Figure 49: Push and pull forces on the platform.

The safety factor for the moment is calculated as:

$$SF = \frac{4,463.1293 \text{ Nm}}{2,754 \text{ Nm}} = 1.62$$

A safety factor of 1.62 is not very high and could indicate that a maximum of three people should be set as a limit during manual movement of the platform to ensure that tipping won't occur.

The full calculation can be seen in Appendix M.

· **Overload test:** evaluates the platform's performance when the rated load is increased by 50%, ensuring that safety margins are maintained and verifying the platform's ability to handle heavier loads without compromising safety.

By increasing the rated load by 50 precent the distributed load will be 900kg or 9,000 N. This load will firstly be simulated to be distributed evenly over the six vertical beams on the bottom base, colored in blue in Figure 50, to ensure the bending stresses in the beams do not surpass the yield strength of the material. Next, the top of the platform will be checked for yielding by using item24's stress calculator.

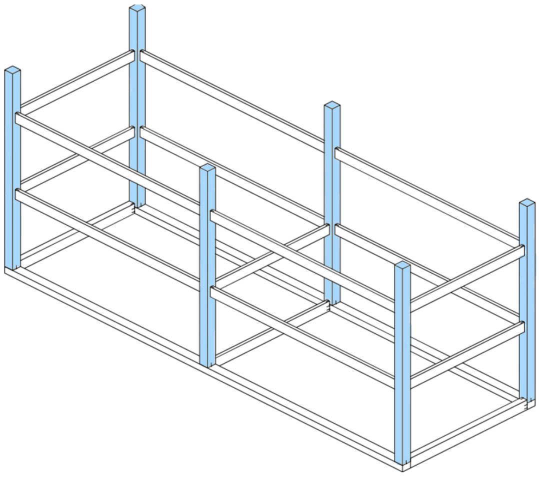


Figure 50: The platform base design with vertical components colored in blue.

In an attempt to simulate real conditions as accurately as possible, a simplified model was tested in SolidWorks.

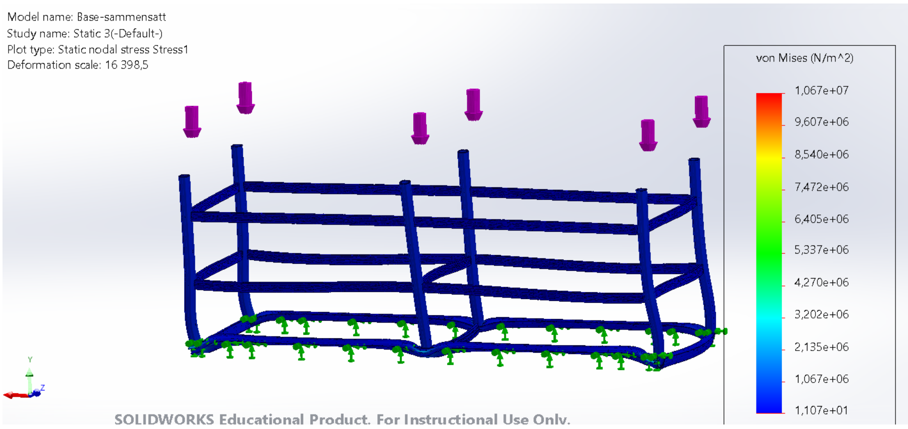


Figure 51: Simplified model with profiles from item24 with material 6061-T4 aluminium

When a force of 9,000N was applied to all vertically oriented beams it results in a maximum stress of 1.067e+07 N/m^2, which is equal to 10.67 MPa, as shown in Figure 51. This stress was compared to the yield strenght of the material, which is 195 MPa according to item24. Resulting in a much lower bending stress than the yield strenght, thus no anticipated permanent deformation under this laod.

At the top of the platform, three beams of various lenght, all with the same profile and a yield strenght of 195 MPa, are used in the desgin of the platform. Three beam lenghts measure 6,000 mm, 1,893 mm, and 1,840 mm, illustred in Figure 52.

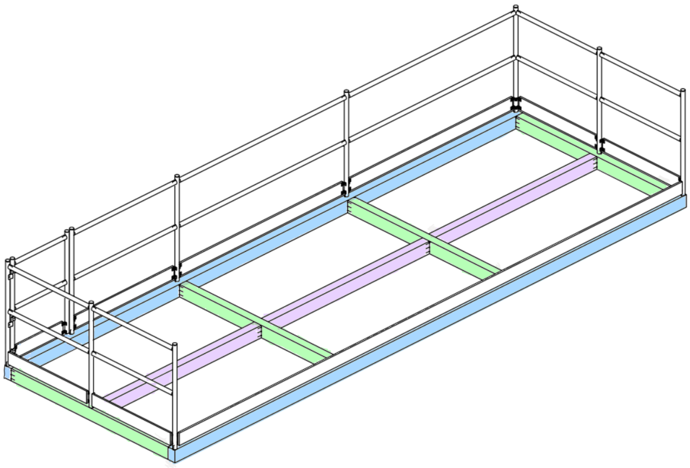


Figure 52: Colored beams illustrating the profiles with applied force, 6,000 mm (blue), 1,893 mm (purple), 1,840 mm (green).

For the beam with a lenght of 6,000 mm, the bending stress amounts to 188.63 MPa, which is close to the yield strenght of the profile but not exceeding it. Therefore, the profile does not experience permanent deformation due to this applied force, as confirmed in Figure 53. Because the beam with a length of 6,000 mm is the most critical, the other two beams, with lengths 1,893 mm and 1,840 mm, are within the yield strength for the same profile.

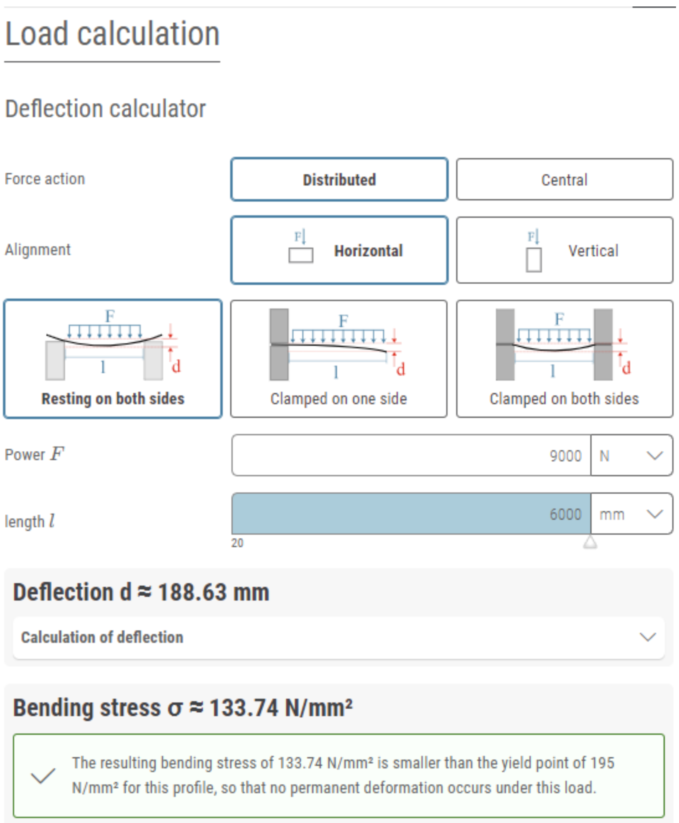


Figure 53: Load calculation on Profile 8 120x80 mm, 6,000 mm. [63].

The overload test has been conducted on various components, resulting in findings that indicate that it will be capable to withstand a weight capacity of 900 kg.

4.4 Stress Analysis and Simulations

To ensure that the platform components are designed to withstand the stresses caused by loads, simulations were done between each step of the assembly of the platform. Each component's maximum stresses, displacements, and strain values were checked to ensure that they could withstand the maximum loads.

4.4.1 Aluminium Flooring

During the process of designing and evaluating the structural integrity of aluminum plates used as flooring on a platform, calculations and simulations were conducted. The platform floor is segmented into six plates, with each plate subjected to a proportional share of the total distributed load of 6,000 N, resulting in a load of 1,000 N on each plate.

Each plate is fixed along its perimeter and is subjected to a uniformly distributed load across the entire surface. As illustrated in Figure 54, the stress on the plate reaches 15.7 MPa at the maximum.

The material of the plates is set as Aluminium 6061 in SolidWorks, however in reality they are made of Aluminium 5754 which has a different yield strength. The maximum stress must be compared to the yield strength of the correct aluminium type, which is EN AW 5754 (H111) which has a yield strength of 80 MPa and tensile strength of 190 MPa as stated in Section 2.13.1.

The maximum bending stress is 15.7 MPa, while the yield strength is 80 MPa, indicating that the material properties are strong enough for the maximum loads. By dividing the yield strength by the stress, a safety factor of approximately 5 is obtained.

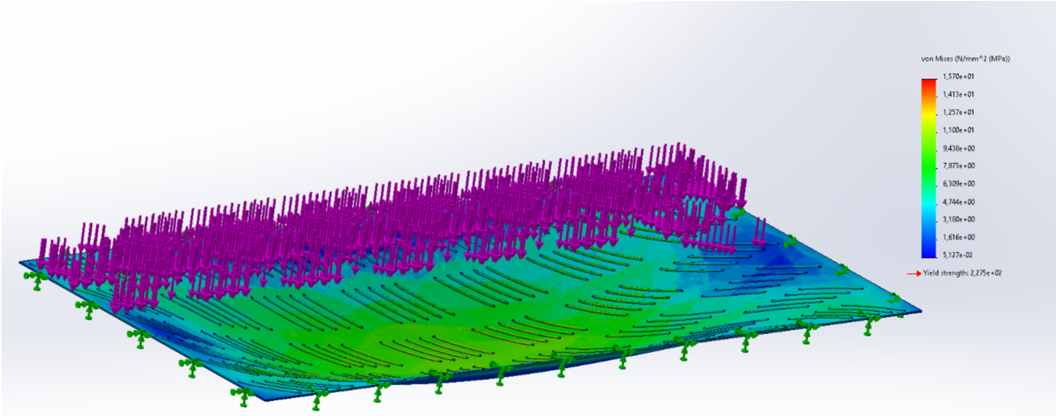


Figure 54: Stress in a 2x1 m aluminium plate, with a thickness of 4 mm, subjected to a distributed load of 1,000 N.

Due to displacement measured at 4.335 mm, as illustrated in Figure 55, no design changes are proposed for the plate thickness. Reducing the thickness could decrease stiffness, potentially leading to increased displacement and negatively affecting the platform's operational flexibility and shock absorption capabilities. Moreover, a thinner plate might reduce the perceived security for workers. Therefore, the current plate thickness of 4 mm will be maintained.

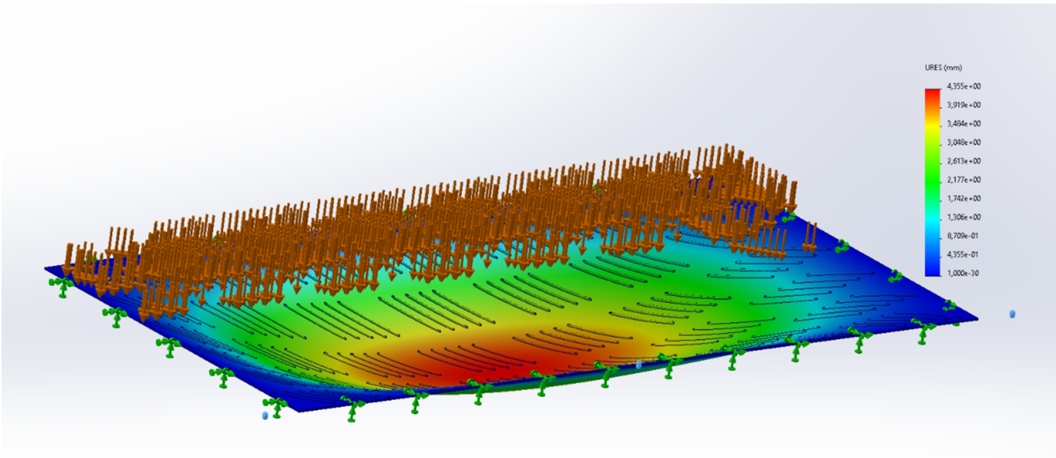


Figure 55: Displacement for a 2x1 m aluminium plate, with a thickness of 4 mm, subjected to a distributed load of 1,000 N.

It is crucial to avoid overengineering or oversizing the platform's components, such as the thickness of the aluminum plates. Overengineering can lead to unnecessary increases in both weight and cost. Therefore, it is important to balance material strength to ensure that components are robust enough to withstand required loads, while avoiding added costs and complexity.

4.4.2 Base

To verify the platform's ability to withstand maximum loads in terms of material strength, simulations will be conducted on the platform base. These simulations will demonstrate how the platform supports the maximum load when fully lowered.

To make sure the base of the platform can withstand the maximum loads, the stress values on the base were simulated in SolidWorks by constraining the parts connected to the supports and wheels on the short sides, and with a distributed load of 6,000 N over the platform floor plates. The placement of the load and constraints are shown in Figure 56.

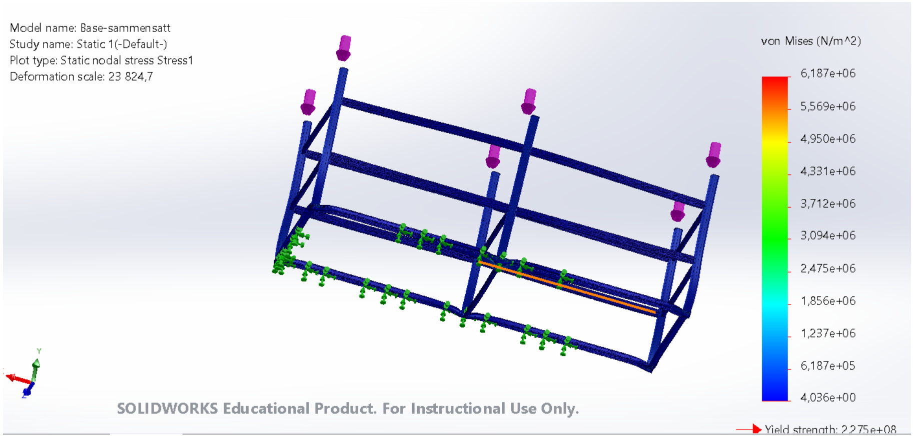


Figure 56: The stress values for the platform base under maximum load (6,000 N) evenly distributed over the entire platform floor.

To confirm that the stresses on the platform remain within acceptable limits, it is important that the maximum stress does not exceed the yield strength. As depicted in Figure 56, the maximum stress under these loads results in a stress value of approximately 6.187e^7 N/m^2, or 6.187 MPa, while the yield strength is 195 MPa as stated in Section 2.13.1. This gives a safety factor of approximately 31, ensuring the platform's structural integrity.

As for the displacement on the base during these loads, the deviation was calculated to be under 0.03 mm as pictured in Figure 57.

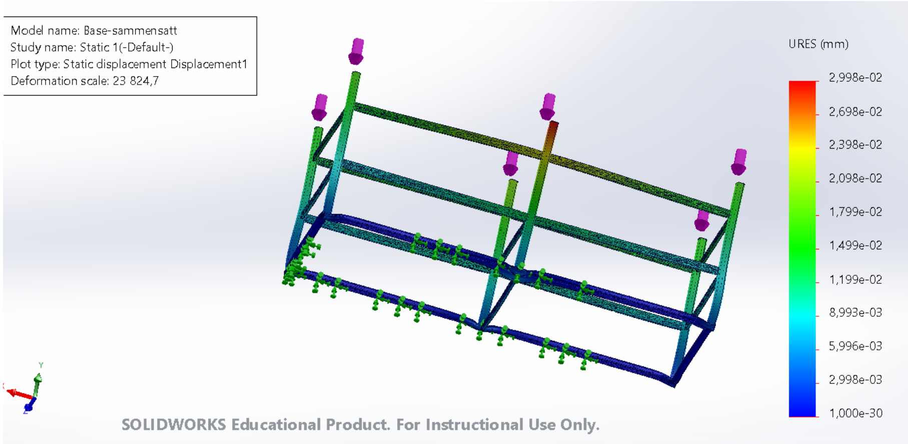


Figure 57: The stress values for the platform base under maximum load (6,000 N) evenly distributed over the entire platform floor.

As shown in Figure 58, the maximum strain on the base is 5.057e-05 ESTRN (engineering strain). This value is considered very small. This indicates minimal deformation of the material, meaning it is within the elastic range where it can return to its original shape after the load is removed. Such a strain value typically suggests that the structure is not experiencing significant stress or risk of failure under the given loads.

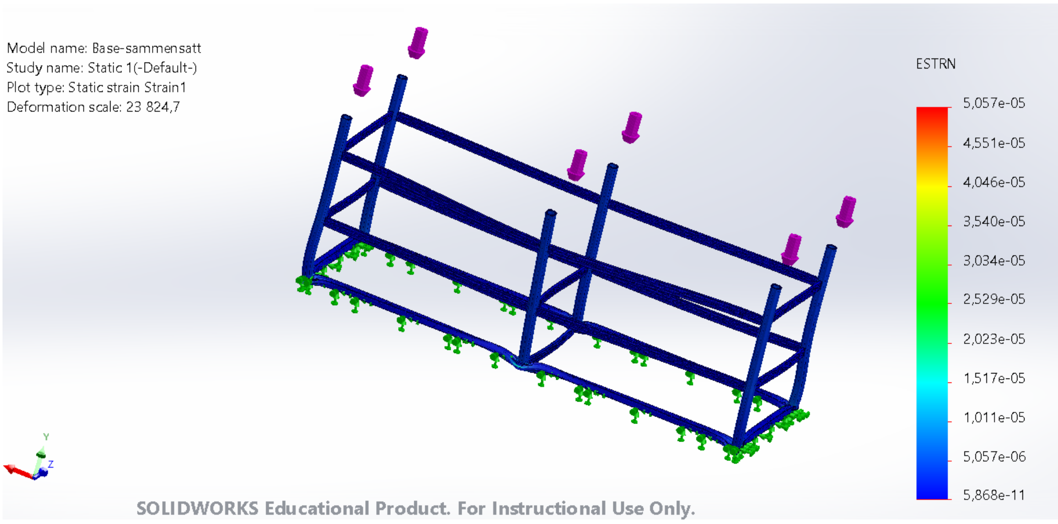


Figure 58: A simulation of the strain on the platform base.

The base can clearly withstand the maximum loads, and further simulations can therefore be continued with this base design.

4.4.3 Fully Extended Platform

Due to the platform being composed of numerous large components, simulating the entire structure as a whole presented challenges. To analyze the fully extended platform, a strategy of deconstructing the entire assembly into individual components was implemented. Each part was then examined separately, simplifying the process by reducing the complexity and computational load.

Stress Analysis

The platform will be maintained at a maximum height of four meters by the actuators, and in this static state, no significant load will be exerted on the vertical beams; instead, the load will primarily be borne by the actuators. Since the actuators will be selected based on their ability to handle maximum loads and required strength, it will not be necessary to simulate stress on the vertical platform beams as they do not support this weight directly. This decision is supported by findings in Section 4.4.2, which confirmed that the base material's strength supports the maximum loads. Rather, the focus will be on the horizontal beams where the actuators are attached, which will require stress calculations. These beams are colored in blue and pink in Figure 59.

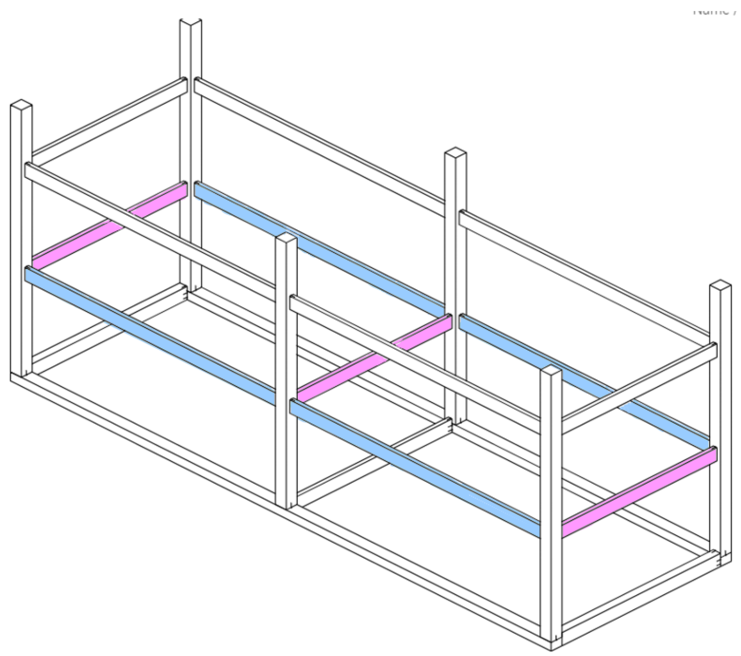


Figure 59: Platform base with colored beams. The acutator-carrying beams are on the middle support frame colored in blue and pink.

Item24's website provides a load calculator that assists in calculating the bending stress on these beams. As shown in Figure 60, the horizontal 120x40 mm beams fastened to the actuators (both short and long sides) can withstand more than the loads imposed by the actuators.

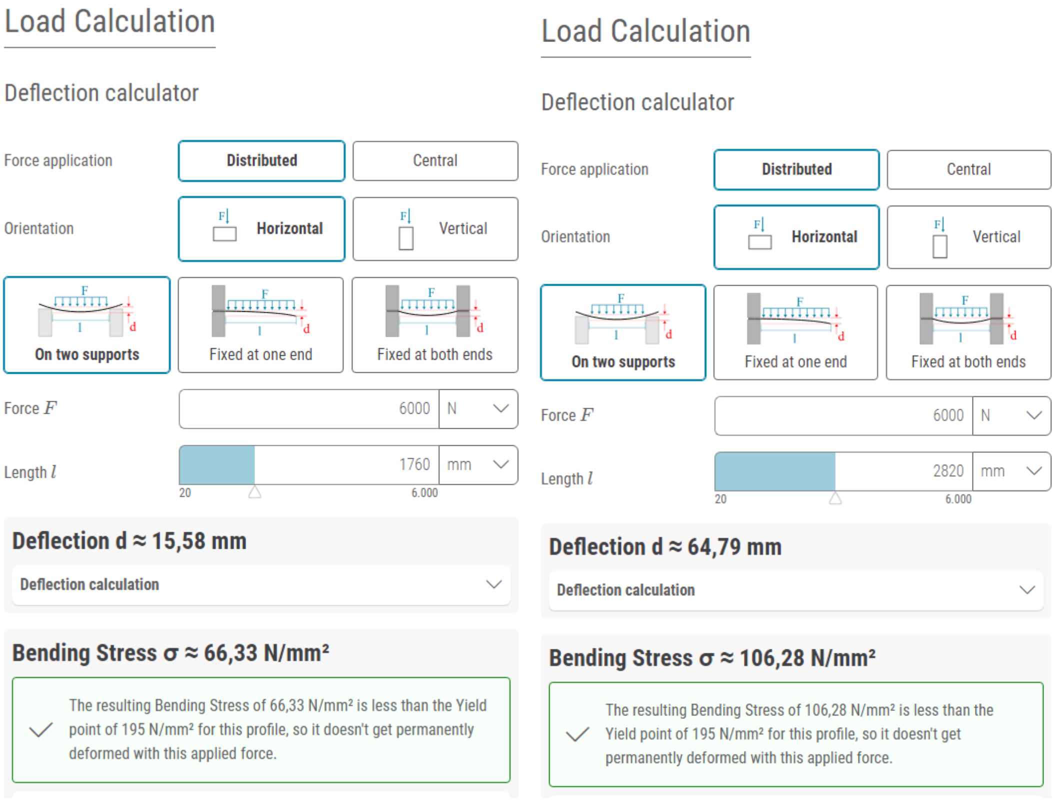


Figure 60: Calculations from item24's load calculator for the carrying horizontal beams: short side beam (pink in Figure 59) to the left, and long side beams (blue in Figure 59) to the right, both within the yield strength limit.

The calculator indicates that the bending stress for the short side beams is approximately 66.33 MPa, and for the long side, it is 106.28 MPa. Given that the yield strength is 195 MPa, both bending stresses are well within the material strength limit. These calculations confirm that the beams can withstand loads of up to 6,000 N, definitively proving they can support the loads distributed from the cylinders and their fastening plates, as this load will inherently be smaller than 6,000 N.

As for the horizontal beams connected to the actuators at the top of the platform, they are larger in dimension (120x80 mm) but have the same length and yield strength as previously mentioned beams. Consequently, their bending stresses will also inherently be below the yield strength of the material.

These findings indicate that the horizontal beams on the base are capable of supporting the actuators and effectively distributing the loads from them. This proves that as long as the actuators are properly dimensioned and selected for the platform, there will be no yield in the simplified platform's base structure.

To confirm that the platform top is equally capable of handling maximum loads, these horizontal beams will also need to undergo checks for yielding. This analysis was conducted following the same methods used for the base beams.

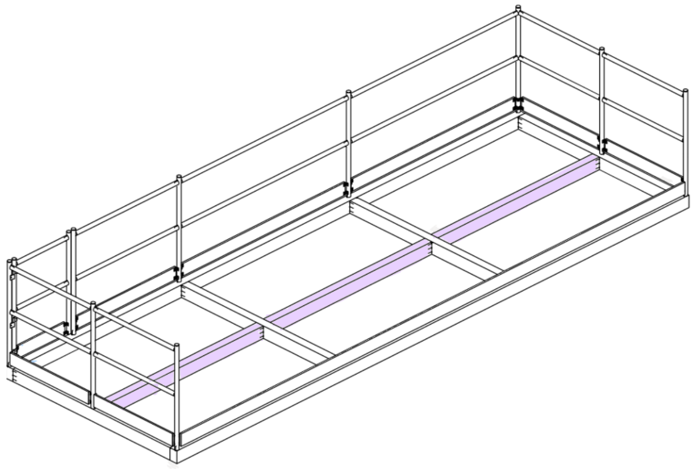


Figure 61: Sketch of the platform top with numbers for different components.

As the longest beams carrying the load from the aluminum floor are the middle supports, colored in purple in Figure 61, they were evaluated for material yield using the same calculator from item24.

To provide a conservative estimate and confirm the beams' capability to handle the loads, a 1,894 mm long beam was subjected to a yield check under a 6,000 N central load. This load is greater than what the beams will actually face during maximum load conditions, as the real load will be distributed across all beams in the framework. Testing the longest beam for the maximum load of the entire floor ensures that all components can withstand the load. As shown in Figure 62, the beams' calculated bending stress is 56.3 MPa which is below the material's yield strength. So, even under this heightened load, the material properties are sufficiently strong.

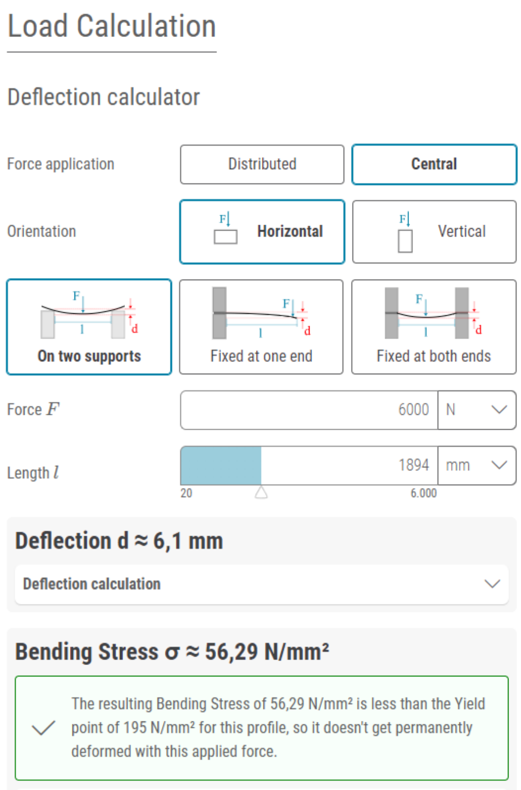


Figure 62: Calculations from item24's load calculator. For the longest carrying horizontal beam (purple beam in Figure 61), the bending stress is within the yield strength limit.

The final component of the platform that must be evaluated for yielding includes the steel tubes and their corresponding plastic cases.

When they are constrained at the bottom of the lower plastic case and a 6,000 N load is applied normal on the surface of the top plastic case as depicted in Figure 63, the maximum stress is calulated as $2.027e^7$ N/m^2 which is 20.27 MPa. Based of SolidWorks's POM material properties the tenisle strength of this plastic is $71.5e^6$ N/m^2 which is 71.5 MPa. The yield strength of alloyed steel is, according to SolidWorks, $7.1e^8$ N/m^2 which is 710 MPa. Both the plastic and steel will therefore not yield during maximum load.

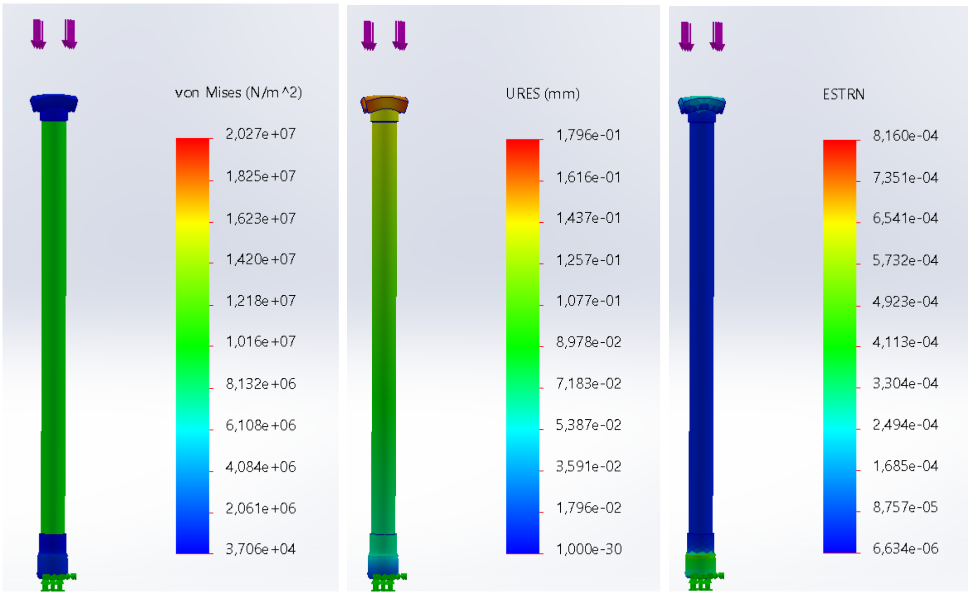


Figure 63: The SolidWorks simulation results during static study of the steel tubes with plastic casings. Stress, displacement and strain results from the left.

This simulation only serves to demonstrate that the material properties of the component comfortably meet the necessary safety and performance standards. In the actual platform, these tubes function primarily as stabilizers within the base of the platform. Their role is to reinforce the structure, thereby facilitating the actuator's task of lifting the platform vertically with greater stability.

Buckling

The critical components for buckling in the platform design are the long carrying profiles in the platform base, measured at 120x120 mm with cylindrical hole, and the actuators. Buckling calculations are crucial to ensure these profiles do not fail under maximum load.

<u>120x120 Profiles:</u>

The properties of the profile, sourced from item24's website, are as follows:

1. E = 70,000 MPa

2. A = 3,129 mm^2

3. I = 4,658,600 mm^4

For a conservative calculation, the effective length factor (K) was set to 1. This factor is used to modify the actual length of the column to an equivalent length that reflects the end conditions that may affect buckling. The formula for the slenderness ratio, Equation 13, was applied first to determine whether buckling might occur in the columns. To find the most conservative result, the entire length of the beam was used, even though, in reality, the supporting horizontal beams will secure the columns from buckling. The slenderness for the entire beam is calculated below, employing Equation 13.

$$\lambda = \frac{K \cdot L}{\sqrt{\frac{I}{A}}} = \frac{1 \cdot 2420 \text{ mm}}{\sqrt{\frac{4{,}658{,}600 \text{ mm}^4}{3{,}129 \text{ mm}^2}}} = 62.72$$

This indicates that the column is classified as an intermediate column and thus may be prone to buckling.

For a more realistic, yet still conservative, analysis, the slenderness calculation is performed for the longest unsupported segment of the column, which measures 940 mm. The slenderness ratio for this section is calculated as follows:

$$\lambda = \frac{K \cdot L}{\sqrt{\frac{I}{A}}} = \frac{1 \cdot 940 \text{ mm}}{\sqrt{\frac{4{,}658{,}600 \text{ mm}^4}{3{,}129 \text{ mm}^2}}} = 24.56$$

This indicates that the longest column segment defines as a short column, which is unlikely to buckle and should rather be checked for the material yielding (which it has already been established that it doesnt in Section 4.4.2).

To ensure that bucling will not occur, the Euler critical buckling load (F_{CR}), as shown in Equation 12, is calculated and checked against maximum load, which is the load from carrying the platform top with the maximum load applied.

$$F_{CR} = \frac{\pi^2 \cdot E \cdot I}{(K \cdot L)^2} = \frac{\pi^2 \cdot 70,000 \text{ N/mm}^2 \cdot 4,658,600 \text{ mm}^4}{(1 \cdot 2420 \text{ mm})^2} = 594,570 \text{ N}$$

The full calculation is shown in Appendix K.

Since the maximum load on the platform is 6,000 N and the platform top has a weight of approximately 430 kg according to SolidWorks, the maximum load on the columns would never exceed:

$$\text{Maxumum Load on Columns} = 6,000 \text{ N} + 4,300 \text{ N} \approx 10,300 \text{ N}$$

This load is substantially smaller than the critical buckling load calculated earlier. Therefore, this ensures that no buckling will occur in the critical columns. The safety factor, calculated based on these loads, is given by:

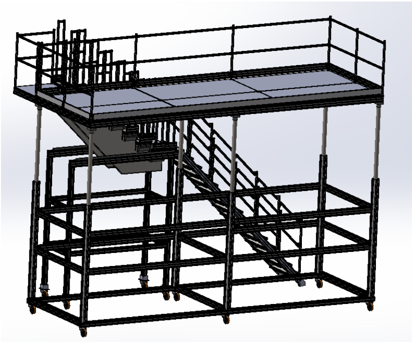
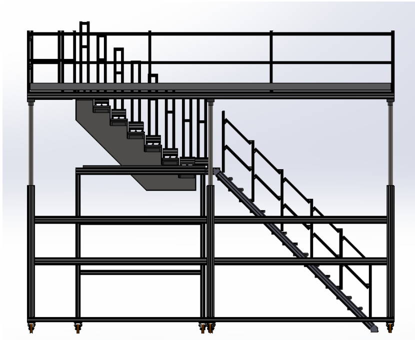
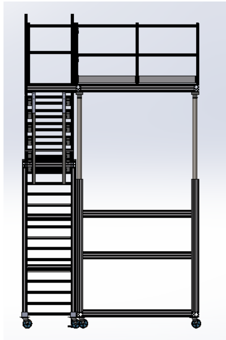
$$SF = \frac{594,570 \text{ N}}{10,300 \text{ N}} = 57.7$$

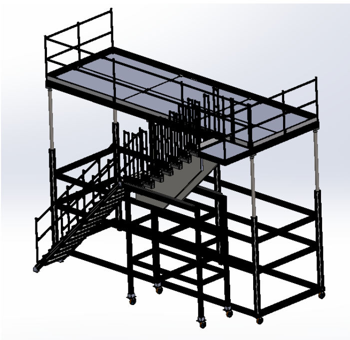
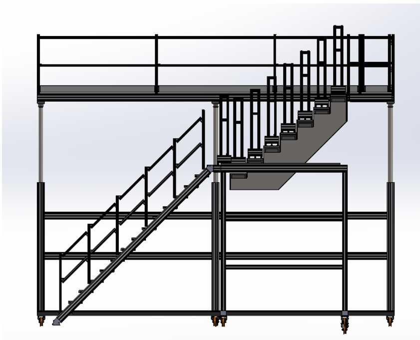
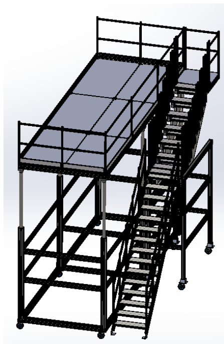
Actuators:

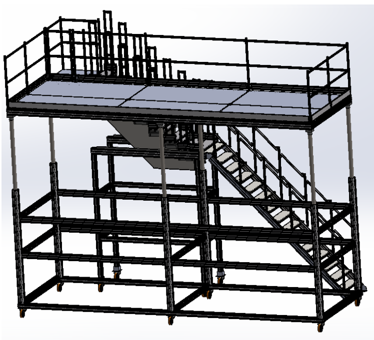
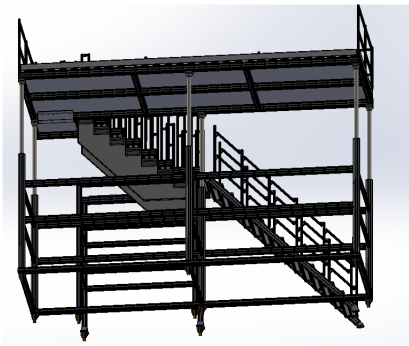
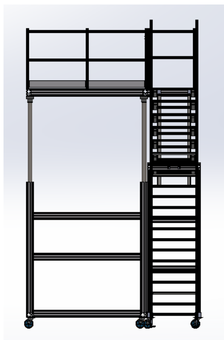
The selected actuators must also be able to withstand buckling. This capability must be verified before finalizing the choice of a specific actuator, as further commented in Section 8.3.1.

5 Results

In this section, the resulting platform design, and its intended use, is presented. The nine pictures below show the finalised design. Further, each component is described, with images to enhance clarity and understanding, and the exact dimensions for all parts are provided to ensure clarity.

5.1 Platform Design

Following the iterative design method used during the design phase as detailed earlier in this report, the 3D model for the platform was finalized. This section presents the resulting design of components, which has been evaluated to ensure its compliance with the standards outlined in Section 2.16. The simulations, in Section 4.4, have confirmed that the platform can withstand all necessary loads and stresses. This verifies its suitability for the intended applications.

The platform is equipped with six aluminum columns that help stabilize the platform during lifting. These columns help connecting the base and top of the platform together. Inside these columns, there are steel tubes that move along with the platform to improve stability, ensuring that the platform moves correctly in relation to the platform base when vertically lifted/lowered by the electrical cylinders. The top and bottom of the steel tubes are encased by POM plastic castings, which serves as a safety feature (bushing) to prevent direct contact between steel and aluminum. Because of POM's self-lubricating properties, the low friction makes it a suitable choice for bushing.

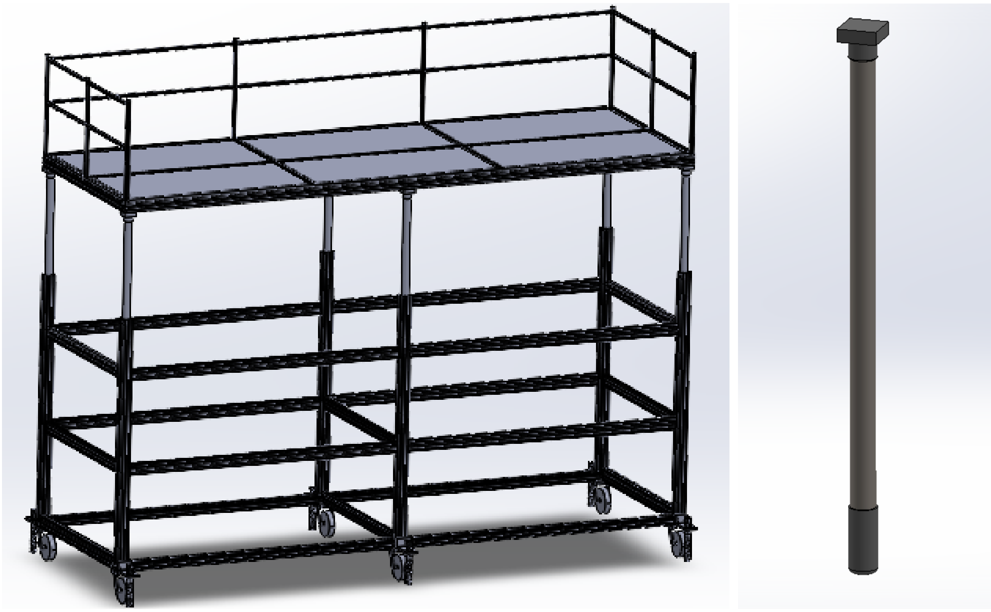


Figure 64: Simplified version of the platform featuring six columns and steel tubes, with POM safety components.

The side of the platform facing the jacket is deliberately designed without railing to facilitate workers access and accommodate the rotation of the jacket, shown in Figure 65. When the jacket rotates, a leg in the junction point can be pointing towards the platform floor, and a railing would obstruct this necessary movement. As mentioned earlier, while this design does not fully comply with the standard requirements, its intended use minimizes the risk of falls. Additionally, if a temporary solution is necessary, Aker can implement this as needed.

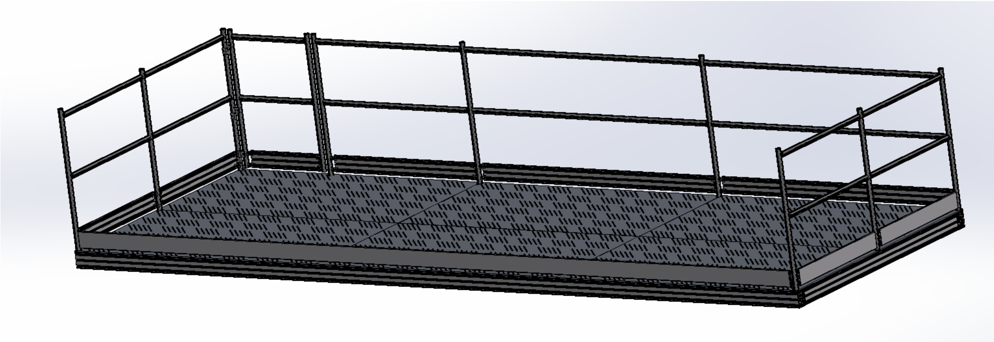


Figure 65: Side view of the platform top. The side facing the jacket, without a railing, pointing out.

The entrance to the platform is located at the stairs, strategically placed at the opposite end of the open side to optimize safety. To prevent tools and other equipments from falling, a toe board has been included to ensure safety on and around the platform. Additionally, the railing is equipped with a knee rail, to adhere to relevant standards and to maintain safety, shown in Figure 66. This contributes to creating a safe and structured workplace for the workers at Aker.

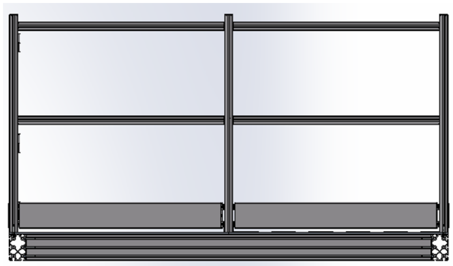


Figure 66: Safety features including a toe board, railing, and knee rail.

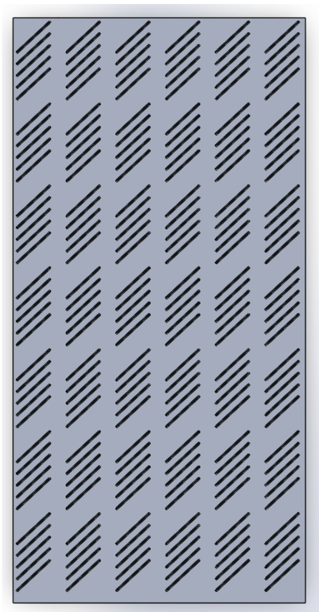


Figure 67: Platform floor designed with a checker plate pattern

The platform floor is designed with a checker pattern. This textured surface provides essential traction, reducing the risk of slipping and falls. This design ensures both safety and structural integrity under load. The platform will be exposed to a distributed load all over the floor. As a result of difficulties finding an aluminium plate with six meters length and two meters width, the floor was divided into six smaller parts with the dimension 2x1m, as shown in Figure 67. Following recommendations from Aker regarding the choice of plate supplier, it was decided to test a 4 mm thick aluminium plate from Norsk Stål, a supplier and size previously used by Aker.

5.2 Stairway Design

The stairs are designed in two parts, movable and static. The static section is attached to and will remain in the same position relative to the platform base at all times, even while the platform rises. This is then connected to a movable set of stairs, which is also connected to the movable corner platform.

5.2.1 Static Stairs

The static section consist of a 45 degree staircase with railing, with a total height of 2.5 meters. This is connected to a stair base-frame that supports the static stairs at all times. The design is shown in Figure 68.

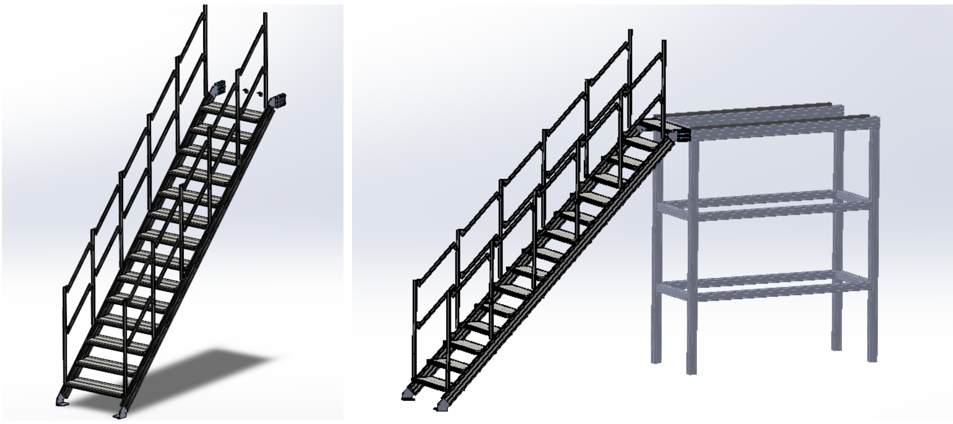


Figure 68: Static stair design, with railing, shown alone and connected to the stair base.

At the bottom of the stair base-frame wheels will be connected to each vertical beam. In addition, potential supports should also be fastened to the stair base.

5.2.2 Movable Stairs

The movable part of the stair design has a lowered heigth of 2.5 meters, where the static stairs end, and extend to four meters as the platform rises. When the platform is at its lowest, the movable stair steps are in a flat position, resembling an aisle. They are then resting on the stair base-frame. The lifting frame, a steel construction shaped like a 45 degree stairway, is connected to the moving platform. As the moving platform rises, the lifting frame connects with the resting steps and they rise as a whole. A description of their connected movement is depicted in Figure 69. With this design the platform provides a stairway that automatically changes with the elevation of the platform, all the way up to its maximum height of four meters.

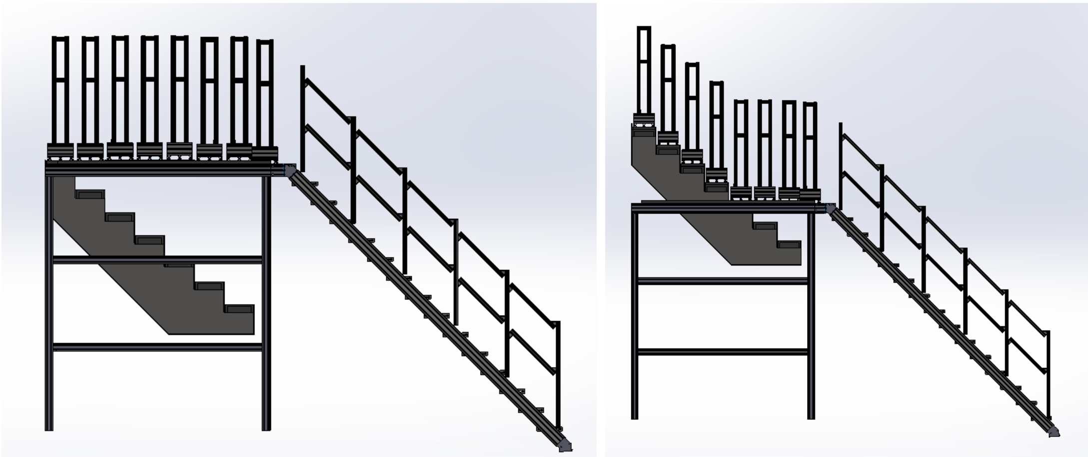


Figure 69: The moving concept for the movable stairs, showing how the stairs lay flat when the platform is lowered, and how they get lifted by the lifting structure.

The movable stairs end in a small platform corner, making a 90 degree turn onto the main platform. Connecting this platform corner and the platform top is a steel structure, located and fastened underneath the platform floor as previously depicted in Figure 25.

5.3 Wheels

The platform is equipped with ten wheels, all with swivel castors, that allow easy movement.

5.4 Electric Cylinders

To lift the platform, six electrical cylinders are used, shown in Figure 70, ensuring that the platform can be raised and lowered smoothly and safely under load. Since the company producing the electric cylinders did not respond to our inquiries, it was decided to proceed with the design process without their direct involvement. To get a better understanding of how the cylinders will fit into the final concept, electric cylinders with platform fixtures were designed as shown in Figure 71 and 70. Figure 70 shows the fasteners that will be used to attach the cylinders to the platform.

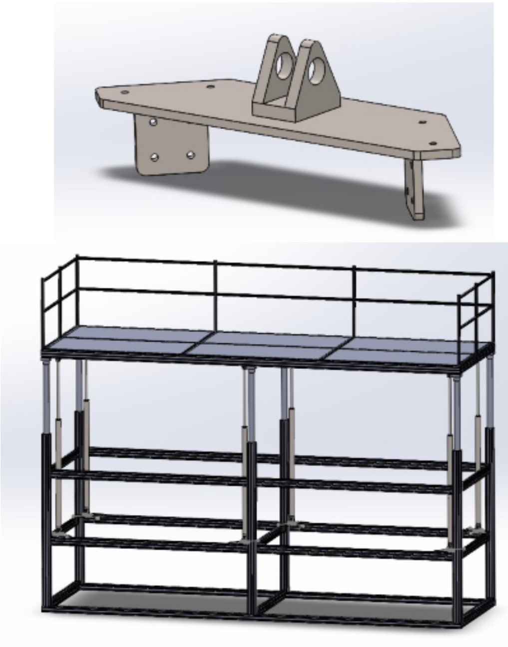


Figure 70: At the bottom: Simplified platform including six electric cylinders and how they are attached to the beams. At the top: the designed fasteners to the electrical cylinders.

Figure 71: Illustration of an electric cylinder.

5.5 Workbench

The resulting CAD model for the working bench design is shown in Figure 72. The workbench serves as mentioned as an accessory for both welders and platers, offering support to achieve the correct working position. Upon rotation, it facilitates access to the jacket for further work. As previously noted, this design is a prototype; both length and height can be adjusted for specific projects as required dimensions may vary from one project to another.

Figure 72: Workbench with a height of 0.5m and a lenght of one meter.

5.6 Dimensions

The dimensions of all the components are detailed in Appendix D, presented in a comprehensive inventory-style format to ensure clarity and ease of review.

5.7 Intended Use

The platform will primarily be used for a project at Aker where they will assemble wind turbine generator foundations. The platform will be utilized in work hall A2. It will replace the traditional scaffolding solution they currently use to save time, money, and labor. This solution aims to increase productivity in the hall.

During the intended project there will be six jackets in the hall simultaneously, arranged in three side by side, in two rows. This is shown in Figure 73. Each row, consisting of three jackets each, will be worked on at a time. There will be a platform on each side of the jacket, at each junction point. With two of these per jacket, this will result in 12 platforms being used simultaneously.

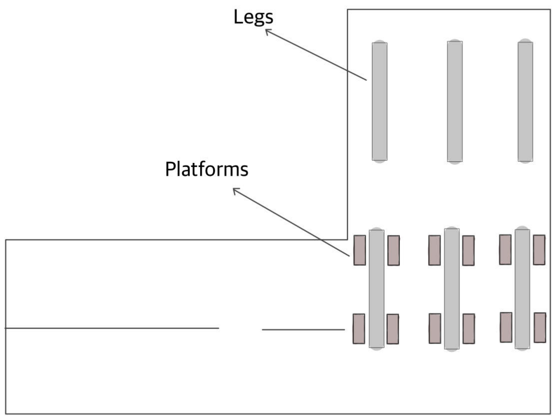


Figure 73: Sketch of A2 with six cylinders, seen from above.

Two workers will operate on each platform at a time, either two plate workers or two welders. Most of the work will take place on the "top" of the jacket, requiring workers to access the top of the cylinder from the platform. Due to different working positions for plate workers and welders, it is important that the platform can be raised and lowered. Additionally, a considerable amount of equipment will be brought up on the platform during use. Therefore, considerations have been done to ensure cables and wires brought onto the platform do not pose a pinch hazard and are securely fastened during use.

The platform is designed to be operated either from the chassis or from the controls on the platform. During vertical movement of the platform, there will be only one person allowed on the platform, and this person's only task should be to operate the controls. To ensure safety, the control panel on the platform will be placed to eliminate any risk of the operator falling during lifting and lowering. This is especially important since one side of the platform, which is adjacent to the WTG jacket, lacks a railing. This is achieved by placing the control center at the position furthest from the open side, and furthest from the gate. During horizontal manual movement of the platform, no person is allowed on the platform to ensure safety. When the platform is so close to the WTG-jacket that there is no fall-hazard, the last bit of manual movement can be excecuted with people on the platform to make small adjustments of it's position.

The junctions on the jackets are configured so that each jacket must be rotated because the legs that make up the junctions must be welded with an angle relative to each other. This means that the pre-welded leg can obstruct the platform on one side. When this happens, the platform should be able to be lowered for rotation, then raised again to just below the welded leg. Then, work benches can be used beside it to access the top of the jacket for further work. To ensure an overview of how this works, a flow chart has been developed for one rotation in Figure 74.

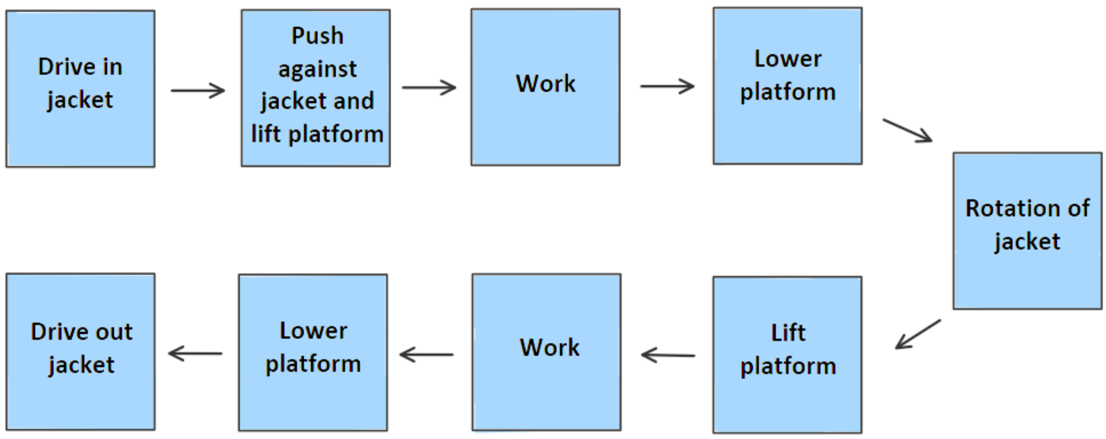


Figure 74: Flow chart for the platform with one rotation.

When three jacket sections are finished, the platform will be lowered completely and manually pushed aside so that three new ones can be brought in. The platform can then be raised again and pushed up against the jacket to eliminate any fall hazards.

6 Project Costs and Profit Potential

In the following section, the potential savings from replacing traditional scaffolding with the suggested platform design will be estimated and discussed. It will also detail the estimated cost of producing one platform. Finally, a comparison and analysis of the savings and cost figures, highlighting the financial implications of this transition will be presented. However, it is crucial to recognize that the actual figures may differ from those estimated, and there are inherent uncertainties in all the savings and cost estimations presented in this section.

6.1 Material Costs of Current Scaffold Solution

Due to the hybrid model of ownership and rental of scaffolding at Aker, precise data on scaffolding material costs was not readily available. However, an approximate estimate of kilo price for their scaffolding was set to 143 NOK per kilo. This value will therefore be used as the base value for scaffolding materials. Since Aker has about 25-30 tons of scaffolding during production in the hall, an approximate price for this amount of scaffolding will be:

$$\text{Scaffold Material Cost} = 25,000 \text{ kg} \cdot 143 \text{ NOK/kg} = 3,575,000 \text{ NOK} \approx 3.5 \text{ million NOK}$$

The estimated cost for scaffolding materials may correspond to the complete scaffold inventory in hall A2, rather than the specific requirements of the project where platforms are being considered. Consequently, this estimate could surpass the true scaffolding needs, leading to a potential wrongful comparison to the platform cost. However, since this scaffolding is already readily available at Aker, this does not impact the potential savings that the platforms could offer. The only potential for material cost savings would be in the rental scaffolding, for which no available figures currently exists.

6.2 Personnel Cost of Current Scaffold Solution

The current personnel cost of scaffolding will be used as a benchmark for potential savings.

Based on the information provided by Aker, the current operational setup is as follows:

- Total currently planned production consists of 15-18 units, with three units being produced concurrently.
- 12 platforms are used concurrently within the hall, focusing on three jacket sections simul-

taneously.

- One shift is 7,5 hours long, and three shifts are required for the construction, adjustment, and dismantling of scaffolds per junction point.
- At each of the two junction points per jacket section, tasks are carried out by three workers.
- The hourly wage is between 550-600 NOK.

This framework serves as the foundation for calculating the labour cost of the current method.

By opting for the lower end of the rate spectrum, the aim is to establish the most conservative cost estimate:

Personnel Hours Used: For three shifts of 7,5 hours, across three workers on each of the two junction points, the total hours used is equal to 3 x 7.5 x 3 x 2 = 135 hours.

Personnel Cost per Jacket: Multiplying the Personnel Hours Used by the hourly wage (550 NOK) results in a scaffolding labour cost of 74,250 NOK per jacket.

Cost for Multiple Series: For a total of 15 jackets, the cumulative personnel cost is Personnel Cost per Jacket times 15 jackets, which is 74,250 NOK x 15 = 1,113,750 NOK.

The scaffolding labor cost saving per platform, when divided by 12 platforms, amounts to approximately 92,812.5 NOK per platform. This figure represents the break-even point for each platform on this production project alone. If the platforms can be utilized during other projects as well, the personnel savings - and thus the cost justification - will increase.

6.3 Material Cost of Platform Solution

The overall estimated cost for the platform amounts to 464,077.87 NOK, as depicted in Figure 75. It is important to note that this total represent an approximation and may not accurately reflect the final cost. See Appendix F, or Figure 75 below, for a detailed explanation on how specific estimates were produced and the various costs provided by suppliers.

Estimated cost of the platform

Estimated product cost from item 24:

Product	Quantity	Cost	Sum
Bottom	1	100 139,81	100 139,81
Top	1	82 835,49	82 835,49
Corner	1	9 240,74	9 240,74
Railing to movable stairs	7	1 717,98	12 025,86
Frame for stairs	1	37 701,98	37 701,98
Work bench	1	6 138,17	6 138,17
Total			**248 082,05**

Estimated cost from different supplier:

Product	Quantity	Cost	Sum
Wheels	10	1791,99	17919,9
Steel tubes 6m	2	3500	7000
Motor	1	2000	2000
Aluminium floors	6	4200	25200
Lifting columns	6	25000	150000
Total			**202119,9**

Assembly of components in SW with a cost estimation by us:

Product	Quantity	Cost	Sum
Static stairs: Railing	22	307	6754
Static stairs: Step	14	0	0
Static stairs: Beams	2	3560,96	7121,92
Static stairs: Assembly set	1	0	0
Movable stairs: Step	7	0	0
POM parts	40	0	0
Connector: Movable stairs to corner platform	1	0	0
Movable stairs: Steel lifting structure	1	0	0
Connector: Corner platform and platform top	1	0	0
Fasteners for electric lifting sylinders	6	0	0
Supports	6	0	0
Total			**13875,92**

Total estimated cost = 464 077,87 NOK

Figure 75: Estimated costs of the platform components.

Some components are not estimated due to difficulties in finding corresponding costs, resulting in an estimated cost of zero for these items in the sheet. Therefore, the total cost is likely to be higher than currently estimated. However, due to uncertainties in several components and potential variations in pricing or discounts from bulk purchases, the value is considered "close enough" for further comparisons.

6.4 Personnel Cost of Platform Solution

The platform will have to be repositioned with each new series as work shifts to different jacket sections. The resulting labour time is:

- **Lowering and Lifting Time:** Approximately five minutes per platform.
- **Moving Time:** About 25 minutes per platform for positioning in relation to the WTG jackets and lower the supports.
- **Total Estimated Labour Time:** 30 minutes per platform.
- **Estimated Labour Time for Entire Project:** 30 minutes per platform $\cdot$ 15 jackets $\cdot$ 4 platforms per jacket = 30 hours

With 15 jackets in the hall this results in a labour cost of approximately 30 hours $\cdot$ 550 NOK/hour = 16,500 NOK. This cost is substantially lower than the scaffolding labor cost of 1,113,750 NOK for the same project, demonstrating a significant cost efficiency with the use of platforms.

6.4.1 Platform Assembly Cost

Item24 estimates that assembling the top base, bottom base, corner platform, and static stairs base takes approximately 22 hours for one person. This estimate does not account for the static and movable stairs, steel tubes, POM castings, wheels, or electrical components. Therefore, an additional 22 hours are added for the assembly of all the remaining components, bringing the total estimated assembly time for one person to approximately 44 hours. Given a standard workday of 7.5 hours, the platform would be completed in:

$$\text{Number of Days} = \frac{44\ \text{Hours}}{7.5\ \text{Hours/Day}} = 5.9\ \text{Days} \approx 6\ \text{Days}$$

The hourly wage stands at 550 NOK, therefore, the total cost of assembling one platform will then be:

$$\text{Cost of Assembly} = 44\ \text{Hours} \cdot 550\ \text{Hour/Day} = 24,200\ \text{NOK}$$

6.5 Overall Profit Potential

The total personnel savings from utilizing platforms can be calculated as follows:

$$\text{Personnel Savings} = \text{Personnel Cost of Current Scaffold Solution} - \text{Personnel Cost of Platform Solution}$$

$$\text{Total Personnel Savings} = 1,113,750\ \text{NOK} - 16,500\ \text{NOK} = 1,097,250\ \text{NOK}$$

This figure shows approximate personnel savings, when the assembly of the platforms are not taken into consideration. By considering the assembly time as well, the real personnel savings will be:

$$\text{Real Personnel Savings} = 1,097,250\ \text{NOK} - 12\ \text{Platforms} \cdot 24,200\ \text{NOK}$$

$$= 1,076,850\ \text{NOK} - 290,400\ \text{NOK} = 806,850\ \text{NOK}$$

The real personnel savings for one project is estimated to be approximately 806,850 NOK, which gives a saving of 806,850 NOK / 12 platforms = 67,238 NOK per platform, or 806,850 NOK / 15 jackets = 53,790 NOK per jacket. This estimate does not include potential efficiency savings, which could lead to even greater savings for Aker by completing the project in a shorter timeframe. This efficiency saving value can be found by comparing the different personnel hours during rotation against each other and finding the difference:

$$\text{Personnel Hours Used with Current Scaffolding} = 135 \text{ hours}$$

It is assumed that amongst these personnel hours, approximately 35 of them go to adjustments of the scaffolds because of rotation of the jackets:

$$\text{Adjustments During Rotations for Current Scaffold Solution} = 35 \text{ hours}$$

Personnel hours used during rotation of the jackets with platforms can be estimated to:

$$\text{Adjustments During Rotations for Platform Solution} = \text{approximately 5 minutes per platform} \times 12 \text{ Platforms}$$

$$= 60 \text{ Minutes} = 1 \text{ hour}$$

This means that Aker can save approximately:

$$35 \text{ Hours} - 1 \text{ Hour} = 34 \text{ hours}$$

If there's one rotation of each jacket during the project, and the project consists of 15 jackets, this equals to 15 rotations in total, making the total efficiency savings:

$$\text{Efficiency savings} = 15 \text{ Rotations} \times 34 \text{ Hours/Rotation} \times 550 \text{ NOK/Hour} = 280,500 \text{ NOK}$$

Per production project, the efficiency savings will equal approximately 280,500 NOK. For one platform, the efficiency saving is equal to 280,500 NOK / 12 platforms = 23,375 NOK, and for one jacket it is 280,500 NOK / 15 jackets = 18,700 NOK.

To be cost-effective within a single project, the material cost of each of the 12 platforms would need to be around 67,238 NOK. Given the required safety measures, electrical components, and size, this cost target is challenging. Therefore, the platforms are designed for reuse across multiple projects. By comparing the material cost of one platform to the labor savings from this project, it can be determined how many projects are needed for the platforms to achieve cost-effectiveness.

Given the estimated material cost of approximately 464,078 NOK for one platform, Aker begin to profit from the new platform after a certain number of projects. Assuming that Aker will acquire similar projects in the future, an estimate can be made. Considering that each project lasts three months, which allows for four projects per year, the calculation for the number of projects required to start earning is as follows:

$$\text{Number of Projects} = \frac{\text{Total Cost of the New Platform}}{\text{Personnel Savings per Platform}} = \frac{464,078 \text{ NOK}}{67,238 \text{ NOK} + 23,375 \text{ NOK}}$$

$$= 5.12 \text{ projects} \approx 5.5 \text{ projects}$$

Aker will see profit from exchanging scaffolds with the platform design after approximately 5.5 projects. Given that each project lasts three months, this suggests that the platform will become profitable in under 17 months.

In number of jackets, this equals:

$$\text{Number of Jackets} = 5.12 \text{ projects} \cdot 15 \text{ jackets} \approx 77 \text{ jackets}$$

7 Risk Assessment And Risks

Aker has requested a risk management plan for the access platform, which identifies the key risks and challenges that may arise during operations. The plan is based on a risk assessment that evaluates incidents with potential consequences for personal safety during the operational phase of the platform. Risks associated with the construction or decommissioning phases have not been covered. The plan outlines strategies for effectively managing risks that may occur. This approach ensures that identified risks are properly highlighted and managed, thereby enhancing the safety of the workers.

The risks associated with the platform have first been identified based on activities involving its use, then analyzed, and finally evaluated. The following risks have been identified and presented in Table 2:

- Pinch point
- Tipping
- Fall hazard
- Falling objects
- Electrical shock
- Risks following electrical cylinders

Major risks	Analysis		
	Probability and consequences	Risk	Mitigation strategies
Pinch point 	3.3	One risk associated with the use of the access platform is pinch points. There is a higher risk of pinch points at the junction where the platform meets the leg. Additionally, there is a risk of pinching between the moving part of the staircase and the frame. The lifting columns used also pose a risk of pinching.	Clearly mark all pinch points with warning signs and labels to alert operators. Ensuring that all operators and workers are properly trained on the platform, including awareness of all pinch points and the safety measures requires to avoid them. Position the controller on the side opposite both the entrance and the leg. Additionally, ensuring that only one person is on the platform while it is in motion.
Tipping 	5.4	Tilting poses a risk when the center of gravity is not well balanced. Tilting can happen from an uneven surface, too much surface, too much weight on one side, a person hanging from the railing, or sudden drop of one wheel.	To prevent tilting it is important to have an even surface. Avoid placing all the weight on one side, and only being used by trained professionals.
Fall hazard 	4.3	Fall hazards are another risk associated with the access platform. This can result in serious injuries if not proper managed.	Installing railing, including a knee railing, around the perimeter of the platform to prevent falls. Designing the platform floor with a checker plate pattern. Ensuring that the surface provides essential traction, reducing the risk of slipping and falling.

Major risks	Probability and consequences	Risks	Mitigation strategies
Falling objects 	2.2	Given that workers bring equipment onto the platform, there is an associated risk of objects falling off.	Install toe boards around the edges of the platform to prevent objects form falling.
Electrical shock 	4.4	Electrical current poses a risk on the platform, where control panels, motor or wires are positioned. Poor insulation of equipment and wiring can result in electrical shock, potentially leading to serious injury or death. Additionally, incorrect installation or overloading may trigger a fire hazard	To prevent this risk, ensure that all electrical components have proper insulation and are well maintained. Only allow qualified professionals to install electrical equipment and wiring. Ensure that the electrical current is properly sized for the planned load. Regularly inspect electrical equipment to identify and address any issues promptly. Ensure there is a fire extinguisher available.
Risks following electrical cylinders 	4.4	Electrical cylinders pose risks of electrical shock, fire, and pinch points. The risk of shock arises from poorly insulation, incorrect connections, or improper use. Insufficient ventilation can develop to a fire and moving parts of the cylinder can create pinch points.	To prevent risks with electrical cylinder, ensure proper insulation and conduct regular inspections. Keep a fire extinguisher nearby and mark the locations of pinch points. Ensure that personnel are trained to identify pinch points

Table 2: Risk assessment and risk, with symbols from [29], [26], [27], [85] and [78]

Below in Table 3 is the presentation of the identified incidents in a risk matrixs, and the assessed consequences and probabilities. The colour coding is based on the risk rating matrix from Project Management Research Institute [70].

Probability	Very high (1)				
	High (2)		2.2			
	Medium (3)			3.3	4.3	
	Low (4)				4.4	5.4
	Very low (5)					
		Very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)

Consequences

Table 3: Probability and consequences: Pinch point (3.3), Tipping (5.4), Fall hazard (4.3), Falling objects (2.2), Electrical shock (4.4), Risk following electrical cylinders (4.4).

8 Discussion

This section evaluates the design decisions, mechanisms, and material selections for the access platform. Additionally, it discusses the limitations and objectives previously outlined in the introduction, assesses the risk management plan, and reviews our method and collaboration efficiency. We also provide Aker with suggested modifications and detail the necessary steps to finalize the design.

8.1 Risk Assessment and Risks

This subsection analyzes key risks associated with the access platform, such as pinch points, tipping, and electrical hazards. It discusses their potential consequences for personal safety, probabilities, and the preventive measures designed to enhance safety and operational stability.

8.1.1 Pinch Point

The consequences of encountering a pinch point can include injuries ranging from minor bruises and cuts to more severe injuries such as fractures, crush injuries, or amputations of fingers and limbs. Although the consequences of a pinch point incident are severe, the probability is very low, as Table 3 illustrates. The low probability is maintained as long as mitigation strategies are implemented. These include marking all pinch points clearly, providing comprehensive training for workers, strategically positioning the controller away from the access point, and ensuring only one person is on the platform during motion. These measures collectively help maintain a safe working environment.

8.1.2 Tipping

Calculations confirm that the platform can withstand the expected external disturbances, therefore the possibility of the platform tipping is very low, but if tipping occurs, the consequnces would be dramatic. It has therefore been evaluated to be 5.4 in the probability and consequences in Table 3.

8.1.3 Fall Hazard

The consequences of falls from the access platform can be severe. Injuries can range from minor bruises and sprains to more critical injuries like broken bones, and severe head traumas. To mitigate this risk, railings, including knee railings, are installed. Additionally, designing the platform floor with a checker plate pattern can effectively reduce the likelihood of slipping or falling. While the probability of falling from the platform may be low, the severity of the consequences is high, as illustrated in Tabel 3.

8.1.4 Falling Objects

When workers bring equipment onto the platform, there is a risk of objects falling off, potentially causing various injuries. Falling objects can injure workers below the platform, with potential injuries ranging from minor to more severe. To reduce the risk of head injuries, it is essential for all workers to always wear helmets. Additionally, falling objects can cause damage to other equipment or parts of the facility, leading to expensive repairs and operational downtime, resulting in delays. To mitigate these risks a toe board has been installed around all edges of the platform. The probability of objects falling off the platform is higher compared to other risks, but the consequences are less severe. Therefore, it is evaluated as 2.2 in Tabel 3.

8.1.5 Electrical Shock

The platform includes a control panel, both at the top and bottom, an electrical motor and wiring. Handling electrical components requires professional expertise to avoid potential dangers. Regular inspections can prevent accidents, and having a fire extinguisher nearby could reduce any accidents that occur. While the possibility of an accident is low with professional installation, the consequences could be serious. As a result, the risk of electrical currents has been evaluated at 4.4 in the probability and consequences Tabel 3

8.1.6 Risks Following Electrical Cylinders

When evaluating the risks associated with electrical cylinders, the key concerns include electric shock, fire hazards, pinch points and programming errors. To reduce these risks, professional installation and inspection are necessary for ensuring proper grounding and insulation, while presence of nearby fire extinguishers and clear markings for pinch points can aid in emergency response and accident prevention. Additionally, trained personnel in programming is key to minimize the risk of errors. Considering these factors, the electrical cylinders have been rated at 4.4 in Tabel 3

8.2 Initial Design

In the initial stages of the design process, we developed a platform incorporating a central jack mechanism, supplemented by four static lifting columns. This decision was influenced by the advantages and disadvantages associated with each lifting mechanism discussed in Section 2.14.

The original design leveraged a combination of a jack mechanism for its proven reliability and simplicity, alongside static lifting columns that provide strong, stable support. These choices were based on the need for a robust and efficient lifting solution that could be integrated into Aker's operational workflow.

However, as further analyzed, several challenges with this initial design became apparent:

- **Space Constraints**: The inclusion of static columns required fixed vertical space, which was limited in some of Aker's operational areas.
- **Limited Adaptability**: The static nature of the lifting columns restricted the versatility of the platform, making it less suitable for various tasks that required more dynamic positioning.
- **Mechanical Complexity**: While jacks are simple in their mechanisms, integrating them with static columns introduced unnecessary complexity in terms of maintenance and operation.

Fortunately, we received valuable feedback during a consultation with the client, where we were directed to the item24 website. This resource offered alternatives that were more aligned with our needs for adaptability and space efficiency.

8.3 Continued Platform Development

This project concludes with the development of a 3D model for the platform and a detailed list of standardized components essential for its physical realization. As a result, there are tasks that Aker must undertake to make a finalized platform prototype.

8.3.1 Motor and Actuators

To move forward with finalizing the platform prototype, Aker will have to select an electric motor and actuators. Due to the limited timeframe, no decisions have been made regarding the choice of motor or electrical actuators, but this section will provide some suggestions.

Actuators

Aker already obtains actuators for the platform in the VPL hall, so a suggested solution would be to use these or something similar from the same manufacturer. These actuators are electric cylinders, and they had the possibility to get synchronized by making one of the actuators a ”leader” so that the others move equally to this one. This can be done to ensure the cylinders operate at the correct velocities and are properly synchronized with each other. Therefore, hydraulic and pneumatic options aren’t practical for Aker since they can save costs through bulk purchasing, especially considering their tendency to be more expensive, as discussed in Section 2.12.3.

The platform will be installed with six cylinders on the base, to enhance stability during vertical movement. Additionally, incorporating at least one cylinder into the movable part of the stairs would be advantageous. One option is to place this cylinder on the corner platform at the top of the stairs, ensuring all cylinders operate at the same height, which simplifies synchronization. Alternatively, positioning the cylinder lower on the movable stairs, specifically on the stair steel frame, could improve its’ stability. However, this configuration may complicate synchronization with the platform’s cylinders, requiring more complex control solutions. Ultimately, the decision on this placement will be determined by Aker based on what is deemed most suitable for their needs.

Motor

The platform can be powered either by electricity directly from the AC mains (in which case, there would be no need for a motor), by an electric motor with a rechargeable battery, or by a combustion engine.

For greater convenience in the working hall, an electric motor is recommended. This option is quieter, more sustainable, and easier to manage compared to combustion engines. The various types of electric motors considered for this purpose are briefly described in Section 2.11. Additionally, using a battery-operated motor enhances the platform’s convenience by allowing it to be used wirelessly when necessary.

The choice of motor will ultimately be determined by Aker. Due to time constraints within the project timeline, the selection of the motor was deprioritized as part of the project outcomes.

A proposed placement for the motor on the platform is to secure the motor casing to the framework along the short side, as depicted in Figure 77. This casing encloses the electrical motor that drives the electrical cylinders.

8.3.2 Wiring

To ensure both safety and functionality, the wires running from the motor to the cylinders will be securely fastened within the grooves of the profiles to prevent any pinching. An example of this fastening is shown in Figure 76.

Figure 76: Example of suggested wiring method.

8.3.3 Control Panel

The vertical movement of the platform can be controlled by a control panel. A suggested design for the control panels is shown in Figure 77. The control panel simplifies the operation of the platform and is designed for user-friendly interaction. It features three buttons, each equipped with symbols and text indicating their function: one for upward movement, one for downward movement, and one for emergency stop. A safety feature, such as a protective casing or a requirement to rotate before pushing, should be added to the emergency stop button to prevent accidental activation.

Additionally, there is a need for a control panel at ground level for emergency situations. This panel includes an emergency button, an on/off switch, and a power input.

The shown control panel serves as an illustrative representation of its potential appearance. The dimensions of the grey box covering the motor, as well as the design of the buttons, are suggestions for Akers final design decisions.

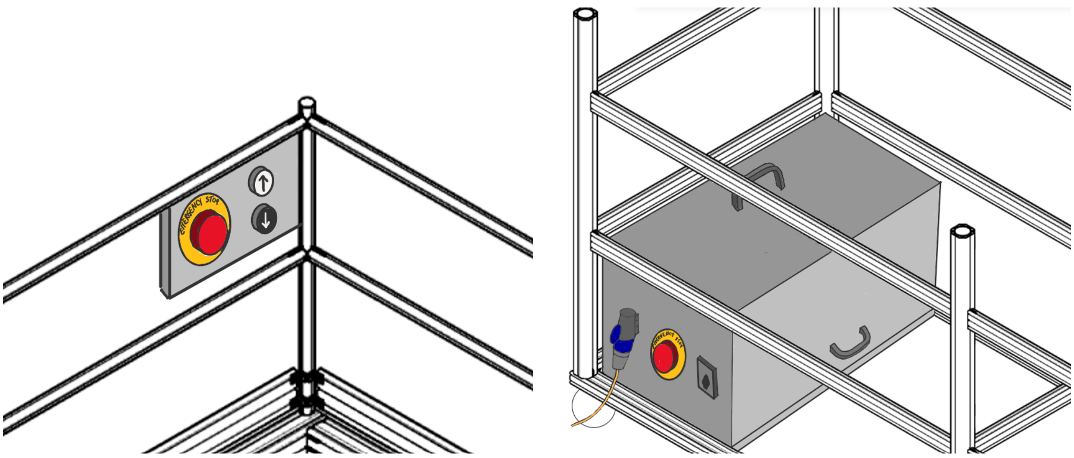


Figure 77: Suggested illustration of control panel and a grey box covering the motor for safety reasons.

8.3.4 Bolts for Fastening Aluminium Flooring

The aluminum plates must be securely fastened to the beams underneath. Therefore, it is necessary to calculate the number of bolts required for sufficient fastening. This includes determining the type of bolt, diameter, and length, as well as the spacing between each bolt. Additionally, considerations must be made for the stresses that arise. Due to the broad description of this task and time constraints, these details are not included in the current report. Therefore, Aker must continue to work on this aspect.

8.3.5 Fastening Stair Base to Platform Base

The stair base must be securely attached to the platform base to minimize the risk of the bases separating during movement. Using bolts is recommended because both bases are made of aluminum, which provides a durable and consistent material connection. Figure 78 shows suggested placements for the bolts.

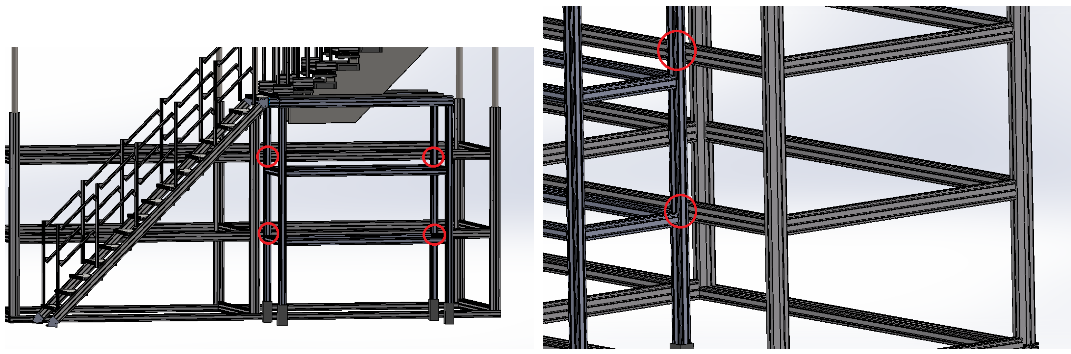


Figure 78: Suggested placement for bolts to connect platform base and stair base.

8.3.6 Smoke Suction System

As mentioned is Section 3.1 regarding interviews, implementing a smoke suction system for welding was highlighted. The suggestion of easily connecting a tent to the platform, for managing smoke dispersion, was mentioned. Although this aspect was not thorughly examined due to time contraints, it is anticipated that the platform design can accommodate a suction system because of its similarity to traditional scaffolding in design. However, this needs to be approved by Aker.

8.4 Suggested Changes to the Platform

Since the CAD file for the 3D model will be sent to Aker, they will have the flexibility to make any adjustments they deem necessary. The model serves primarily as a suggestion. Potential modifications could be applied to the following elements:

8.4.1 Profiles

During the design phase, some simple changes could have resulted in a cleaner apperance for the platform. The platform profiles' grooves were made with an open pattern, however, these profiles can be tailored with different groove patterns. Options include having one side closed, both side closed at 90 or 180 degrees, three sides closed, or fully closed as depicted in Figure 79. This adjustment could have made the design cleaner and helped prevent dust to gather over time. However, more closed profiles will limit the wiring routing opportunities.

Figure 79: Some of the different groove-options from item24's website [65].

8.4.2 Work Benches

The CAD-model for the working benches provided under Results, Section 5.5, will serve as an adjustable model. This will be sent to Aker with adjustable height and length features. This flexibility ensures the bench can be adapted for various tasks and sizes of junctions, making it versatile for use in other projects at Aker as well as the intended one.

8.4.3 Railing Between Static and Movable Stairs

As depicted in Figure 80, the static stairs' railing and the first part of the railing on the movable stairs present a gap. Since the first step on the movable stairs is unmovable, a railing can be fastened between them. This will enhance safety by reducing risk of losing equipment off the side, and give the stairs a cleaner look.

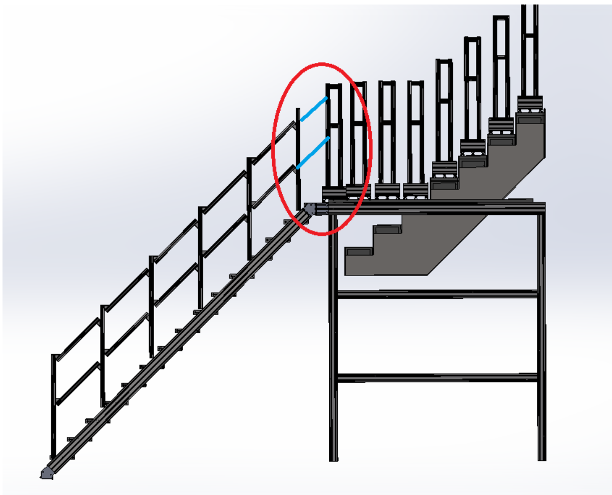


Figure 80: The stairs with a suggested placement for an extra railing is drawn in blue.

8.4.4 Taller Railing

The railing designed for the platform does not fully comply with the safety standard NS-EN 280, as detailed in Section 4.3.4. Currently, the railing stands at one meter tall and includes a toe board and a knee rail. However, according to the standards, a one-meter railing might need to be replaced with one that is 1.1 meters tall to fully meet safety requirements. This adjustment would also enhance worker safety. Workers on the platform need to feel secure to perform effectively, as any compromise in safety can affect job performance. Therefore, Aker may consider increasing the railing height to ensure compliance and safety.

8.4.5 Wheels

Since the access platform is significantly heavy, the stability and durability of the wheels are essential. When selecting the most reliable wheels for the platform, it is important to consider aspects such as material of the wheels, their width and diameter, the profile of the wheel, as well as the type of wheel.

The wheels selected for the platform are based on three key factors: the total weight of the platform, ease of maneuvering, and the material composition of the wheels. These considerations are crucial to ensure that the wheels can support both the platform's weight and any additional loads. Another consideration is the surface the platform will operate on. The floor in A2 is made of concrete and features some small ridges. The wheels must therefore be hard enough to withstand this surface. Rubber wheels are assumed to be too soft and prone to damage from the floor.

The wheels have been chosen from Rollenbau, as recommended by engineers contacted at Metronor

[39]. This manufacturer offers a wide range of wheels for various needs. However, Aker has the option to select wheels from other suppliers if they have existing partnerships or specific preferances that have not been disclosed.

ARTICLE NUMBER	ARTICEL TYPE	WHEEL-Ø A X WIDTH B MM	LOAD CAPACITY KG	OVERALL HEIGHT H MM	DIMENSION OF TOP PLATE TP MM	HOLE SPACING HS MM	HOLE-Ø HD MM	SWIVEL RADIUS SR MM	WHEEL BEARING	PRICE €
61-151 ZK	Swivel castor	150x50	680	181	162x133	140x105	11	120		168,00

Figure 81: Dimensions for the product "Heavy Duty 61-150 ZK" from Rollenbau [38].

The suggested wheels for the platform are the Heavy Duty 61-150 ZK from Rollenbau, pictured in Figure 82. They are constructed from molded polyurethane and can withstand a load of 680 kg each as depicted in Figure 81. With six wheels, the total weight capacity exceeds four tons, which is significantly above the platform's maximum weight, even when fully loaded. It features swivel wheels for easy movement [37].

Figure 82: Suggested wheel for the platform - "Heavy Duty 61-150 ZK" from Rollenbau [38]

8.4.6 Supports

Stability should be enhanced by fastening supports onto the platform base and stair base, at the vertical beams. The platform's stability is crucial, as the workers at Aker will preform various tasks at height, including welding tasks that require great precision. The inclusion of these elements ensures that the platform remains safe and reliable, providing a stable foundation for work at heights. An approximation of a support was designed to do the tilting calculations in Section 4.1. This approximation is shown in Figure 83. However in reality this type of support would need to either have triangular steel plates welded onto the sides or another design solution to gain strength. The L-shaped supports in the figure will not be strong enough alone.

The supports for the platform have been designed to function similarly to the supporting wheels (Jockey wheels) on a trailer. By rotating the screw/bolt to the right, the supports are lowered to the ground. The bolts should be rotated down until they all make contact with the ground, thereby providing the platform with greater stability. They have been incorporated into the design due to uncertainties regarding the effectiveness of wheel brakes on such a large and heavy platform. This design choice, while effective, results in a longer setup time needed to secure the platform before work can commence. To enhance efficiency in the working hall, it is suggested to implement supports that engage with the ground in a less time-consuming manner.

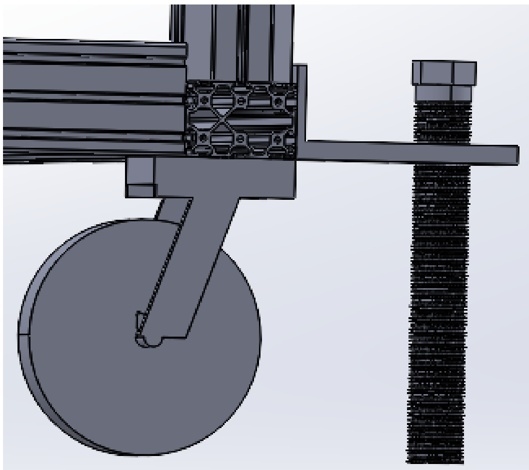


Figure 83: Wheel with simple support used on the platform's 3D model.

An example of a more efficient mechanism would be the one used in a "Quick-Release Clamp" as depicted in Figure 84 [68]. This type of system would allow the supports to be quickly lifted and secured when the platform needs to be moved manually. This mechanism works so that when the gold button on the clamp is pushed in, the screw slides along the hole in the clamp, but when the button is in its normal position, fastening and unfastening is done by rotating the handle (as a regular screw). This would mean that the button can be pushed in to easily unfasten the screw, lowered to the ground, and then securely fastened by screwing when the button is released. This type of design would enhance the speed and ease of transitioning the platform from mobile to stationary states.

Figure 84: "Quick-Release Clamp" where the screw can be moved without needing to rotate it when the gold button is pushed in, but otherwise works as a regular screw [68].

8.5 Limitations

In this section, the key limitations listed in the introduction, Section 1.4, are examined. We discuss whether these limitations influenced the design process and, if so, how they were accounted for. The discussion provides insights into the factors that restricted the design choices and suggests potential changes for overcoming these constraints in future iterations.

- **Constructing and testing a physical prototype within the study's timeframe is not feasible. Therefore, in designing the access platforms, we will incorporate feedback from individuals at Aker Solutions to create a concept that we believe would perform well if further developed and tested.**

  Due to the considerable scope of the project, overlapping schedules between our team and Aker, and the long distance to Aker's facilities, we were unable to maintain the level of feedback we initially intended. The broad scope of the project demanded a lot of attention, leading to our team working mostly independently.

  We adapted our design from Aker's platform used in Hall VPL, a design we know meets all relevant requirements and standards. By using this proven platform as a foundational model for Hall A2, we aim to ensure that our design will similarly comply with Aker's standards. Since this project proposes only a preliminary design, it remains flexible and open to modifications to better suit Aker Solutions' specific needs. This adaptability should help offset the limited feedback received

- **The tailored platform design to the specific requirements may not be universally applicable. Modifications may be necessary for different project specifications.**

  Due to the platform's limited lifting capabilities and its minimum height of 2.5 meters, it may not be suitable for all projects in Hall A2. However, its adaptability could make it valuable for more projects than just the intended one, potentially serving multiple purposes at Aker.

  Enhancing the platform design to allow for a lower starting height when fully lowered, as well as a higher maximum height, could increase its applicability across other projects. Additionally, its big size - measuring 2x6 meters for the platform floor, plus stairs - means it will not fit in every working hall and could be challenging to move over long distances. Addressing these size and mobility challenges through design modifications, such as collapsible or modular features, could improve its versatility and ease of transport within different operational environments.

- **Limitations in available materials, manufacturing processes, and budgetary con-**

straints may restrict the final design of access platforms.

In this project, all the materials required were available and easy to source, so this potential limitation did not impact our design. Additionally, the budget was not a constraining factor during this project. The focus was on discussing and comparing the estimated material costs of the finished platform design to traditional scaffolding. This cost analysis was accomplished to illustrate to Aker how costs and potential savings would evolve when implementing the platform. Even though the budget did not limit the design process, it was deemed a priority to make for Aker because it might become a limitation for them.

8.6 Outcome Goals and Effect Goals

In this section, we evaluate the achievement of the established outcome and effect goals. We will explore whether these goals were met and analyze the factors contributing to their success or shortfall. If certain goals were not achieved, we will discuss potential strategies and adjustments necessary to meet these objectives in the future.

Outcome Goals

The main objective of the project is to design a platform that can replace the exisitng scaffolding currently used by Aker. Achieving this objective requires the completion of the supplementary goals:

- **Ensure that the structure provides a safe work environment that follows relevant regulations and standards.**

  In order to achieve this objective, the design is developed to align with regulations and standards, ensuring a safe work environment. For example, the railing is as mentioned equipped with toe boards and knee railings, while also being robust enough. Compliance with standards is previiously outlined in Section 4.

- **Develop a solution that is cost-effective both in term of initial setup and long-term maintenance when compared to traditional scaffolding.**

  To accomplish this objective, it was estimated that the developed platform will provide a positive cost-effect for Aker after completing 5.5 projects, which is less than 17 months, as detailed in Section 6. Meaning that in order for the platforms to be a profitable solution, they will have to be useful in at least 6 different projects, consisting of three months each.

- **Aiming to simplicity and efficiency in Construction and deconstruction of the**

structure, thus reducing downtime.

To achieve this goal, the design focuses on efficiency compared to traditional scaffolding. The platform only needs to be built once and will last for years. Unlike traditional scaffolding, which requires demolition and reconstruction for each rotation, the platform will only be lowered and raised during rotations. Consequently, this platform minimizes downtime, as it is only lowered and raised when rotation is necessary. This aspect is previously described Section 5.7.

- **Considering the environmental impact and aim for eco-friendly materials.**

  This objective is accomplished by sourcing suppliers locally in Norway and Scandinavia to minimize transportation distances and reduce CO2 emissions. In additions, the majority of the components are constructed from aluminium, a material renowned for its limitless recyclability [69]. The sustainability measures are outlined in Section 8.10.

- **Durable design that is capable of withstanding various work environments, especially work conditions special to plating and welding.**

  Based on interviews, we gathered insights into how Aker personell operate on scaffolds and their specific needs. While the platform design aims to meet these preferences, it is challenging to fulfill every individual's requirements. However, we are confident that the design is suitable due to its resemblance to traditional scaffolding. However, testing a real-life prototype of the platform will be necessary to ensure Aker's satisfaction.

- **Satisfaction amongst all stakeholders, including workers and Project managers.**

  To ensure satisfaction amongst all stakeholders, including workers and project managers, we have conducted meetings and interviews throughout the project. We have also examined a design in the VPL hall, aiming for something similar but tailored to the A2 hall. By integrating feedback from workers and drawing inspiration from an already accepted design, we believe our design will meet the expectations of all stakeholders. However, to ensure satisfaction and accomplish the final outcome goal, a comprehensive evaluation and testing phase must be conducted by Aker to ensure the finished prototype meets their requirements.

Effect Goals

The effect goals involve acquiring skills and knowledge to enrich capabilities related to engineering work.

- **Gain experience of the design processes used in professional settings, particularly**

focusing on how complex engineering projects like the adjustable access platform are conceptualized and executed at Aker Solutions.

Even though there has not been direct involvement in the design process at Aker as desired, it was still possible to gain knowledge about these processes through designing the access platform. This has contributed to a better understanding of how complex engineering projects are executed. Through the design of the platform, it has been possible to learn about the principles and methods, such as item24, which is used in professional environments like Aker. This has led to a deeper understanding of design processes and has helped develop skills in completion of complex engineering projects.

- **Increase our expertise in 3D modeling and simulation by developing a detailed model of the access platform, which will include simulations to test design integrity and functionality.**

  The goal of increasing competency in 3D modeling and simulation was achieved through the development of the access platform in SolidWorks. The model includes simulations to test the integrity and functionality of the design, which contributed to increasing insight into the process. This process also facilitated learning SolidWorks tools and functions necessary for 3D-model work. SolidWorks increased the competence in simulations, offering the opportunity to explore and understand the influence of various factors on the platform's performance under different conditions. This encompassed evaluations of stability under loads, performance under different conditions, and other factors impacting both the durability and functionality of the design.

- **Gain insights into the dynamics within the professional work environment through collaborative efforts across departments, observation, meetings, and interviews with Aker personnel.**

  Understanding the dynamics of the professional work environment was attained through a combination of methods. This includes active participation in meetings held at Aker and one virtually via Teams. Additionally, conducting interviews with Aker personnel provided valuable perspectives that contributed to the design of the platform. Direct observation of their work processes, particularly observing how they operate on the legs, further enriched the understanding of their working process. Furthermore, collaborating across departments, including with Nordvik in the design department and workers in A2, provided valuable suggestions that positively contributed to the designing process.

8.7 Method Efficiency

Several aspects of the project could have been optimized for greater efficiency. With the limited timeframe and the substantial scale of the project, any saved time could have been used to develop a more thoroughly designed platform. This section will discuss some areas where processes could have been managed more effectively.

8.7.1 Broad Task Description

The initial design phase was slow and unclear due to the broad task description, and the most significant design progress began after the meeting with Nordvik about his platform design. The aim to create a new and unique design initially made the task too broad, which risked extending the project's timeframe. However, the decision to use similar parts and suppliers as those in Nordvik's platform improved the design process. This efficiency boost was due to narrowing the range of options by choosing a single supplier for the profiles used in the design. Furthermore, it was ultimately decided that, for ease of procurement for Aker and to simplify the design process, all components that could be sourced from this supplier would be used whenever possible. Since the meeting with Nordvik occurred quite late in the project, time could have been saved by deciding on one primary supplier earlier in the project process.

8.7.2 Interviews vs. External Supervisor

During the interviews with workers at Aker, detailed in Section 3.1, various desired parameters for the platform were identified. Initially, the design attempted to incorporate all these inputs, but integrating every requested feature proved challenging within the project's timeline. Subsequently, in a meeting with our external supervisor at Aker, it was decided to reduce the number of parameters considered. This reduction made the design process more straightforward and achievable within the project deadlines. By focusing on essential features and setting aside less critical desires, the design became more practical to execute, ensuring the project could be completed.

8.7.3 Abaqus to SolidWorks

At the project's inception, Abaqus was the primary tool for 3D modeling the platform and its components. However, the desire to gain proficiency with a program more relevant to future work led to the selection of SolidWorks as the principal software.

Time could also have been saved by avoiding the switch from the 3D program Abaqus to SolidWorks. Although Abaqus was used for only a week, transitioning to SolidWorks required additional training. This training was considered extra work and was completed outside of regular project hours. As a result, project members had to learn SolidWorks on their own while managing their other project responsibilities. This strategy was employed to minimize the impact of the switch on the project.

8.7.4 Multi-user Environment

Another change that could have enhanced the efficiency of the project would be employing collaborative design tools, for example the multi-user environment in SolidWorks. This would have allowed multiple team members to work on the same model simultaneously. Since the design process was the longest phase of the project, this is considered a change that could significantly reduce the project time, and therefore could have led to an even more detailed platform design. The reason why this was not implemented into the process was simply because of too late discovery of the possibility.

8.7.5 Height Reduction: From 3 Meters to 1.5 Meters

Initially, the challenge was to raise the platform from two to five meters in height, starting a discussion on it's stability. After much brainstorming, research and design work, the solution involved using static lifting columns and a jack screw mechanism to make the platform sturdy enough. Various components were explored, and SolidWorks training was undertaken. We developed an original design proposal based off of this, before our meeting with Aker in mid-April.

Following the mid-April meeting, adjustments were needed as the height of the platform requirement changed to min 2.5 and max four meters. This new requirement reduced the needed to lift it 1.5 meters, instead of the expected three meters mentioned in the interviews at first. A new design had to be created to fit these new requirements, and item24 was recommended to use. With guidance from Nordvik and using item24 components, a new design was developed in the following weeks, shortening the project timeline.

8.7.6 Simulations in SolidWorks

Another potential improvement in the project process that could have saved considerable time is the use of more powerful computers or stronger PC processors. Simulating the platform in Solid-

Works was time-consuming; loading different meshes and conducting static simulations required substantial computational time. Even simple simulations, like assessing maximum load on just the platform base, took over 25 minutes to complete. Therefore, upgrading to a more powerful computer could definitely have reduced the simulation time.

Since the resulting 3D model had more than 2,000 components, simulating in SolidWorks was difficult. Configuring the model took considerable time, and many attempts ended with the program crashing. With limited previous experience in SolidWorks, it took additional time to learn the necessary processes for effective simulation. Fasteners were removed and new holes were designed to reduce the number of components, and then assembly in SolidWorks. A simplifies model was used as the basis for simulation due to challenges in simulating the completed model.

There were also times where after waiting for a simulation to finish, the result was not useful because of faulty mates in the model. An example of this is shown in Figure 85 where the steel tubes that slide into the base of the platform were not mated with each other. Thus the whole time computing the simulation was wasted. Keeping track of all components in the assembly proved difficult the more components it contained, which unfortunately led to some wasted simulations.

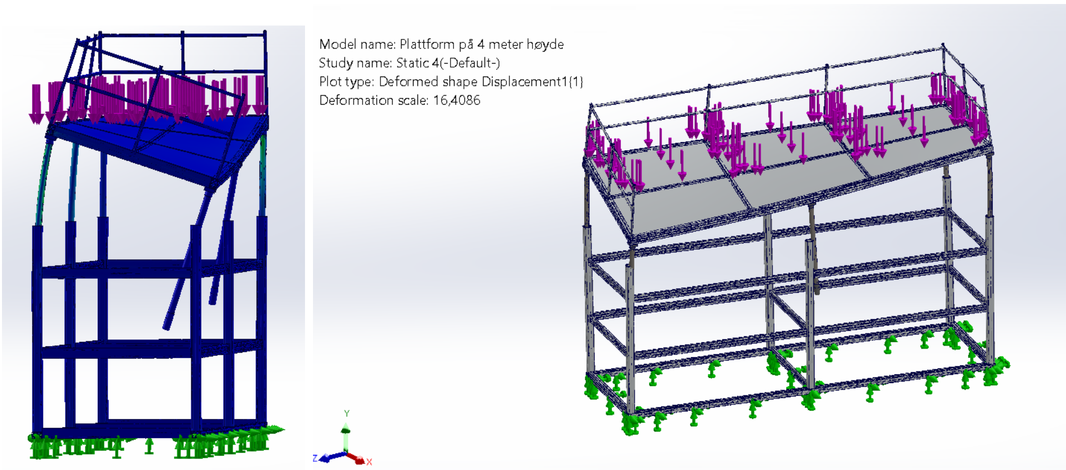


Figure 85: An example of a failed simulation, where mates were not checked before initiation.

8.8 Collaboration with Aker Solutions, Verdal

During the bachelor program, there were three visits to Aker, each visit serving a different purpose. Initially, interviews were conducted, which yielded less information than initially anticipated. Similarly, the survey distributed after the interviews did not provide as much insights as expected. Following this, the design phase began.

In mid-April, the third meeting were held with the supervisor from Aker, Salberg, and Nordvik, the design expert. During this meeting, the solution for hall VPL was examined, which manufactures jackets with a smaller diameter compared to A2 and with a much smaller work area. Nordvik had designed their version using item24 profiles and recommended adopting the same approach to simplify purchasing for Aker, and buying in bulk thereby reducing costs. This required restarting the design phase. Prior to this meeting, the broad scope of the task description had made the project work seem less effective due to the endless possibilities. With little to no experience in designing a new product from scratch, determining where to begin and how to work efficiently was challenging. Collaboration with Aker was minimal at this time, as significant information needed to be gathered to determine the most suitable design. However, after the meeting with Nordvik, the direction became clearer. Although the collaboration with Aker was limited, the in-person meetings with them were highly productive.

8.9 Collaboration Efficiency Within the Thesis Team

The majority of the collaboration during the project was effective, mostly because of frequent in-person meetings and side-by-side work sessions. Additionally, all members of the project were accessible through email and messenger groups, ensuring easy access to feedback and assistance with queries. This availability enabled a fast exchange of ideas and resolution of issues, which contributed positively to the project's progress.

The group members' familiarity with each other from previous university projects enhanced team dynamics. This prior collaboration meant members understood one another's working styles and strengths, enabling more efficient communication and quicker problem-solving. This contributed positively to the project's success by speeding up processes and improving work quality.

The familiarity among team members sometimes, for example in the beginning phase, led to us becoming too cohesive. An idea could seem satisfactory and then be developed further without anyone evaluating the potential downsides. This sometimes led to limited creativity, with the team not exploring multiple options but rather working on the same idea until a better one emerged.

8.10 Sustainability

Sustainability has been an important factor in the design of the new access platform. The design and suggestions include several aspects intended to minimize environmental impact while enhancing efficiency. To enhance how each of the mentioned sustainable choices minimize environmental impact, the United Nation's (UN) Sustainable Development Goals (SDG) were used as a baseline.

8.10.1 The UN's SDG Mentioned:

SDG 7: *"Ensure access to affordable, reliable, sustainable, and modern energy for all"* [35].

SDG 8: *"Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all"* [36].

SDG 11: *"Make cities and human settlements inclusive, safe, resilient, and sustainable"* [33].

SDG 12: *"Ensure sustainable consumption and production patterns* [34].

SDG 13: *"Take urgent action to combat climate change and its impacts"* [34].

8.10.2 Electric Motors vs. Combustion Engines

We recommend the use of electric motors for the access platform primarily for their sustainability benefits over combustion engines. Electric motors offer a significant reduction in carbon emissions since they do not burn fossil fuels. This not only helps in reducing greenhouse gas emissions but also minimizes air pollution, contributing to a cleaner environment. This approach aligns directly with SDG 13, which calls for urgent action to combat climate change and its impacts.

Additionally, electric motors are more energy-efficient, converting up to 90% of electrical energy into mechanical motion compared to combustion engines, which are often much less efficient due to heat loss and exhaust emissions [18]. This efficiency directly supports SDG 7, which aims to ensure access to sustainable, and modern energy for all.

8.10.3 Electric vs. Pneumatic/Hydraulic Actuators

When comparing electric actuators to pneumatic or hydraulic systems, electric solutions stand out as more sustainable. Electric actuators are generally more efficient, require less maintenance, and do not involve hydraulic fluids or compressed air, which can pose environmental risks due to leaks and disposal issues, as mentioned in section 2.12.3. This alignment with SDG 12 supports the goal to ensure sustainable consumption and production patterns.

8.10.4 Locally Sourced Materials

Incorporating locally sourced materials reduces the carbon footprint associated with transportation, also adhering to SDG 13. This practice not only supports local businesses but also decreases the overall environmental impact of the platform's construction. By choosing materials from producers based in Norway, the travel distance for these products is considerably shorter than sourcing from abroad. Specifically, the aluminum profiles, fasteners, aluminum floor plates, and steel tubes are all produced locally, thereby supporting SDG 11's objective to make cities and human settlements inclusive, safe, resilient, and sustainable.

Additionally, the plastic casings and blocks used in the design can be 3D printed right at Aker's facility, eliminating transportation needs entirely. By prioritizing local sourcing, the platform not only becomes more environmentally friendly but also actively contributes to the local economy, supporting local industries and reducing ecological impact. This promotes sustainable economic growth, thus adhering to SDG 8.

8.10.5 Recyclability at End-of-Life

The platform is primarily constructed from aluminum, plastic, and steel, all of which are materials highly valued for their recyclability. Resulting in the design facilitating easy separation and recycling at the end of its lifecycle thereby ensuring sustainable production patterns and following SDG 8.

9 Conclusion

This thesis has developed and verified a suggested design for a specialized work platform aimed at enhancing the efficiency and reducing costs of WTG jacket assembly at Aker. The introduction of the movable platform represents an improvement over traditional scaffolding methods, addressing the primary concerns of operational efficiency and cost-effectiveness.

The platform is specifically tailored for operation in the designated working hall (A2). Its dimensions and adjustability are based on Aker's input, ensuring the design meets their specific needs.

Through a design process that incorporated both manual calculations and simulations in SolidWorks, we have developed a platform that closely adheres to current industry standards. Its adjustable features and robust construction enable it to accommodate a diverse range of jacket sizes and configurations, optimizing the workflow on the assembly line. The platform's design also considers environmental impacts, promoting the use of eco-friendly components and sustainable practices.

Furthermore, the project outcomes indicate a significant reduction in personnel costs. It not only offers direct financial benefits but also enhances operational efficiency, which further results in savings as it allows projects to be completed in shorter timeframes. By adopting these platforms, while the initial investment in these platforms is significant, Aker is expected to achieve a break-even point after approximately 5.5 projects, which corresponds to a period of less than 17 months.

The collaboration with Aker and the utilization of engineering tools, like the Engineering tool from item24 and SolidWorks, have been essential in achieving a design that is both innovative and practical. This project has hopefully provided Aker with a solid foundation for improving its operations, and it has certainly facilitated our professional growth through hands-on experience in managing and executing a complex engineering project.

In conclusion, the developed platform design demonstrates that smart application of modern engineering can offer significant advantages, even in traditional and seemingly straightforward parts of a production process.

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Appendix

A Bill of Materials

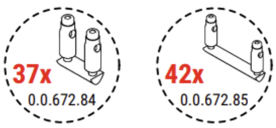
The bill of materials contains all the various components needed to build the overall platform

A.1 item24

Platform Top

Position	Article designation	Article No.	Page	Quantity
1	Profile 8 120x80 light, natural, Length: 1840mm	0.0.416.65	4	4
2	Profile 8 120x80 light, natural, Length: 1893mm	0.0.416.65	4	2
3	Profile 8 120x80 light, natural, Length: 1894mm	0.0.416.65	4	1
4	Profile 8 120x80 light, natural, Length: 6000mm	0.0.416.65	4	2
5	Profile 8 D40, natural, Length: 600mm	0.0.493.36	4	2
6	Profile 8 D40, natural, Length: 940mm	0.0.493.36	4	8
7	Profile 8 D40, natural, Length: 970mm	0.0.493.36	5	2
8	Profile 8 D40, natural, Length: 1000mm	0.0.493.36	5	9
9	Profile 8 D40, natural, Length: 1196mm	0.0.493.36	5	2
10	Profile 8 D40, natural, Length: 1946mm	0.0.493.36	5	4
11	Profile 8 120x16 E, natural, Length: 560mm	0.0.650.86	5	1
12	Profile 8 120x16 E, natural, Length: 920mm	0.0.650.86	5	4
13	Profile 8 120x16 E, natural, Length: 1168mm	0.0.650.86	6	1
14	Profile 8 120x16 E, natural, Length: 1920mm	0.0.650.86	6	2
15	Profile 8 120x16 E, natural, Length: 5900mm	0.0.650.86	6	1
16	Hinge 8 Al PP4, light duty	0.0.488.94	-	3
17	Cap 8 D40, black	0.0.489.53	-	11
18	Automatic-Fastening Set 8 Cap, grey similar to RAL 7042	0.0.616.31	-	158
19	Fastening Set, Groove Plate Profile 8	0.0.687.16	-	36
20	Automatic-Fastening Set 8 40	0.0.672.84	-	37
21	Automatic-Fastening Set 8 80	0.0.672.85	-	42

Fasteners (All together)



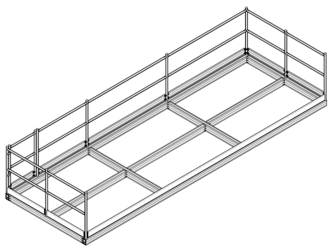
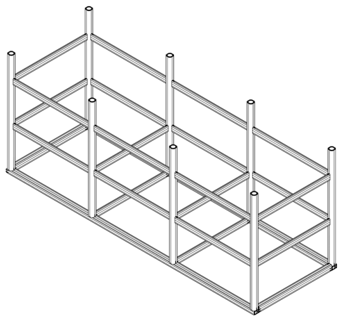


Figure 86: Platform top

Platform Base

Position	Article designation	Article No.	Quantity
1	Profile 8 120x80 light, natural, Length: 1760mm	0.0.416.65	2
2	Profile 8 120x80 light, natural, Length: 6000mm	0.0.416.65	2
3	Profile 8 120x40 light, natural, Length: 1760mm	0.0.416.66	8
4	Profile 8 120x40 light, natural, Length: 1840mm	0.0.416.66	12
5	Profile 8 120x120-45° D87, natural, Length: 2420mm	0.0.463.25	8
6	Automatic-Fastening Set 8 Cap, grey similar to RAL 7042	0.0.616.31	130
7	Automatic-Fastening Set 8, bright zinc-plated	0.0.388.08	98
8	Automatic-Fastening Set 8 40	0.0.672.84	8
9	Automatic-Fastening Set 8 80	0.0.672.85	8

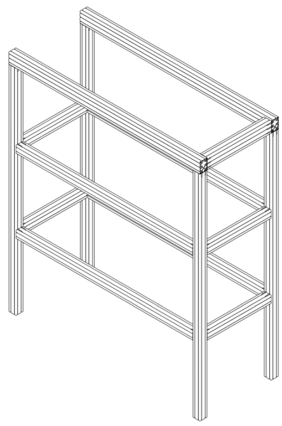


Fasteners (All together)

Figure 87: Platform bottom

Static Stair Frame

Position	Article designation	Article No.	Quantity
1	Profile 8 80x80 light, natural, Length: 710mm	0.0.265.80	4
2	Profile 8 80x80 light, natural, Length: 1960mm	0.0.265.80	4
3	Profile 8 80x80 light, natural, Length: 2380mm	0.0.265.80	4
4	Profile 8 120x80 light, natural, Length: 710mm	0.0.416.65	1
5	Profile 8 120x80 light, natural, Length: 2120mm	0.0.416.65	2
6	Automatic-Fastening Set 8 Cap, grey similar to RAL 7042	0.0.616.31	92
7	Automatic-Fastening Set 8 80	0.0.672.85	46



Fasteners (All together)

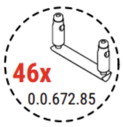
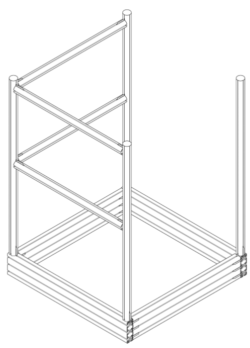


Figure 88: Frame for the stairs

Platform - Stair Corner

Position	Article designation	Article No.	Quantity
1	Profile 8 120x40 light, natural, Length: 710mm	0.0.416.66	2
2	Profile 8 120x40 light, natural, Length: 790mm	0.0.416.66	2
3	Profile 8 D40, natural, Length: 710mm	0.0.493.36	4
4	Profile 8 D40, natural, Length: 1000mm	0.0.493.36	4
5	Cap 8 D40, black	0.0.489.53	4
6	Automatic-Fastening Set 8 Cap, grey similar to RAL 7042	0.0.616.31	48
7	Automatic-Fastening Set 8 40	0.0.672.84	24



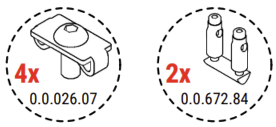
Fasteners (All together)

Figure 89: Platform for the stairs

Railing on One Movable Step

Position	Article designation	Article No.	Quantity
1	Profile 8 120x40 light, natural, Length: 240mm	0.0.416.66	1
2v	Profile 8 D40, natural, Length: 80mm	0.0.493.36	2
3v	Profile 8 D40, natural, Length: 1000mm	0.0.493.36	2
4	Cap 8 D40, black	0.0.489.53	2
5	Automatic-Fastening Set 8 Cap, grey similar to RAL 7042	0.0.616.31	4
6	Standard-Fastening Set 8, bright zinc-plated	0.0.026.07	4
7	Automatic-Fastening Set 8 40	0.0.672.84	2

Fasteners (All together)



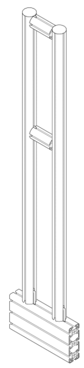


Figure 90: Railing to movable step

The railing for the movable stairs needs to be multiplied by 7, as the stairs consist of 7 steps with railing.

A.2 Remaining Materials

BOM for remaining components for one platform

Part Name	Producer	Quantity
POM-top	3D-printed at Aker	6
POM-bottom	3D-printed at Aker	6
POM Castings, bottom	3D-printed at Aker	14
POM Castings, top	3D-printed at Aker	14
Steel Tube		1
Steel Lifting Structure	Unknown	1
Connector - Movable Stairs and Corner Platform	Unknown	2
Connector - Corner Platform and Platform Top	Unknown	1
Wheels	Rollenbau	12
Step Profile 8, 700 mm	Item24	14
Stairway Assembly Set 45 degrees	Item24	1
Profile 8 120x40, 3540 mm	Item24	2
Step Profile Bracket Set 8 240	Item24	14

Figure 91: Remaining materials

B Profiles

The products chosen for item24 include:

B.1 Profile 8 120x80 light, natural

This profile is used in both the base and frame of the platform. The longest beam using this profile is 6 meters, while the shortest is 1.76 meters. When a 6 meter beam experiences a distributed force of 6000 N and is fixed at both ends, it results in a bending stress of $\sigma = 59.44 \text{N/mm}^2$ and a deflection of d = 25.79 mm. For the shortest length, the bending stress is $\sigma = 17.44$ N/mm^2, and the deflection is d = 0.62 mm. [63]

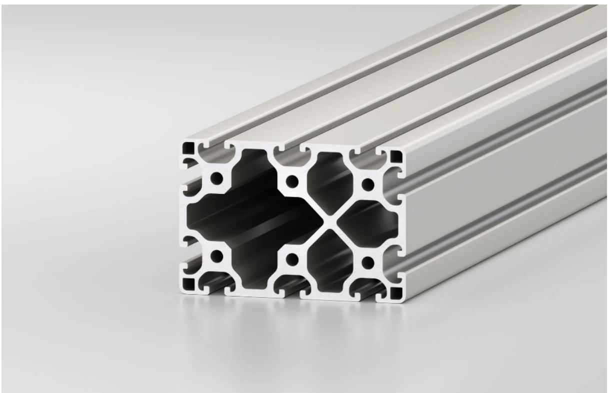


Figure 92: Profile 8 120x80

[63]

B.2 Profile 8 D40, natural

This profile is used in the platform railing.

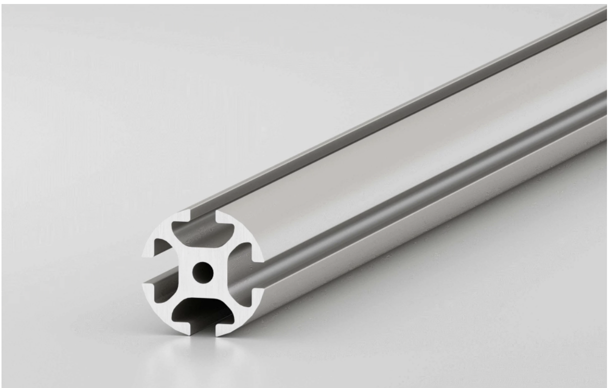


Figure 93: Profile 8 D40

[66]

B.3 Profile 8 120x16 E, natural

This profile is used as a toe board to prevent objects from falling, as mentioned in the safety section in the discussion.

Figure 94: Profile 8 120X16 E

[61]

B.4 Profile 8 120x120-45°

This profile acts as columns to maintain the stability of the platform. Vertically positioned, they cover a steel tube. Additionally, they serve as a shield for the steel tube and, together with a motor, raise the platform.

Figure 95: Profile 8 120x120-45°

[60]

B.5 Profile 8 120x40 light, natural

This profile is used to strenghten the stability of the frame and is smaller than the others, aiming to reduce the overall weight of the platform.

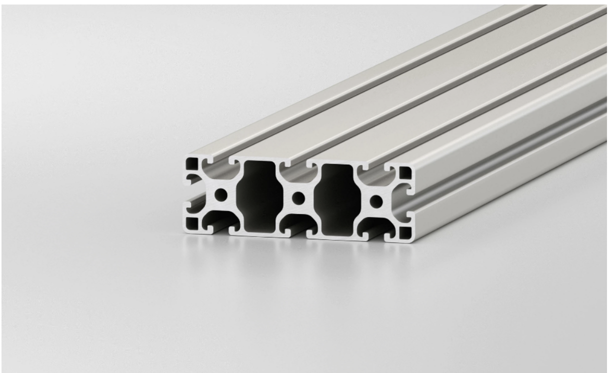


Figure 96: Profile 8 120x40

[62]

B.6 Profile 8 80x80 light, natural

This profile is used as sturdy columns ensuring the stability of the platform that supports the stairs.

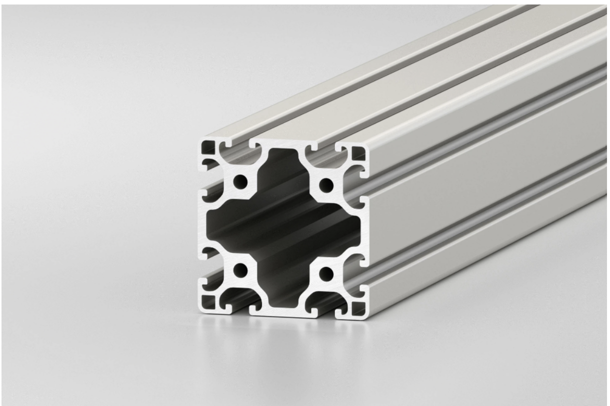


Figure 97: Profile 8 80x80

[64]

B.7 Step Profile 8

This profile is used as stairs, with the largest variant selected, featuring a width of 240mm.

Figure 98: Step Profile 8

[81]

C Video Links

C.1 Kerb Test - front first

https://youtu.be/M9ESxA1NBvw

C.2 Kerb Test - rear first

https://youtu.be/FJIBoYujjvE

C.3 Kerb Test - tipping over 15 cm kerb

https://youtu.be/tPYwZndSLQc

D Dimensions

D.1 Bottom-base

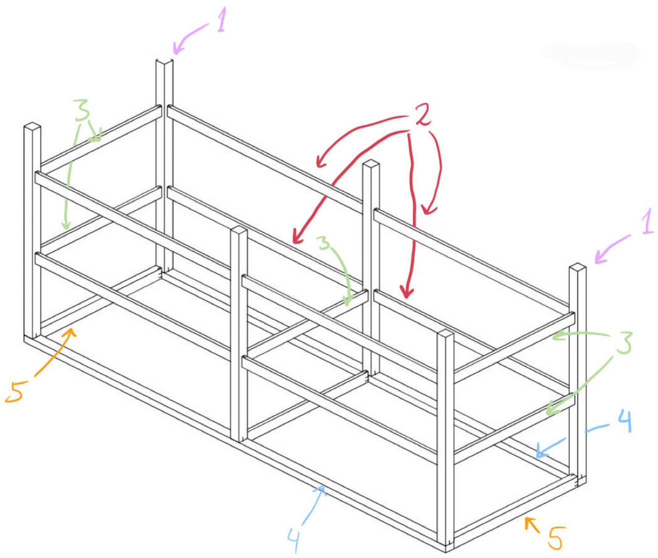


Figure 99: Platform base with numbering of beams.

Profile x length:

- **1 :** Profile 8 120x120-45°D87, natural. Lenght: 2159mm.
- **2 :** Profile 8 120x40 light, natural. Lenght: 2820mm.
- **3 :** Profile 8 120x40 light, natural. Lenght 1760mm.
- **4 :** Profile 8 120x80 light, natural. Lenght 6000mm.
- **5 :** Profile 8 120x80 light, natural. Lenght: 1760mm.

D.2 Top-base

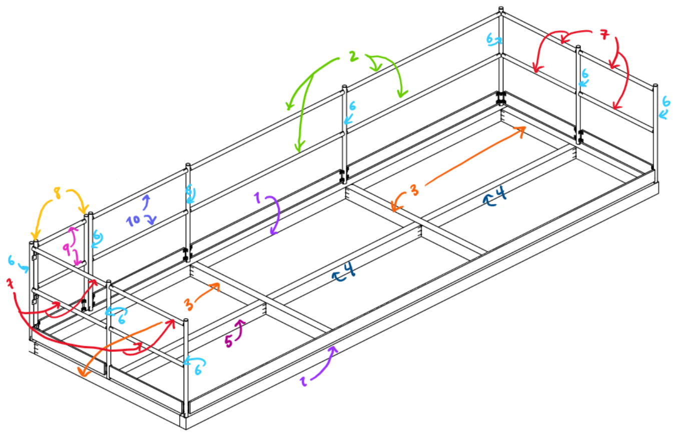


Figure 100: Sketch of the platform top with numbers for different components.

Profile x length:

- **1 :** Profile 8 120x80 light, natural. Lenght: 6000mm
- **2 :** Profile 8 D40, natural. Lenght: 1946mm.
- **3 :** Profile 8 120x80 light, natural. Lenght: 1840mm.
- **4 :** Profile 8 120x80 light, natural. Lenght: 1893mm
- **5 :** Profile 8 120x80 light, natural. Lenght: 1894mm.
- **6 :** Profile 8 D40, natural. Lenght: 1000mm.
- **7 :** Profile 8 D40, natural: Lenght: 940mm.
- **8 :** Profile 8 D40, natural. Lenght: 970mm.
- **9 :** Profile 8 D40, natural. Lenght: 600mm.
- **10 :** Profile 8 D40, natural. Lenght: 1196mm.

D.3 Stair-base

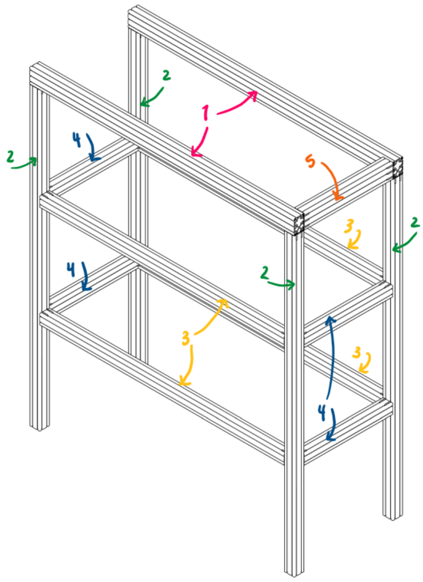


Figure 101: Sketch of the stair base with numbers for different components.

Profile x length:

- **1 :** Profile 8 120x80 light, natural. Lenght: 2120mm.
- **2 :** Profile 8 80x80 light, natural. Lenght: 2414mm.
- **3 :** Profile 8 80x80 light, natural. Lenght: 1960mm.
- **4 :** Profile 8 80x80 light, natural. Lenght: 710mm
- **5 :** Profile 8 120x80 light, natural. Lenght: 710mm

D.4 Steel Tubes and POM Casings

POM-top:

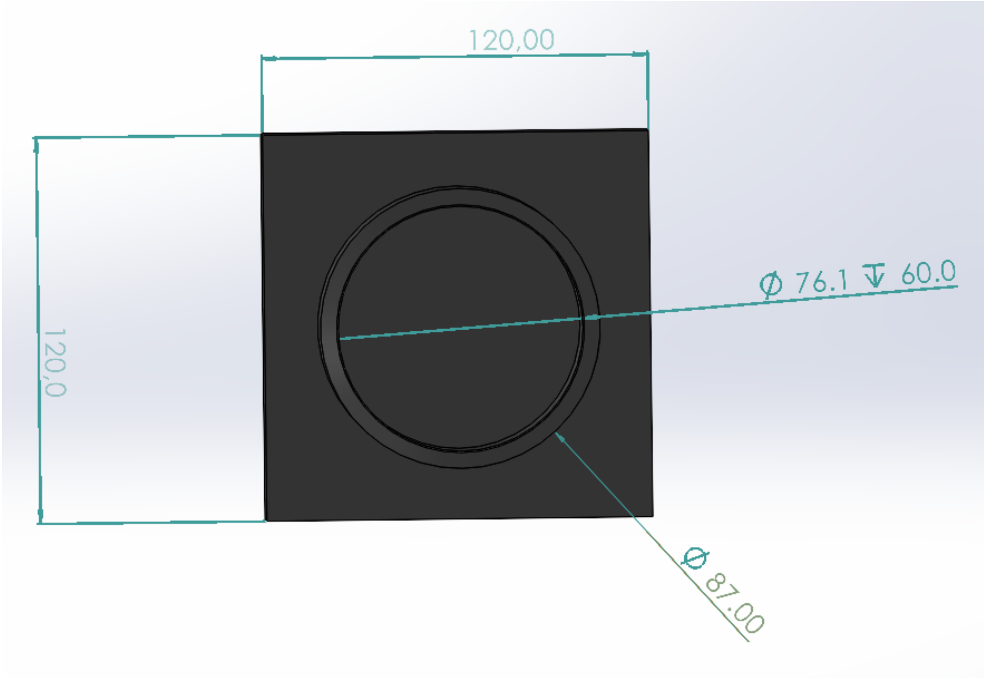


Figure 102: Dimensions in mm for the POM casting on top of the steel tube, seen from the bottom.

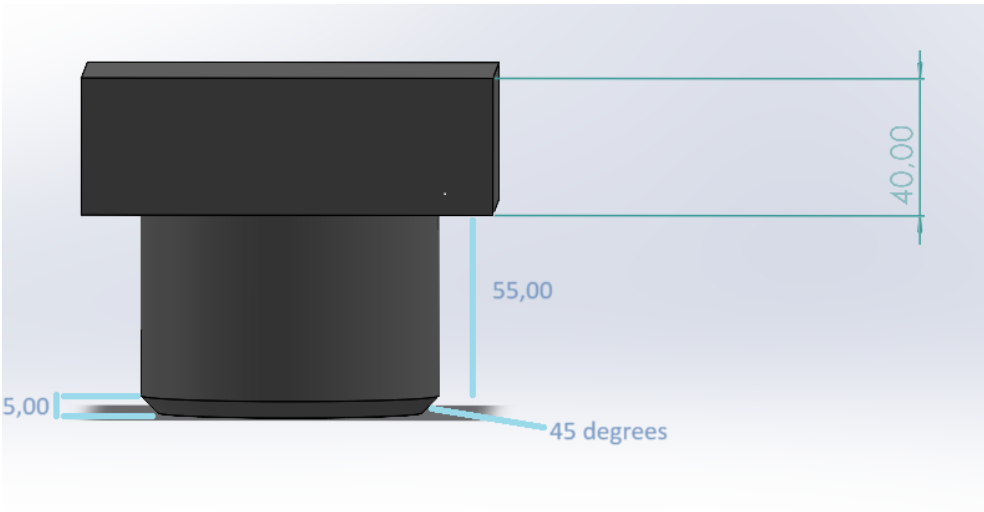


Figure 103: Dimensions in mm (unless specified otherwise) for the POM casting on top of the steel tube, seen from the side.

POM-bottom:

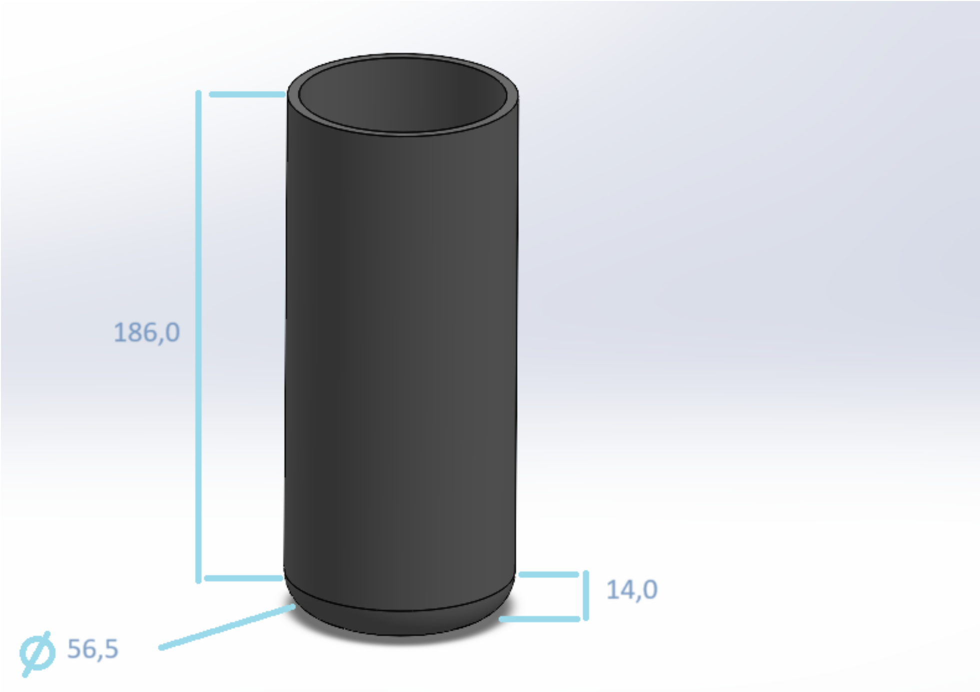


Figure 104: Dimensions in mm for the POM casting on the bottom of the steel tube, seen from the side.

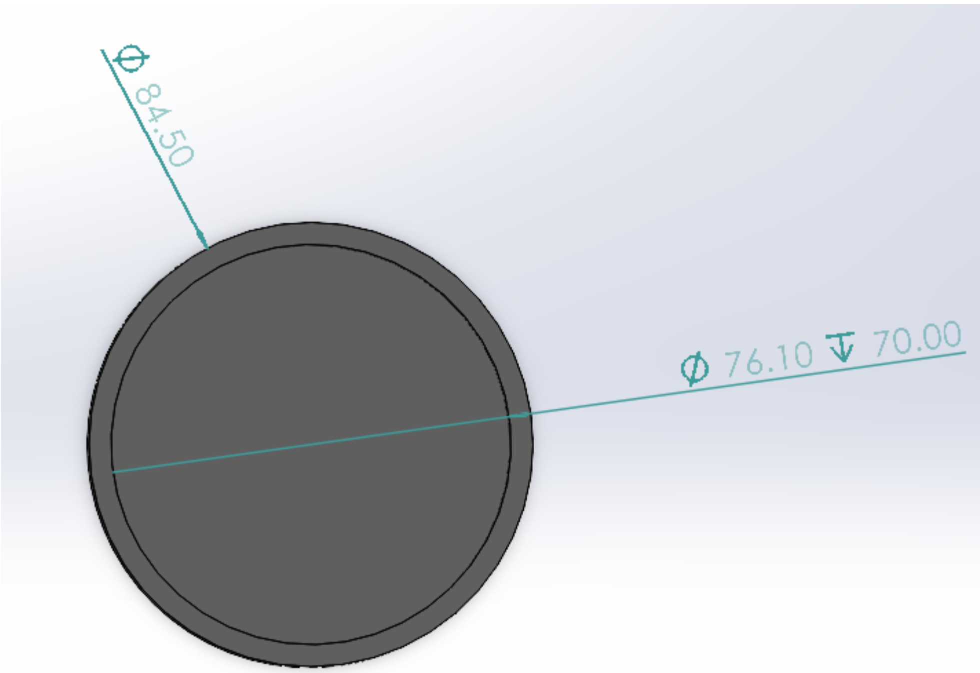


Figure 105: Dimensions in mm for the POM casting on the bottom of the steel tube, seen from above.

Steel-Tube:

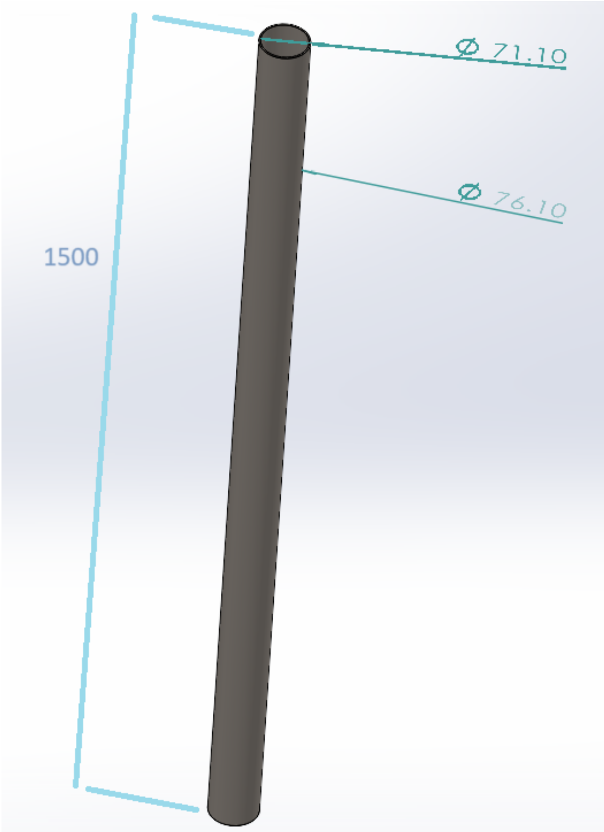


Figure 106: Dimensions in mm for the steel tube.

D.5 Corner Platform

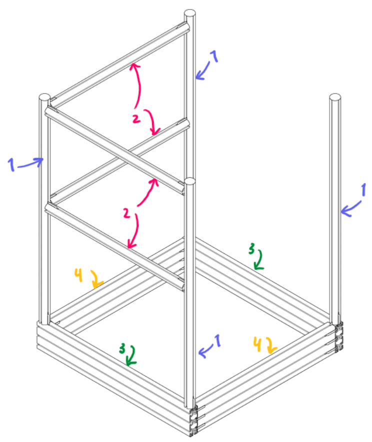


Figure 107: Sketch of the corner platform with numbers for different components.

Profile x length:

- **1 :** Profile 8 D40, natural. Lenght: 1000mm.
- **2 :** Profile 8 D40, natural. Lenght: 710mm.

- **3 :** Profile 8 120x40 light, natural. Lenght 790mm.
- **4 :** Profile 8 120x80 light, natural. Lenght: 710mm

D.6 Static Stairs

Railing - Static:

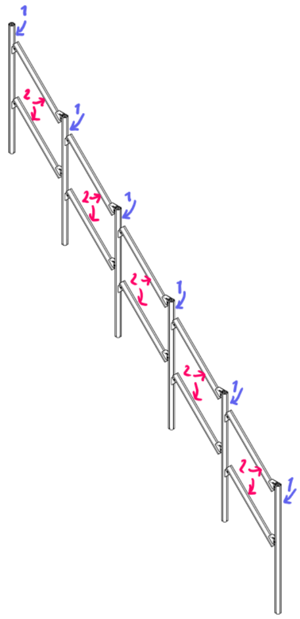


Figure 108: Sketch of the static stairs railing with numbers for different components.

Profile x length:

- **1 :** Profile 8 D40, natural. Lenght: 1000mm.
- **2 :** Profile 8 D40, natural. Lenght: 580mm.

Stairs - Static

Components:	Dimensions:	Quantity:
Step Profile 8	700 mm	14
Stairway Assembly Set 45 degrees	Floor to platfc	1
Profile 8 120x40	3540 mm	2
Step Profile Bracket Set 8 240	Item24	14

Figure 109: Dimensions in mm of the static stairs with image of the stairs assembeled.

D.7 Movable Stairs

Steel Lifting Structure:

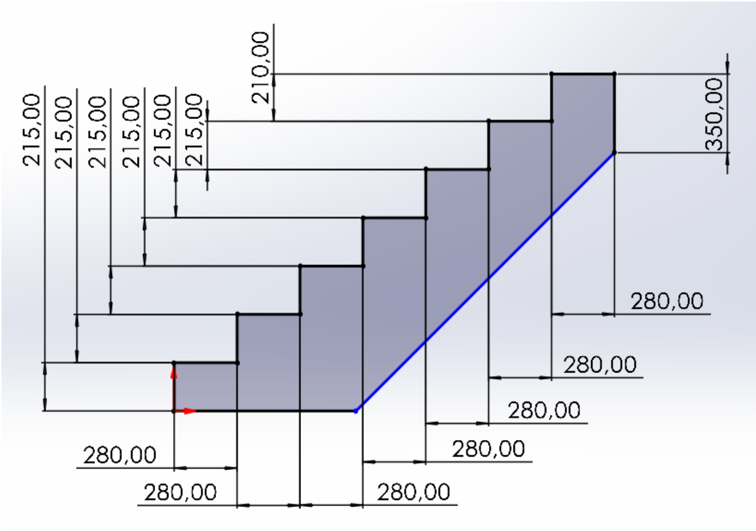


Figure 110: Dimensions in mm of the lifting structure seen from the side.

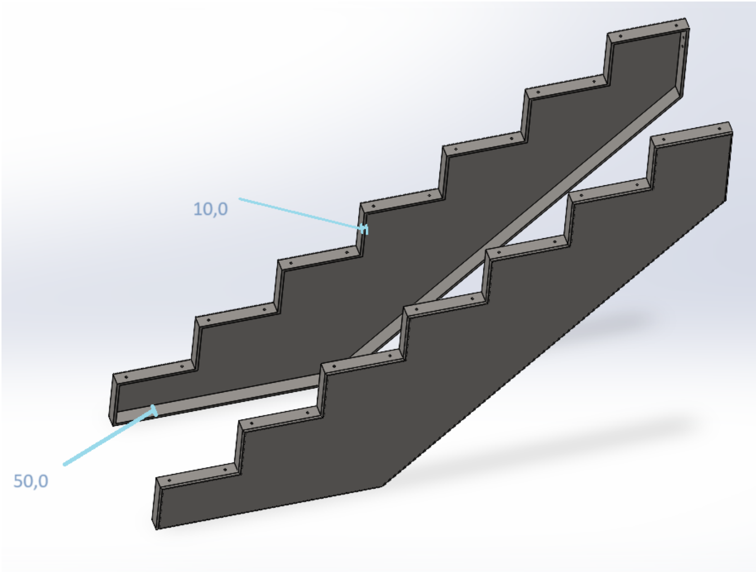


Figure 111: Dimensions in mm of the lifting structure seen from the side.

POM Casings:

Bottom:

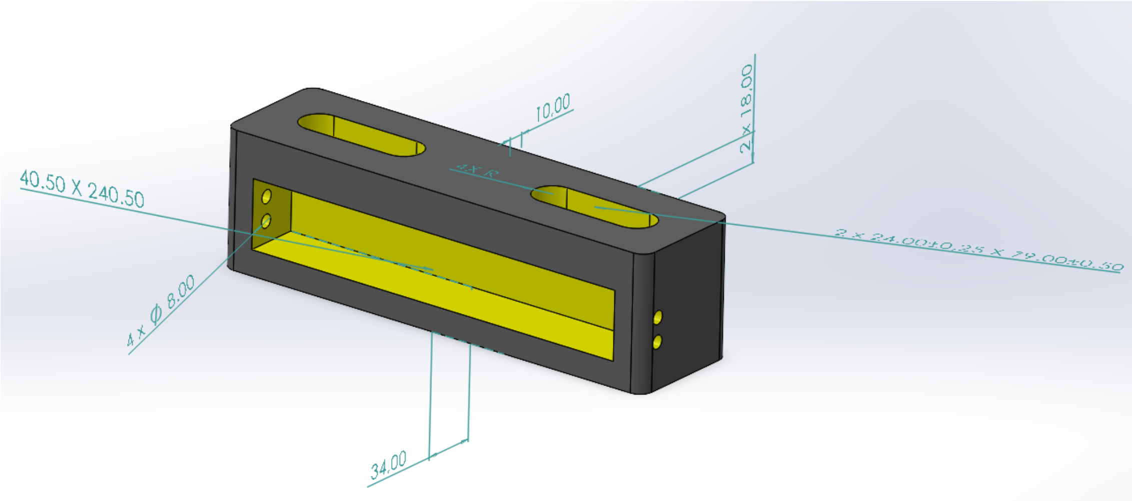


Figure 112: Dimensions in mm of the bottom POM casting on the movable stairs.

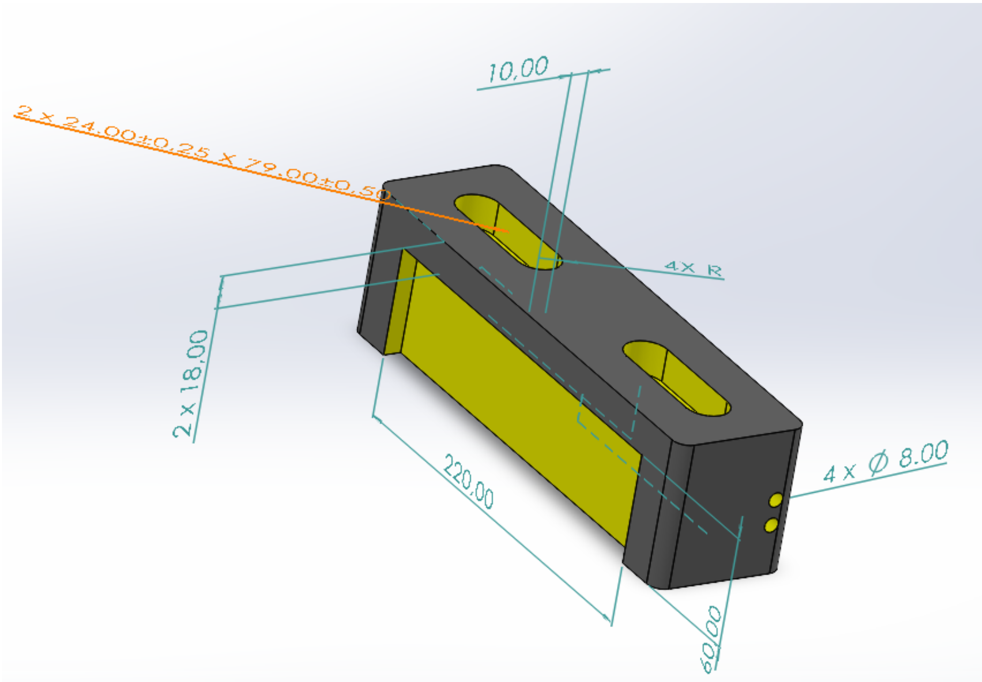


Figure 113: Dimensions in mm of the bottom POM casting on the movable stairs.

Top:

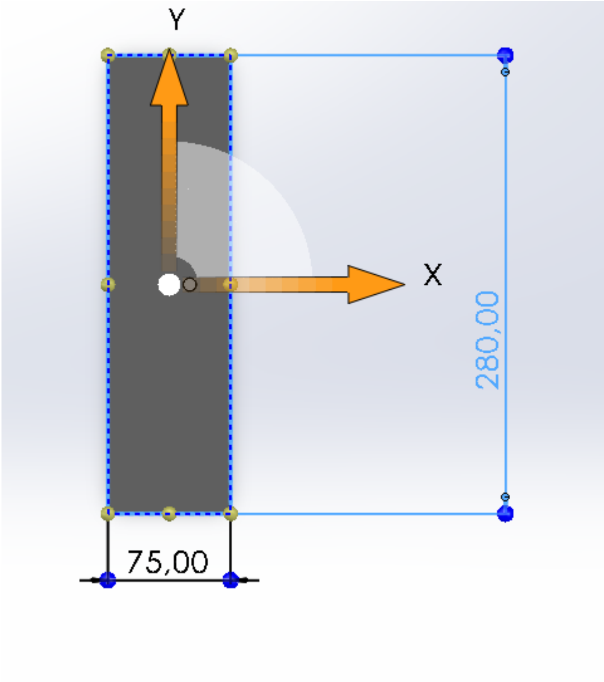


Figure 114: Dimensions in mm of the top POM casting on the movable stairs, seen from above.

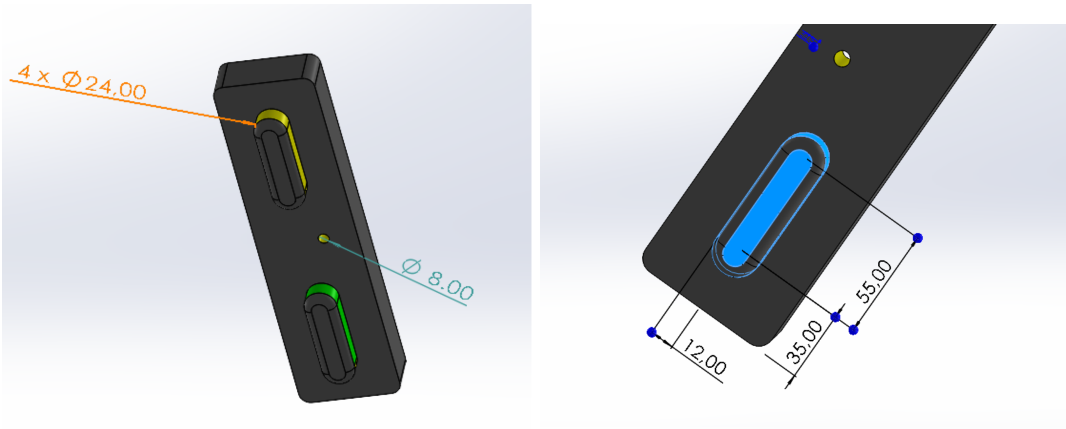


Figure 115: Dimensions in mm of the top POM casting on the movable stairs, seen from bottom.

Step - Fastened to Lifting Structure and Bottom POM Castings:

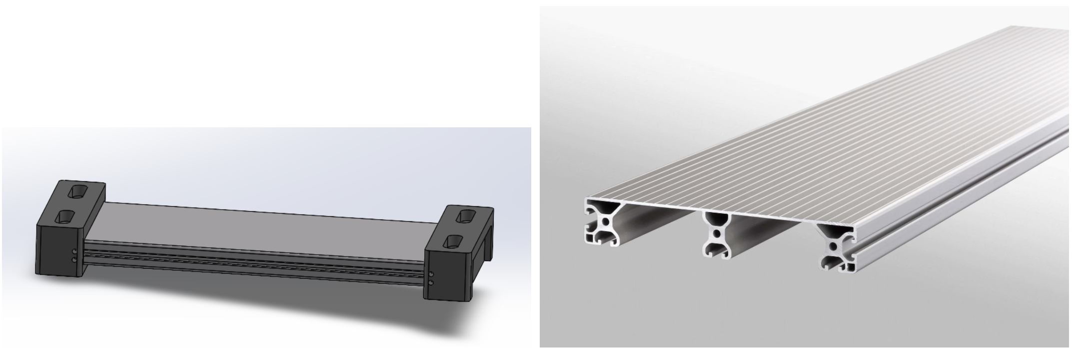


Figure 116: Step Profile 8 from item24, with **Length = 616 mm** shown connected to the POM castings.

Long Step - Fastened to Movable Railing:

Figure 117: Step Profile 8 from item24, with **Length = 790 mm** fastened to the movable railing.

Movable Railing:

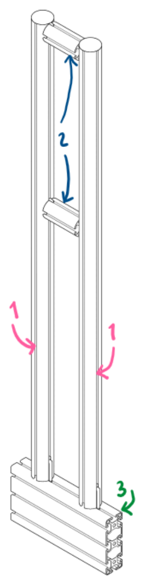


Figure 118: Dimensions of the raling on the movable stairs.

Profile x length:

- **1 :** Profile 8 D40, natural. Lenght: 1000mm.
- **2 :** Profile 8 D40, natural. Lenght: 80mm.
- **3 :** Profile 8 120x40 light, natural. Lenght: 240mm.

D.8 Connector - Movable Stairs and Corner Platform

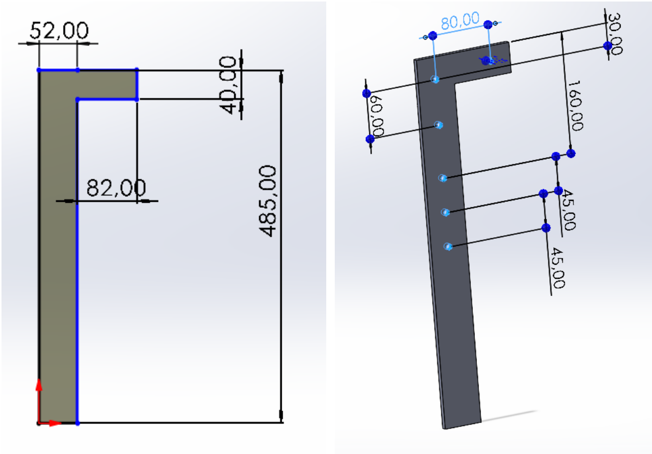


Figure 119: Dimensions for connector between movable stairs and corner platform.

D.9 Connector - Corner Platform and Platform Top

ENDRE!!!!!!!

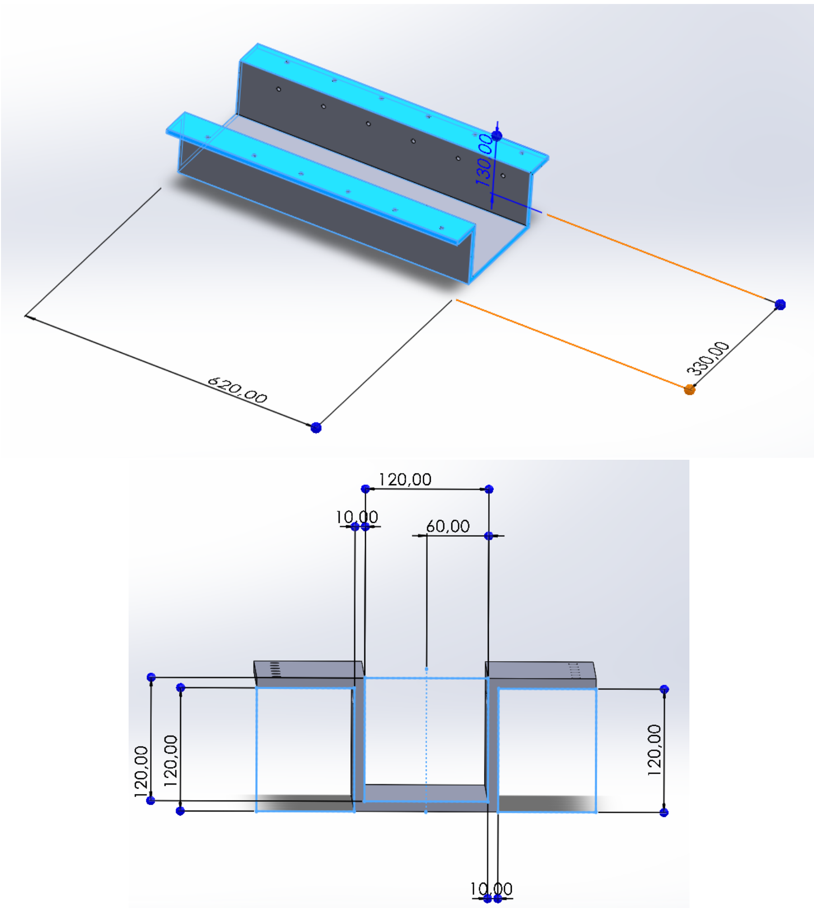


Figure 120: Dimensions for connector between corner platform and platform top.

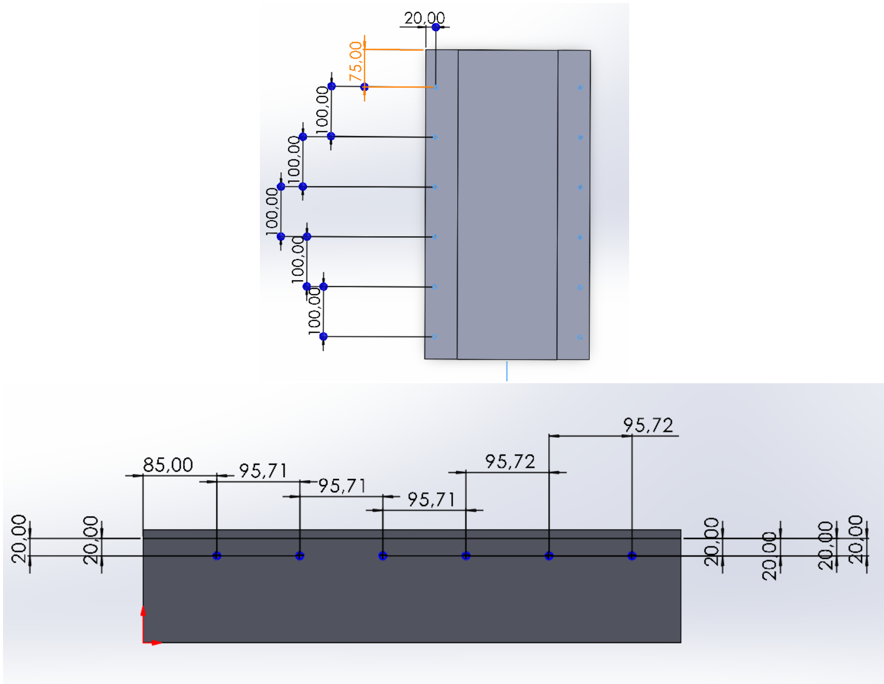


Figure 121: Dimensions for connector between corner platform and platform top.

D.10 Wheels

Figure 122: Suggested wheel for the platform - "Heavy Duty serie 61, wheel Z" from Rollenbau [38].

ARTICLE NUMBER	ARTICEL TYPE	WHEEL-Ø A X WIDTH B MM	LOAD CAPACITY KG	OVERALL HEIGHT H MM	DIMENSION OF TOP PLATE TP MM	HOLE SPACING HS MM	HOLE-Ø HD MM	SWIVEL RADIUS SR MM	WHEEL BEARING	PRICE €
61-151 ZK	Swivel castor	150x50	680	181	162x133	140x105	11	120		168,00

Figure 123: Dimensions for the product "Heavy duty serie 61, wheel Z" from Rollenbau [38]

D.11 Supports

D.12 Electrical cylinders

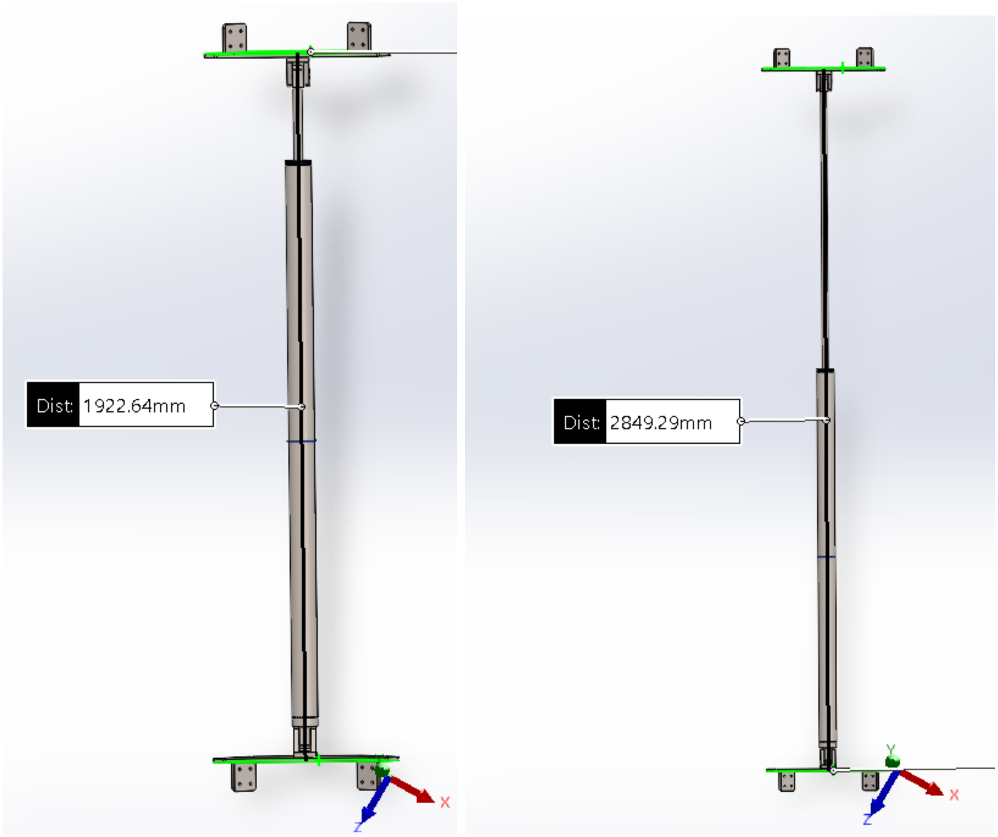


Figure 124: Length of electrical cylinder in lower and upper positions

D.13 Work Bench

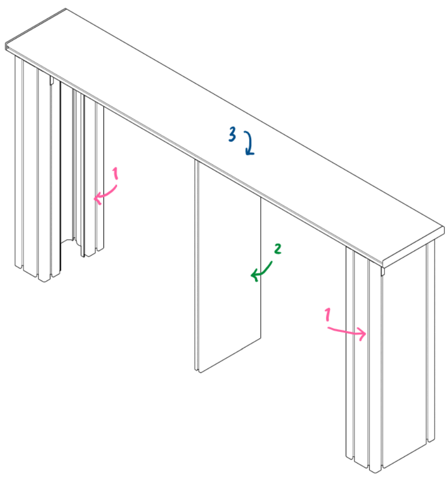


Figure 125: Dimensions of the work bench.

Profile x length:

- **1 :** Profile 8 160x80 K76, natural. Lenght: 484mm
- **2 :** Profile 8 160x16, natural. Lenght: 484mm
- **3 :** Profile 8 160x16, natural. Lenght 1000mm

E Links to different components

Click on picture or figure text to get to the component in item24.

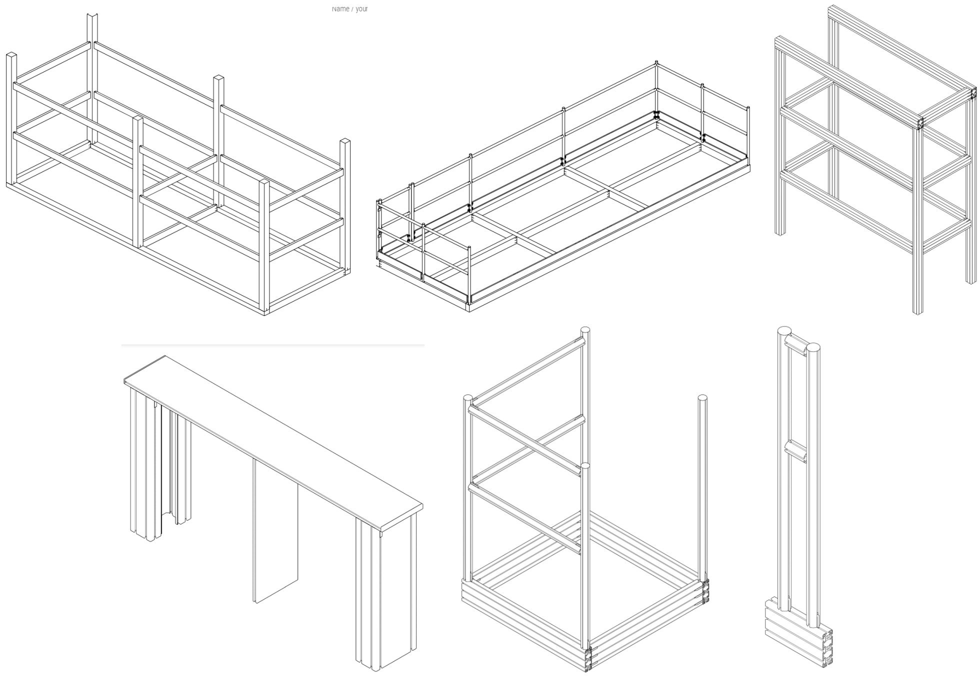


Figure 126: Bottom platform

Top platform, Frame to stairs, Work bench, Corner platform, Railing to movable stairs

F Explanation of estimated prices for components

Estimated cost of the platform

Estimated product cost from item 24:

Product	Quantity	Cost	Sum
Bottom	1	100 139,81	100 139,81
Top	1	82 835,49	82 835,49
Corner	1	9 240,74	9 240,74
Railing to movable stairs	7	1 717,98	12 025,86
Frame for stairs	1	37 701,98	37 701,98
Work bench	1	6 138,17	6 138,17
Total			**248 082,05**

Estimated cost from different supplier:

Product	Quantity	Cost	Sum
Wheels	10	1791,99	17919,9
Steel tubes 6m	2	3500	7000
Motor	1	2000	2000
Aluminium floors	6	4200	25200
Lifting columns	6	25000	150000
Total			**202119,9**

Assembly of components in SW with a cost estimation by us:

Product	Quantity	Cost	Sum
Static stairs: Railing	22	307	6754
Static stairs: Step	14	0	0
Static stairs: Beams	2	3560,96	7121,92
Static stairs: Assembly set	1	0	0
Movable stairs: Step	7	0	0
POM parts	40	0	0
Connector: Movable stairs to corner platform	1	0	0
Movable stairs: Steel lifting structure	1	0	0
Connector: Corner platform and platform top	1	0	0
Fasteners for electric lifting sylinders	6	0	0
Supports	6	0	0
Total			**13875,92**

Total estimated cost = 464 077,87 NOK

Figure 127: Total estimated cost

F.1 Estimated prices for components

Explanation of estimated prices for components:

Static stairs with railing assebled in SW:
(Based on the already estimated costs of profiles from item24)
Railing: (1000mm) 307NOK * 12 + (580mm) 307NOK * 20 = 6754NOK
Step x14: cost = unknown
Beams: 3.540m*2*1005,92NOK = 7121.92NOK
Stairway assembly set: cost =unknow

Movable stairs:
(Based on the already estimated costs of profiles from item24)
Movable railing: 1005.92x7 = 12025.86NOK (Cost form item24)
Step x7: cost = unknown
POM casing to stairs: cost = unknown
Connector movable stairs and corner platforn: cost = unknown
Lifting structure (hidden stairs): cost = unknown
Connector corner platform and platform top: cost = unknown

POM parts:
Aker has the capability to 3D print these themselves

Wheels:
(Cost from Rollenbau)
152.64 euro
152.64 * 11.74NOK (Norwegian currency exchange rate 08.05.24) = 1791.99NOK each

Steel tubes:
(Estimated by Tibnor on mail)
Minimum 6m, cost =3500NOK, need a total of 12 meters

Aluminium floors:
(Cost from Norsk Stål)
4200NOK for each EN AW 5754 H114 Alu dørk 1-bar 4,0 x 1000 x 2000mm

Motor:
(estimated from mekanex on mail)
Cost between 2000-5000 NOK each
Therefore set to 2000NOK

Electric lifting sylinders:
(estimated from mekanex on mail)
Cost between 25,000-50,000 NOK each
Therefore set to 25,000NOK

Fasteners for electric lifitng sylinders designed in SW:
These are designed by us, and are therefore hard to find a prize on.
Cost = unknown

Supports:
Aker need to to find supports that align with their budget and have the capacity to withstand the weight of the platform.

Figure 128: Explanation of estimated prices for components. Rollenbau [38], Tibor [41] Mekanex [21].

F.2 Offers for components manufactured by item24 from the Norwegian supplier AluFlex

Tilbud Nr 605938 — Side 1

Lev.adresse
NTNU Gjøvik
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B-Bygget, Teknologiveien 22
2815 GJØVIK
Norge/ Norway

NTNU
Felles Fakturamottak
0508 OSLO

Lev.betingelser	FCA, Terminal - Gardermoen, eks. emballasje.	Dato	08.05.24
Bet.betingelser	30 dager netto	Kundenr	2013
Vår referanse	Roar Grønvold (A1)	Deres referanse	Marte Sjursen
Externt Vernr.	RFQ BASE, 3 STOLPER		

Nr	Beskrivelse	Antall	Enhet	Nettopris	Beløp
	Base bunn - Base, 3 stolper f28e6f3126124d17a59f49f432bb26d55				
0.0.416.65	Profil 8 120x80 lett	15,52	m	1 770,30	27 475,06
	Lengde Bredde Enhet Antall Merke *1 760 0 mm 2 Pos. 1* *6 000 0 mm 2 Pos. 2*				
0.0.416.66	Profil 8 120x40 lett	33,12	m	1 005,90	33 315,41
	Lengde Bredde Enhet Antall Merke *1 760 0 mm 6 Pos. 6* *2 820 0 mm 8 Pos. 8*				
0.0.463.25	Profil 8 120x120-45°d87(hl=6m)	14,52	m	2 202,20	31 975,94
	Lengde Bredde Enhet Antall Merke *2 420 0 mm 6 Pos. 5*				
800	Kappkostnad profiler	1,2	TIMER	900,00	1 080,00
0.0.616.31	Dekklokk Automatikk 8, grå	94	STK	4,20	394,80
0.0.388.08	Mont.sett automatikk 8	70	SETT	59,80	4 186,00
0.0.672.84	Automatic-Fastening Set 8 40	4	SETT	121,55	486,20
0.0.672.85	Automatic-Fastening Set 8 80	8	SETT	153,30	1 226,40
	Totalt ekskl mva NOK				**100 139,81**

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Tilbud Nr 605939 — Side 1

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NTNU
Felles Fakturamottak
0508 OSLO

Lev.betingelser	FCA, Terminal - Gardermoen, eks. emballasje.	Dato	08.05.24
Bet.betingelser	30 dager netto	Kundenr	2013
Vår referanse	Roar Grønvold (A1)	Deres referanse	Marte Sjursen
Externt Vernr.	RFQ BASE GULV		

Nr	Beskrivelse	Antall	Enhet	Nettopris	Beløp
	Base topp - Base gulv eec914f018104c81835fe83ef9d75a1631				
0.0.416.65	Profil 8 120x80 lett	25,04	m	1 770,30	44 328,31
	Lengde Bredde Enhet Antall Merke *1 840 0 mm 4 Pos. 1* *1 893 0 mm 2 Pos. 2* *1 894 0 mm 1 Pos.3* *6 000 0 mm 2 Pos.4*				
0.0.493.36	Profil 8 D40 (HL=6m)	29,836	m	359,10	10 714,11
	Lengde Bredde Enhet Antall Merke *600 0 mm 2 Pos. 5* *940 0 mm 8 Pos. 6* *970 0 mm 2 Pos. 7* *1 000 0 mm 9 Pos. 8* *1 196 0 mm 2 Pos. 9* *1 946 0 mm 4 Pos. 10*				
0.0.650.86	Profil 8 120x16 E	15,148	m	606,90	9 193,32
	Lengde Bredde Enhet Antall Merke *560 0 mm 1 Pos. 11* *920 0 mm 4 Pos. 12* *1 168 0 mm 1 Pos. 13* *1 920 0 mm 2 Pos. 14* *5 900 0 mm 1 Pos. 15*				

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Tilbud Nr 605940 — Side 1

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NTNU
Felles Fakturamottak
0508 OSLO

Lev.betingelser	FCA, Terminal - Gardermoen, eks. emballasje.	Dato	08.05.24
Bet.betingelser	30 dager netto	Kundenr	2013
Vår referanse	Roar Grønvold (A1)	Deres referanse	Marte Sjursen
Externt Vernr.	RFQ BENK		

Nr	Beskrivelse	Antall	Enhet	Nettopris	Beløp
	Benk - Kne-benk 527aadb99c1444128497151093fa5d2e2				
0.0.265.90	Profil 8 160x16 normal	1,484	m	1 195,60	1 774,27
	Lengde Bredde Enhet Antall Merke *484 0 mm 1 Pos. 1* *1 000 0 mm 1 Pos. 2*				
0.0.672.90	Inst.Profile 8 160x80 K76	0,968	m	2 949,79	2 855,40
	Lengde Bredde Enhet Antall Merke *484 0 mm 2 Pos. 3*				
820	Kappkostnad over 120mm	4	STK	108,00	432,00
0.0.373.00	Endelokk 8 160x16	2	STK	32,20	64,40
0.0.616.31	Dekklokk Automatikk 8, grå	11	STK	4,20	46,20
0.0.388.08	Mont.sett automatikk 8	5	SETT	59,80	299,00
0.0.391.60	Mont.sett automatikk 5	3	SETT	69,00	207,00
0.0.672.85	Automatic-Fastening Set 8 80	3	SETT	153,30	459,90
	Totalt ekskl mva NOK				**6 138,17**

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Tilbud Nr 605941 — Side 1

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Felles Fakturamottak
0508 OSLO

Lev.betingelser	FCA, Terminal - Gardermoen, eks. emballasje.	Dato	08.05.24
Bet.betingelser	30 dager netto	Kundenr	2013
Vår referanse	Roar Grønvold (A1)	Deres referanse	Marte Sjursen
Externt Vernr.	RFQ PLATTFORM TRAPP		

Nr	Beskrivelse	Antall	Enhet	Nettopris	Beløp
	Hjørne base - Plattform trapp 1959d054dbe3497cb52948b7680e1ac07				
0.0.416.66	Profil 8 120x40 lett	3	m	1 005,90	3 017,70
	Lengde Bredde Enhet Antall Merke *710 0 mm 2 Pos. 1* *790 0 mm 2 Pos. 2*				
0.0.493.36	Profil 8 D40 (HL=6m)	6,84	m	359,10	2 456,24
	Lengde Bredde Enhet Antall Merke *710 0 mm 4 Pos. 3* *1 000 0 mm 4 Pos. 4*				
815	Kappkostnad 80-120mm	4	STK	75,00	300,00
805	Kappkostnad profiler tom 40	8	STK	30,00	240,00
0.0.489.53	Endelokk 8 D40	4	STK	27,00	108,00
0.0.616.31	Dekklokk Automatikk 8, grå	48	STK	4,20	201,60
0.0.672.84	Automatic-Fastening Set 8 40	24	SETT	121,55	2 917,20
	Totalt ekskl mva NOK				**9 240,74**

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NTNU
Felles Fakturamottak
0508 OSLO

Lev.betingelser	FCA, Terminal - Gardermoen, eks. emballasje.	Dato	08.05.24
Bet.betingelser	30 dager netto	Kundenr	2013
Vår referanse	Roar Grønvold (A1)	Deres referanse	Marte Sjursen
Externt Vernr.	RFQ GELENDER JUST TRAPP		

Nr	Beskrivelse	Antall	Enhet	Nettopris	Beløp
	Justerbart gelender - Gelender justerbar trapp 105765cd7ec24a288f5eed0fe347bd225				
0.0.416.66	Profil 8 120x40 lett	0,24	m	1 005,92	241,42
	Lengde Bredde Enhet Antall Merke *240 0 mm 1 Pos 1*				
0.0.493.36	Profil 8 D40 (HL=6m)	2,16	m	359,10	775,66
	Lengde Bredde Enhet Antall Merke *80 0 mm 2 Pos. 2v* *1 000 0 mm 2 Pos. 3v*				
800	Kapp-/bearb. profiler	0,35	TIMER	900,00	315,00
0.0.489.53	Endelokk 8 D40	2	STK	27,00	54,00
0.0.616.31	Dekklokk Automatikk 8, grå	4	STK	4,20	16,80
0.0.026.07	Mont.sett standard 8	4	SETT	18,00	72,00
0.0.672.84	Automatic-Fastening Set 8 40	2	SETT	121,55	243,10
	Totalt ekskl mva NOK				**1 717,98**

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NTNU
Felles Fakturamottak
0508 OSLO

Lev.betingelser	FCA, Terminal - Gardermoen, eks. emballasje.	Dato	08.05.24
Bet.betingelser	30 dager netto	Kundenr	2013
Vår referanse	Roar Grønvold (A1)	Deres referanse	Marte Sjursen
Externt Vernr.	RFQ RAMME TRAPP		

Nr	Beskrivelse	Antall	Enhet	Nettopris	Beløp
	Ramme stasjonær trapp - Ramme trapp 114aef7bc48f4233ac9a0fb79a3950d59				
0.0.265.80	Profil 8 80x80 lett	20,2	m	939,40	18 975,88
	Lengde Bredde Enhet Antall Merke *710 0 mm 4 Pos. 1* *1 960 0 mm 4 Pos. 2* *2 380 0 mm 4 Pos. 3*				
0.0.416.65	Profil 8 120x80 lett	5,66	m	1 770,30	10 019,90
	Lengde Bredde Enhet Antall Merke *710 0 mm 2 Pos. 4* *2 120 0 mm 2 Pos. 5*				
810	Kappkostnad profiler 40-80	12	STK	43,00	516,00
815	Kappkostnad 80-120mm	4	STK	75,00	300,00
0.0.616.31	Dekklokk Automatikk 8, grå	100	STK	3,60	360,00
0.0.388.08	Mont.sett automatikk 8	8	SETT	59,80	478,40
0.0.672.85	Automatic-Fastening Set 8 80	46	SETT	153,30	7 051,80
	Totalt ekskl mva NOK				**37 701,98**

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Figure 129: Offer from item24 from the Norwegian supplier AluFlex

G Tipping Angle Calculations

G.1 Without Loads

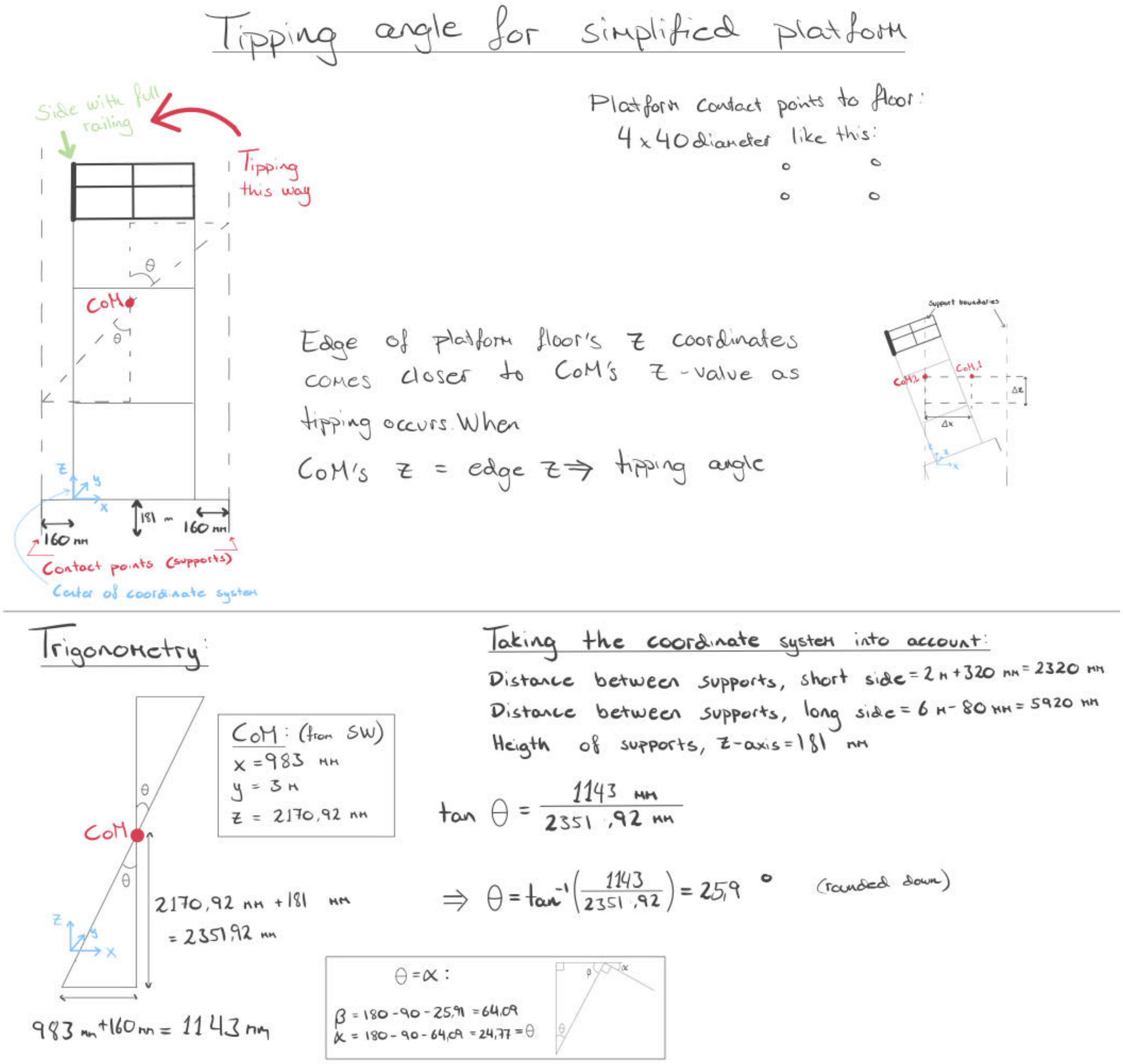


Figure 130: Calculated tipping angle with no loads.

G.2 Recalculated - With Loads

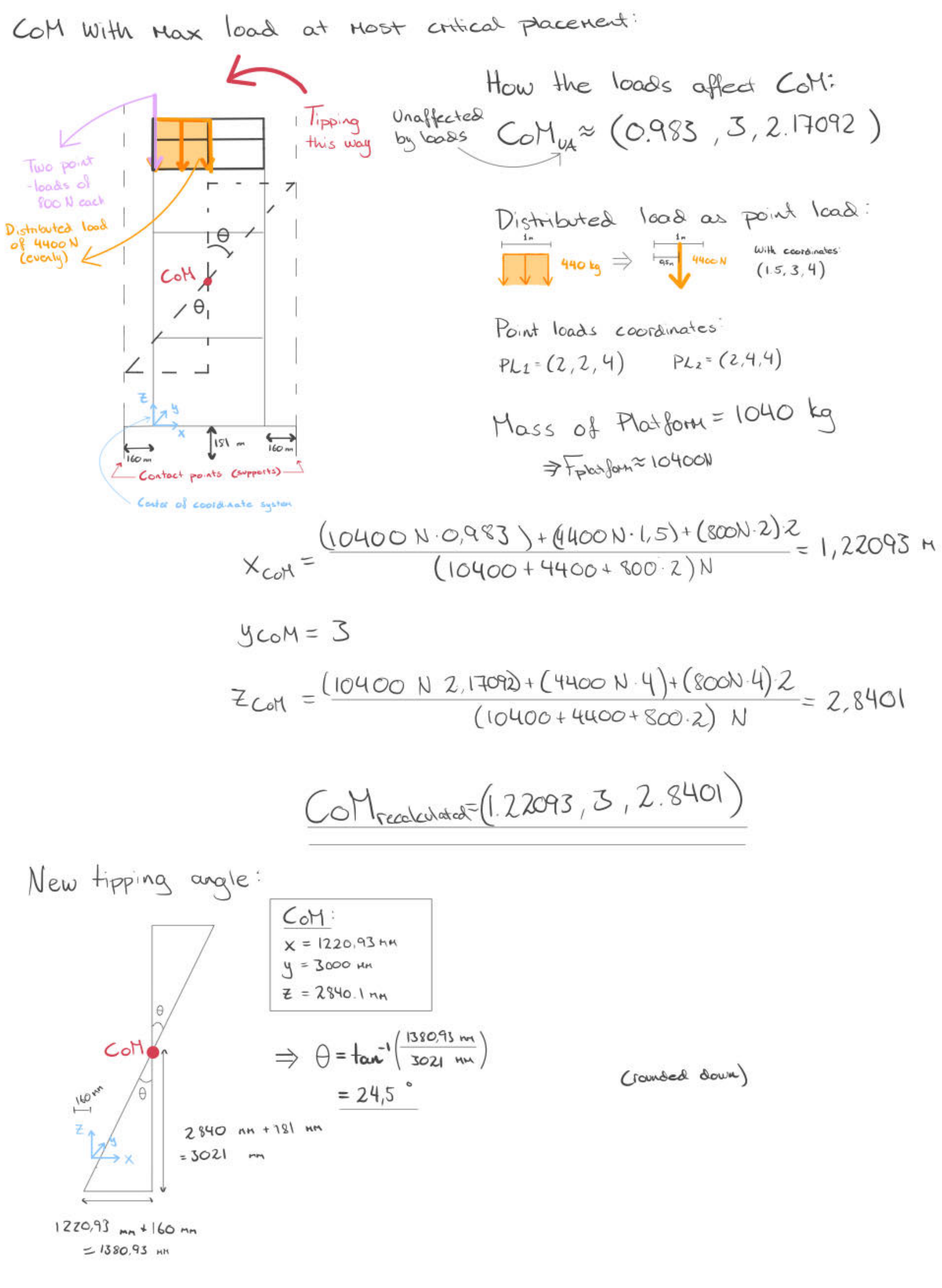


Figure 131: Recalculated tipping angle.

H Stabilizing Moment Calculations

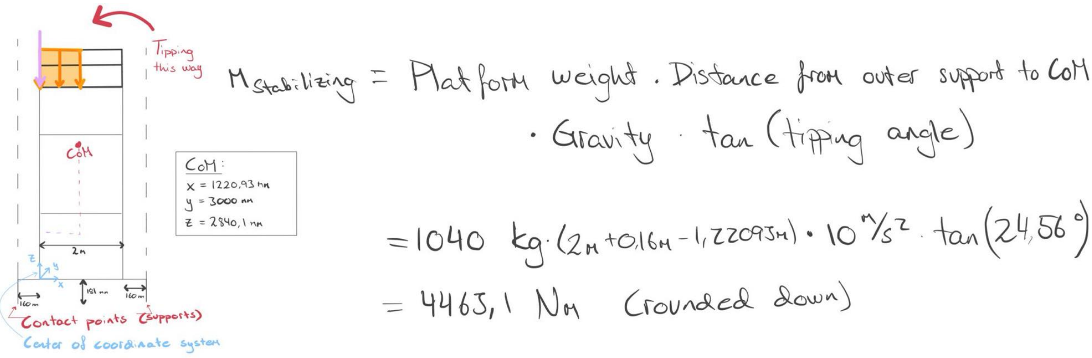


Figure 132: Calculated stabilizing moment.

I Manual Movement Calculations

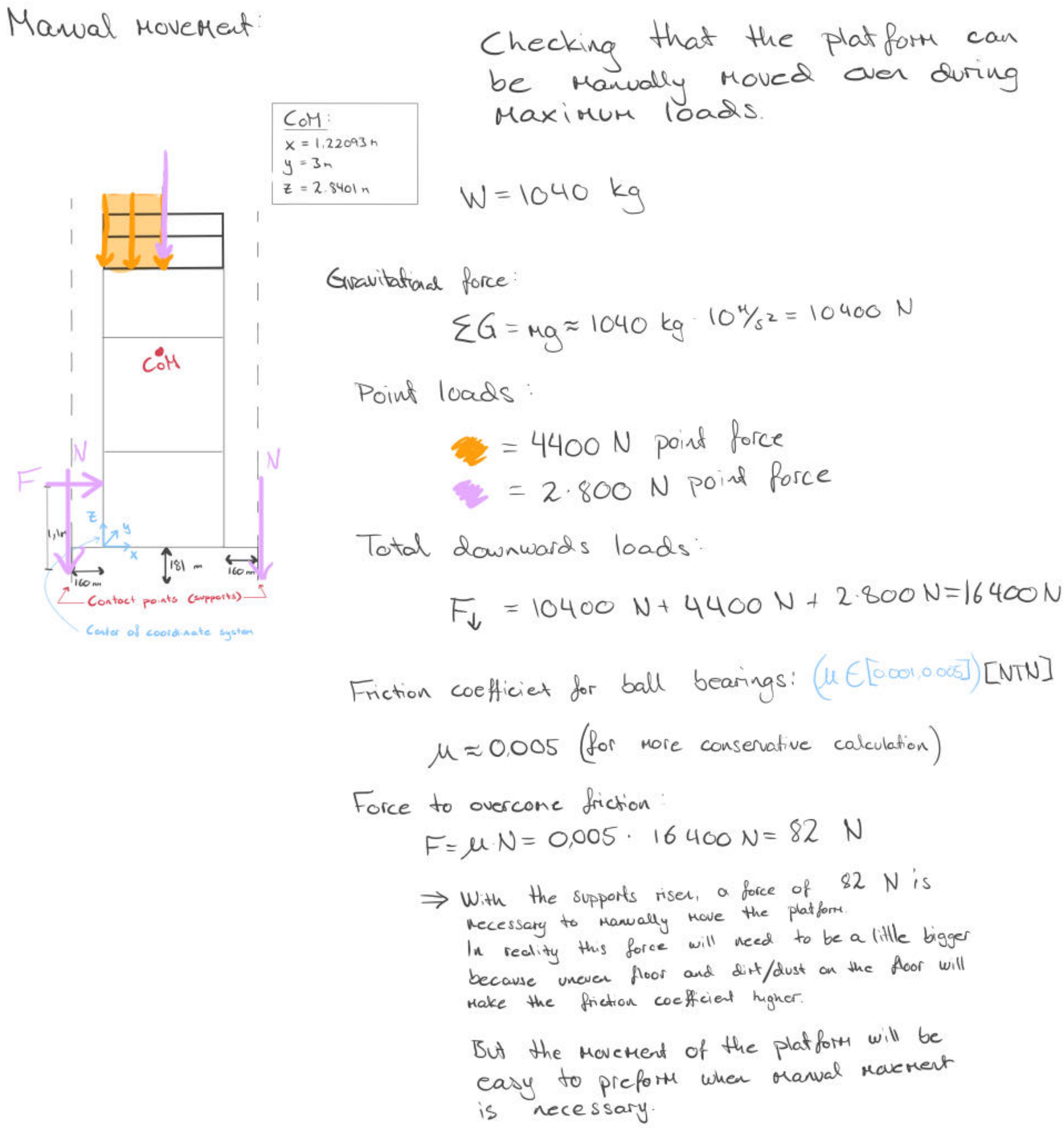
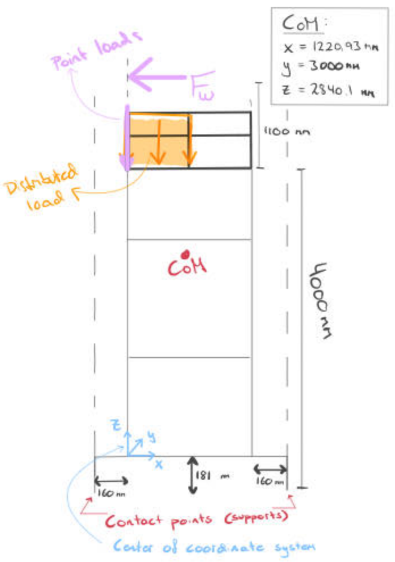


Figure 133: Calculated manual movement.

J Working Force Calculations

Working force, worst case:



Force excerted by workers: (F_w)

$$F_w \geq 400\ N \approx 600\ N$$

$$W = 1040\ kg$$

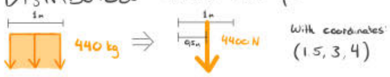
$$M_{stabilizing} = 4463,1\ Nm$$

Moment due to F_w:

$$M_{F_w} = F_w \cdot (4000\ mm - 2840,1\ mm + 1100\ mm)$$

$$= 600\ N \cdot 2.2599\ m = 1355,94\ Nm$$

Distributed load as point load: (DL)



Point loads coordinates: (PL)

$PL_1 = (2, 2, 4)$ $PL_2 = (2, 4, 4)$

$$M_{DL} = 4400N \cdot (1500 - 1220,93)\ mm = 1227,908\ Nm$$

$$M_{PL} = 2 \cdot 800\ N \cdot (2000 - 1220,93)\ mm = 1246,512\ Nm$$

Total moment due to forces:

$$M_{tot} = M_{F_w} + M_{DL} + M_{PL}$$

$$= 1355,94\ Nm + 1227,908\ Nm + 1246,512\ Nm$$

$$= 3830,36\ Nm$$

$$M_{stabilizing} = 4463,1\ Nm$$

$$M_{tot} < M_{stabilizing} \Rightarrow \text{no tipping}$$

$$SF = \frac{4463,1}{3830,36} = 1,165$$

Figure 134: Calculated working force.

K Buckling Calculations

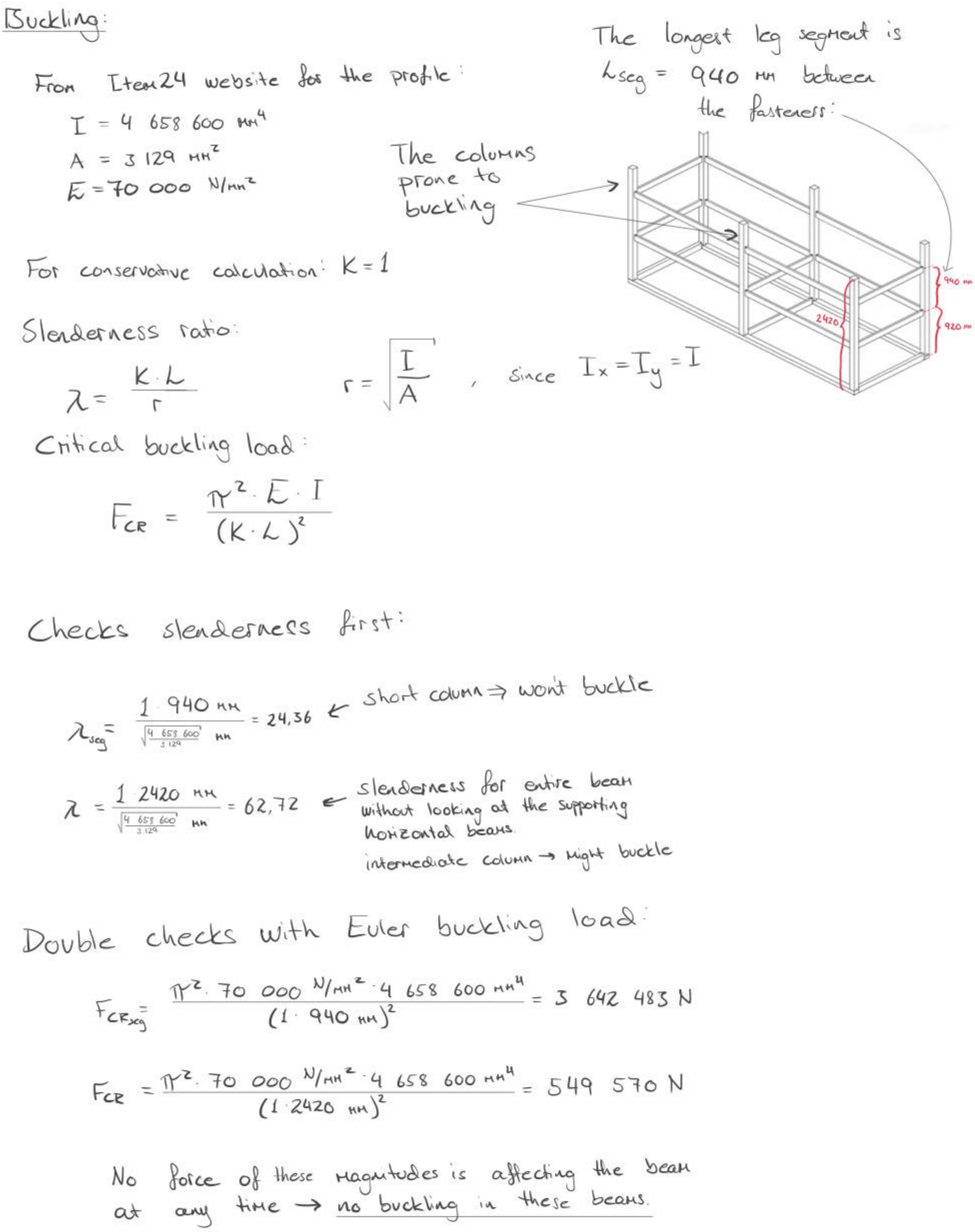
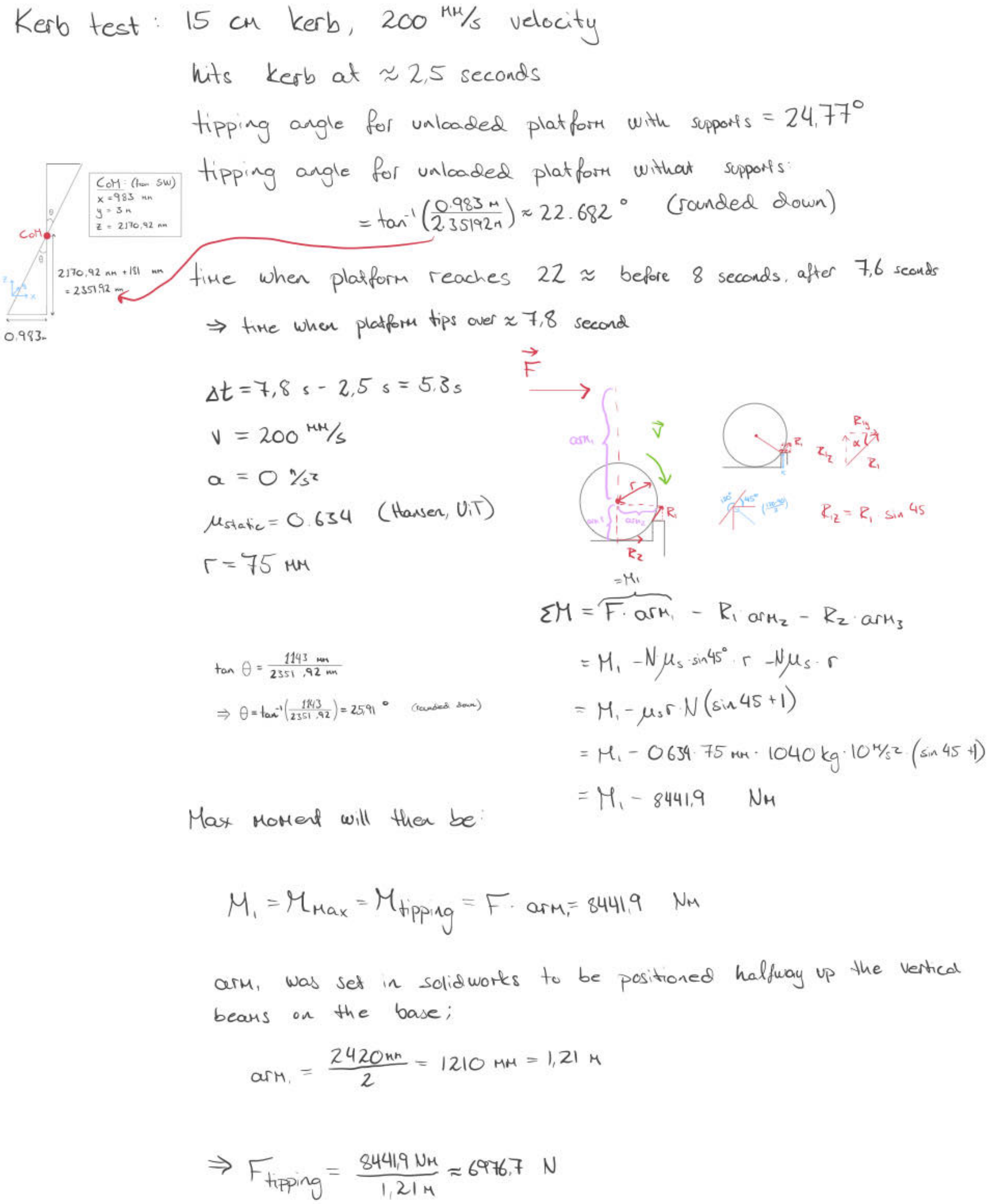


Figure 135: Calculated buckling load and slenderness on platform base.

L Kerb Test Calculations


Kerb test: 15 cm kerb, 200 mm/s velocity

hits kerb at ≈ 2,5 seconds

tipping angle for unloaded platform with supports = 24,77°

tipping angle for unloaded platform without supports:

$= \tan^{-1}\left(\frac{0.983\ m}{2.35192\ m}\right) \approx 22.682°$ (rounded down)

CoM: (from SW)
x = 983 mm
y = 3 m
z = 2170,42 mm

2170,92 mm + 181 mm = 2351,92 mm

0.983 m

time when platform reaches 22 ≈ before 8 seconds, after 7,6 seconds

⇒ time when platform tips over ≈ 7,8 second

$\Delta t = 7{,}8\ s - 2{,}5\ s = 5{,}3\ s$

$v = 200\ mm/s$

$a = 0\ m/s^2$

$\mu_{static} = 0.634$ (Hansen, UiT)

$r = 75\ mm$

$R_{1z} = R_1 \sin 45$

$\Sigma M = \overbrace{F \cdot arm_1}^{=M_1} - R_1\, arm_2 - R_2\, arm_3$

$= M_1 - N\mu_s \sin 45° \cdot r - N\mu_s \cdot r$

$= M_1 - \mu_s r N (\sin 45 + 1)$

$= M_1 - 0.634 \cdot 75\ mm \cdot 1040\ kg \cdot 10\ m/s^2 (\sin 45 + 1)$

$= M_1 - 8441{,}9\ Nm$

$\tan\theta = \frac{1143\ mm}{2351{,}92\ mm}$

$\Rightarrow \theta = \tan^{-1}\left(\frac{1143}{2351{,}92}\right) = 25{,}91°$ (rounded down)

Max moment will then be:

$M_1 = M_{max} = M_{tipping} = F \cdot arm_1 = 8441{,}9\ Nm$

arm_1 was set in solidworks to be positioned halfway up the vertical beams on the base;

$arm_1 = \frac{2420\ mm}{2} = 1210\ mm = 1{,}21\ m$

$\Rightarrow F_{tipping} = \frac{8441{,}9\ Nm}{1{,}21\ m} \approx 6976{,}7\ N$

Figure 136: Calculated force for tipping during 15 cm kerb test.

M Braking Test Calculations

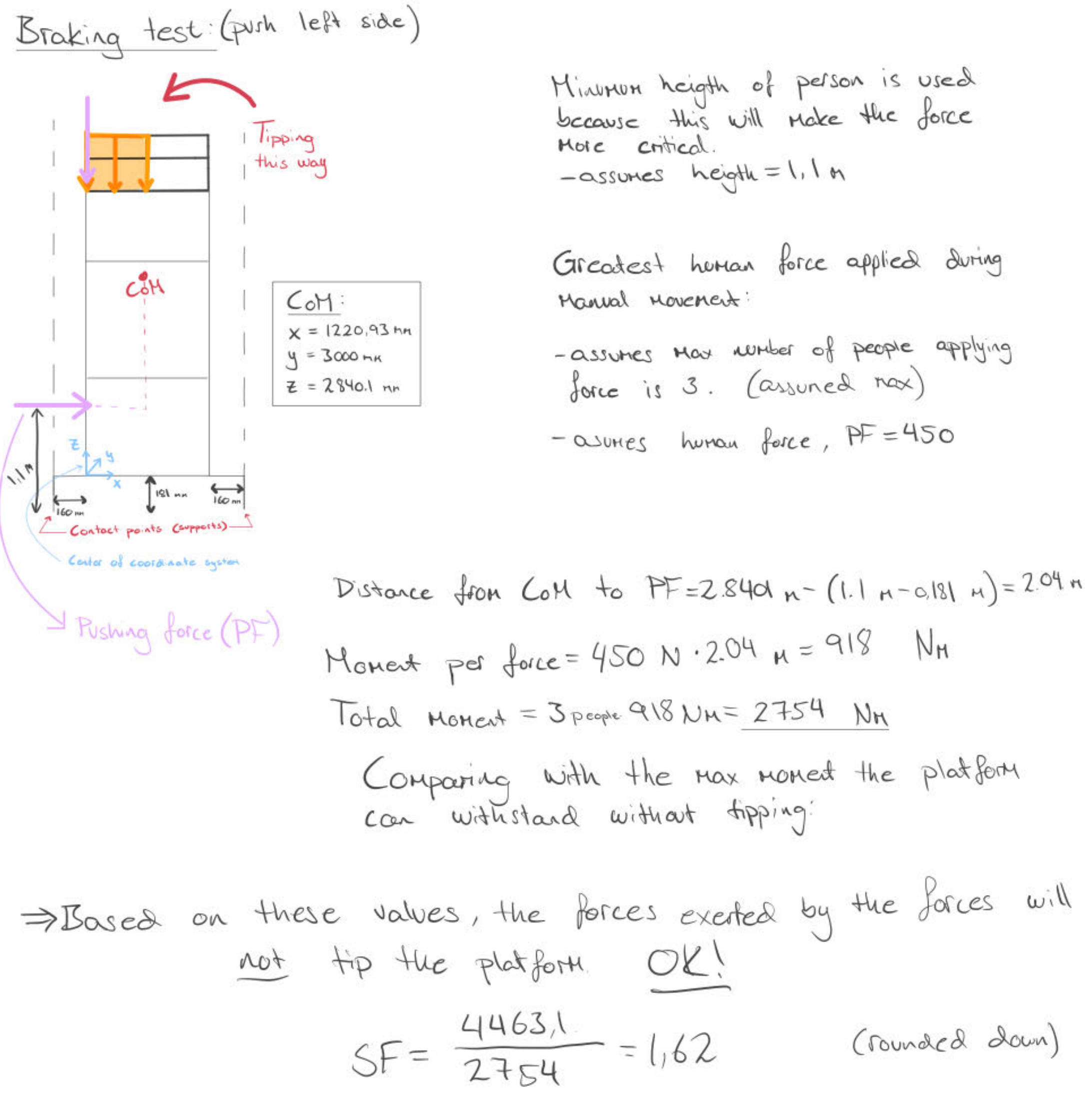


Figure 137: Calculated moment from push/pull forces during braking and pushing the platform.

N Survey

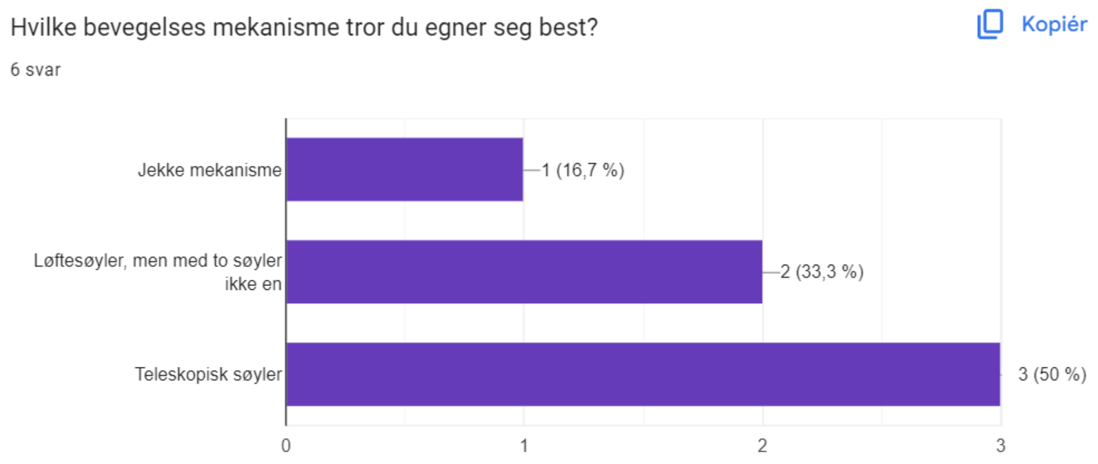


Figure 138: Question one in survey

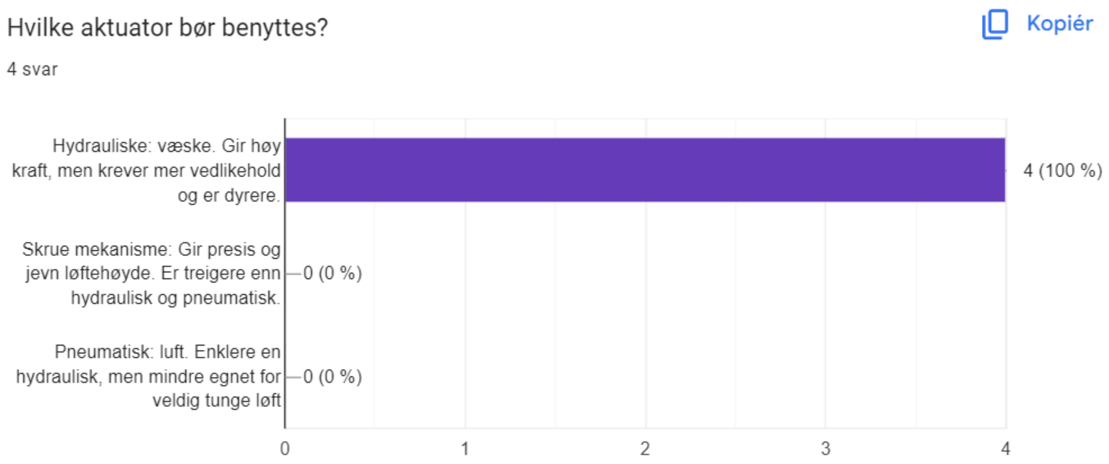


Figure 139: Question two in survey

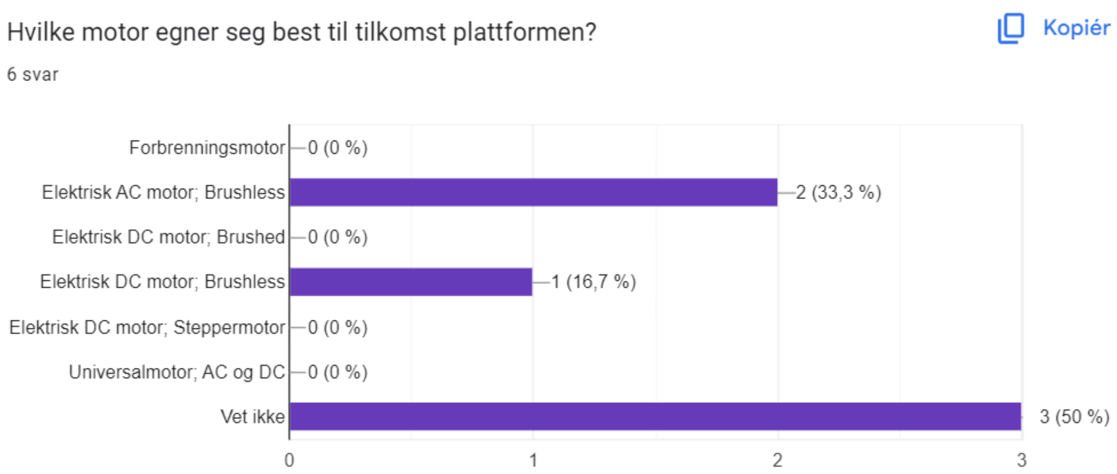


Figure 140: Question three in survey

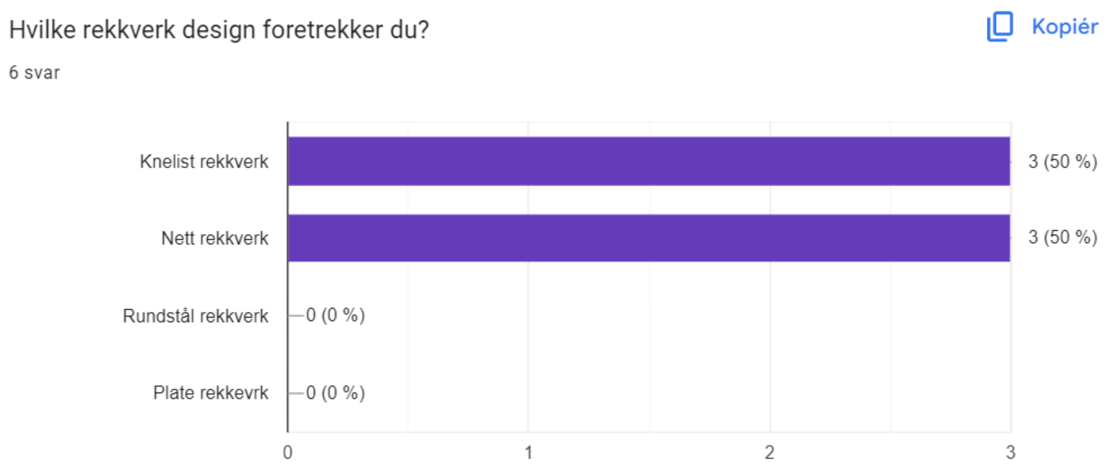


Figure 141: Question four in survey

Holder det med at plattformen kan gå opp til 5 meter, eller vil du ha den høyere? Hvor høy?

6 svar

- 5 meter er nok mer enn nok. Anslår at 3 vil være nok
- 5 meter klarer seg.
- Opptil 7 meter.
- 5 meter skal vel være nok
- vil ha høyere
- 7 meter. Vi trenger å komme oss inn i stubbene, er det en mulighet å heve plattformen over leggen å skyve ut en midlertidig "altan" på tvers over leggen?

Figure 142: Question five in survey

Omtrent hvor mye veier utstyret du skal ha med deg opp på plattformen?

5 svar

- 80 kg?
- 30 kg +.
- 30 kg pr pers
- 30 ++
- 50 kg

Figure 143: Question six in survey

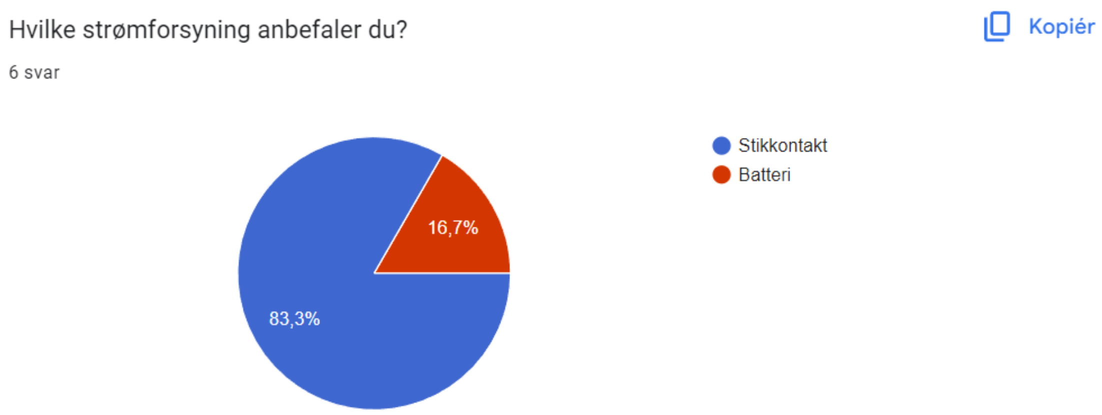


Figure 144: Question seven in survey

Figure 145: Question eight in survey

O Calculations for Top and Bottom Platform

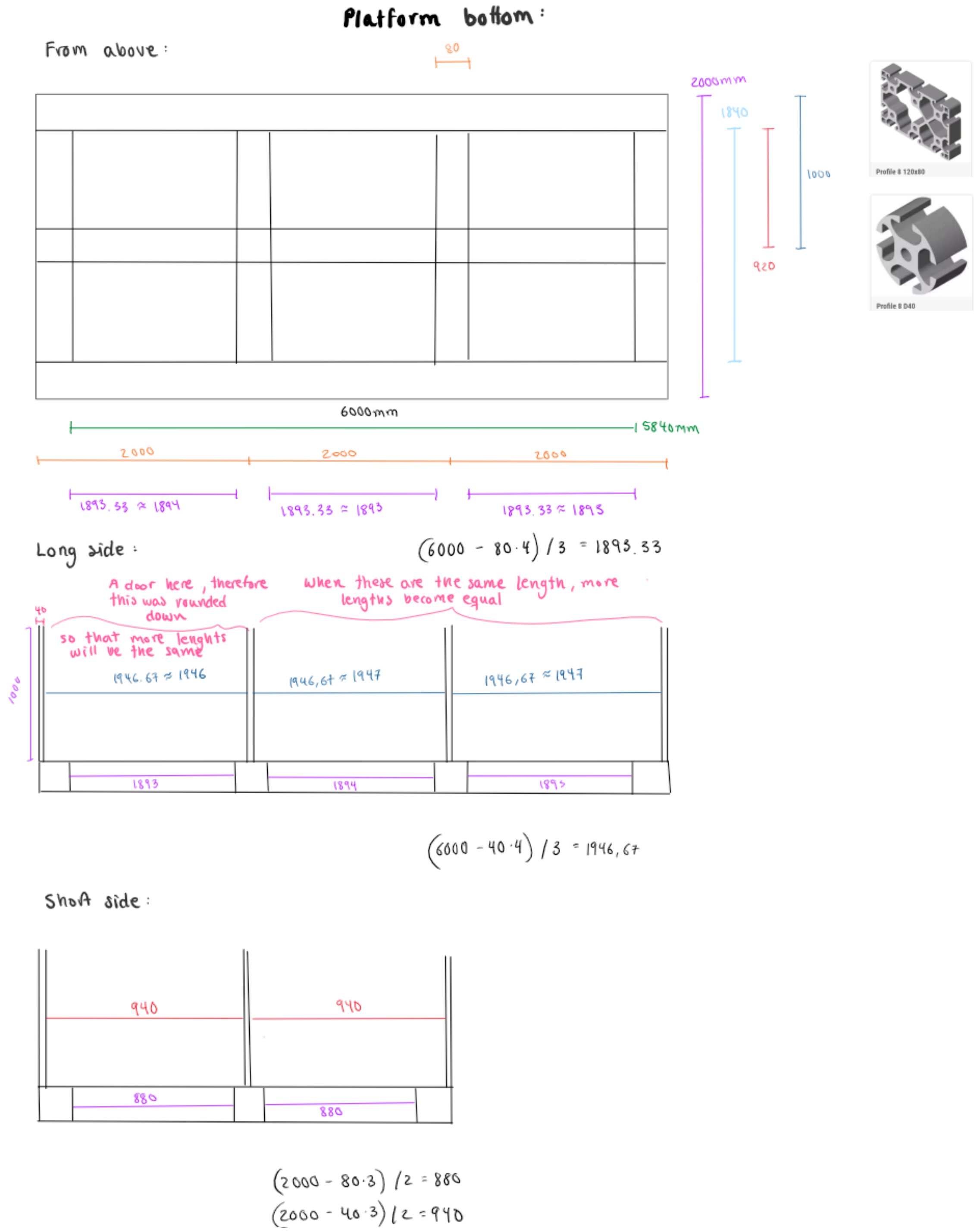


Figure 146: Platform bottom calculations

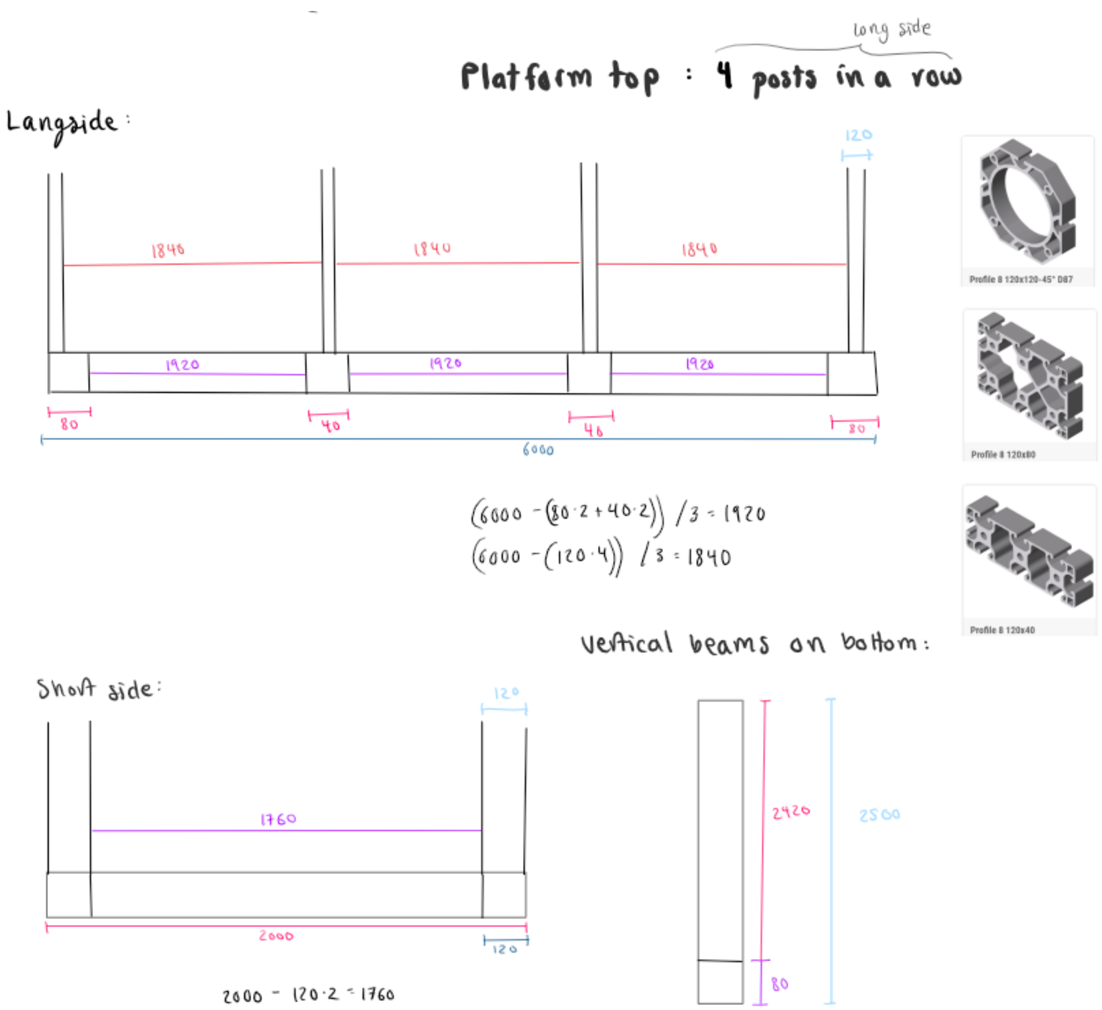


Figure 147: Platform top calculations

List of Tables

List of Figures

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