DESIGN AND MANUFACTURING OF THE LIFTING BEAM FOR THE OVER-HEAD CRANE WITH 5T CAPACITY

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Mechanical Engineering, Master's Thesis

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ABSTRACT

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71 pages, 32 figures, 8 tables and 2 appendices

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Keywords: single-span, double-span, overhead crane, girder, span beam, design process, manufacturing process, FEA, value analysis.

The topic of the current thesis work was the investigation of the optimal combination for the design and manufacturing aspects of the loaded beam of the overhead crane with a maximum capacity of 5T. The main purpose of the beam is to act as a part of the crane and movement of the loads in the specified work area. Due to the presented fact, the current structure has to be optimized based on the own weight and price of the manufacturing.

The design process phases are based on an iterative workflow process. In the product design stages, buckling analysis, fatigue capacity, and stiffness have been observed with the help of the finite element method as well as analytical calculations. Manufacturing aspects were considered with the help of different prices of the raw materials and the manufacturing methods and their utilization. The value analysis table has been utilized for the comparison of the results.

The thesis aimed to provide an optimized solution for the structural member. During the process, elements of the structure were selected based on the requirements and prioritizing of the different options considering the most important aspects.

The result of the work is ready for the manufacturing optimized design of the lifting beam which is ready for the implementation for the selected workshop.

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SYMBOLS AND ABBREVIATIONS

Roman characters

a	throat thickness of the weld	[mm]
b	mid-plane width of the beam	[mm
F_v	combined static load	[N]
f_d	designed yield strength	[N/mm^2]
f_u	ultimate strength of the weakest base material	[mm]
G_{max}	maximum load applied to the crane	[N]
h	mid-plane height of the beam	[mm]
M_{max}	maximum moment without considering safety factors	[Nm]
ΔM_{ekv}	equivalent moment	[Nm]
N_{req}	required number of cycles	[m3/kg]
Q_{DL}	dead load	[N]
Q_{LL}	maximum life load	[N]
t	thickness of the flange	[mm]
t_b	thickness of base material	[mm]
t_w	thickness of the web	[mm]
W_f	minimum section modulus	[mm^3]

Greek characters

β_b	ratio between width and the thickness of the flange.
β_c	ratio between width and the thickness of the flange.
γ_{M0}	material safety factor

γ_{M2}	partial safety factor of material	
γ_f	safety factor	
$\Delta\sigma_{eqv}$	equivalent stress	[N/mm^2]
γ_L	safety factor for the load	
η	ratio between height and thickness of the web	

Abbreviations

AC	Air conditioning
ASD	Allowable stress design
CAD	Computer-aided design
FEA	Finite Element Analysis
FEM	Finite Element Method
HAZ	Heat affected zone.
LRFD	Load and resistance factor design
LSDM	Limit stage design method
SLS	Serviceability limit state
ULS	Ultimate limit state
WPS	Welding specification procedure
WSD	Work stress design

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1 Introduction

Overhead cranes as overall are utilized widely in different spheres of industry, like construction, logistics, and manufacturing. The girder (middle beam) plays an important role in carrying the loads and transfers the forces as well as moments to the supporting construction of the crane. Based on that, the design process and analysis of the manufacturing processes of this structural member is vital for verifying the efficiency, safety, and cost-effectiveness of the overhead crane. The need of the current structural design is coming from the Finnos Oy Company for updating their workshop facility with the new overhead crane.

The design process of beam structures for cranes is a complicated task because of the undetermined loading conditions. Traditional design methods based on the allowable stress design (ASD), or the working stress design (WSD) have restrictions in connected with spectrum of loads and strength of material. Load and resistance factor design (LRFD) is a fresher design method that considers the partially uncertainties and provides more reasonable approach for structural designs, including current phase.

1.1 Scope and limitations

The scope of current thesis project is focused on the integrated design and manufacturing analysis of beam for overhead cranes using LRFD, and the investigation of analytical models for behaviour prediction of girder under different loading conditions and different options for the girder construction.

As it has been mentioned above LRFD, which is a up to date design method. The beam will be considered to meet the necessity of the desired application as well as ensuring safety.

The current research work will not consider the manufacturing and design aspect of the whole overhead crane system, including the support structures, the hoist, and the controls. The focus in this thesis will be on the span beam, which is the main load-bearing component of the subjected setup. The end beams which are connected to the span beam will not be considered in the current research work.

Even though the current design case will be specifically made for determined factory, geographically scope of the research will be global, as the research methods could utilized in different factors and regions.

The time scope of the thesis work will be adjusted to the current state of the art and the resources. The research will be grounded on the literature review and the models and data obtained during the research.

The results of current thesis work will provide valuable insights into the design and manufacturing analysis of beams for overhead cranes different design options based on the different requirements. The findings can be used to improve the safety and performance of overhead cranes and to guide future research in this field. Safety and cost effectiveness aspect could be observed in detail.

1.2 Motivation

The motivation for the selected thesis work is to update the structure of the current girders and make a more pleasant experience for the end users without the different deviations in the production and less costs for the customers. For that sense selected work provides an exact approach with the upgraded design technics with the several aspects considered. It would also be interesting in the thesis to observe the connection and interaction between design and manufacturing aspects for the beam structures as well as getting the best possible outcome with help of value analysis.

1.3 Objectives of the studies

Objectives of the current thesis work is to design the spam beam and consider manufacturing procedure for the overhead crane to achieve the most efficient result. From that follows the need to consider the benefits and drawbacks of the different cross-sectional profiles for the beam structure and their effect on the performance of the beam. As well as consider the effect of the single beam versus double beam structure which is done with the value analysis table. As well as consideration of different production facilities and their effect on the final price.

1.4 Research problems

Due to the fact that design process and manufacturing abilities are gradually improving on the yearly manner it is important to emphasize the fact that some desired design aspects which would be utilized for the maximum efficiency of the structure is limited with the manufacturing processes. As well as take the maximum efficiency of the construction by optimizing weight strength ratio would be interesting in combination with the safety of the beam.

In addition to the fact mentioned above the research problem is how to improve the design and manufacturing methods for girders in overhead cranes and ensuring the allowable deformation will be secured.

1.5 Research questions

Main research question of this thesis is: How to design the optimal shape of the beam for the overhead crane taking? Followed some derived sub questions based on the main one:

- How does the loading affect the optimal steel (material) grade?
- How material grade effects on the manufacturing aspects for the structure?
- What is the designing difference for the double or single beam structure?
- What is the best way to attach hoist or the motor to the girder?
- How to manufacture and make a quality control for the girder beam?

1.6 Research method

As the research methods for the current thesis all the modern tools have been utilized such as Solidworks 2022 for the FEM analysis and for the 3D modelling. Info about the design stages, standards and the background knowledge has been obtained from the LUT library and online sources. Connecting to the place specific data, the interview with the final customer has been conducted and the necessary information has been obtained. It will be discovered later in the specification of current crane section.

Based on the lecture material analytical calculations has been done for the starting points of the design and manufacturing aspects, followed up by them utilizing 3D modelling has been build based on the scratch calculations and then the models have been analysed.

Based on the design models the manufacturing part has been investigated based on the lecture's material and literature review as well. Prices and lead times has been taken from the real supplier located in Finland.

1.7 Timetable of the project

Timetable for the thesis work will be presented in a schedule before. Has to be noted that the thesis writing process has been done at the same time with the full-time work.

The schedule including all the important steps and all the lead times have been included, based on the presented data, and considering the starting time of the thesis, work should be ready around August 2023.

Most time-consuming part of the thesis is combining writing work itself and analysing and building of the CAD and FEA models.

One of the crucial parts to be considered is that all the information which has to be obtained from the possible subcontractors. As far as summertime is popular for the holidays, some schedule modifications have to predicted.

1.8 Literature review

In the following chapter the literature background for the current thesis will be discovered which will be utilized as a background for the all the further research.

1.8.1 Different girder designs

As overhead cranes are widely used in different spheres of industry the variety of different design options as shapes have been developed during the years. They are all different based on the strength-weight ratio as well as ease of manufacturing as well as price for the end product. It has to be noted as well, that specially designed and manufactured profiles are more preferred as the strength in the most critical design spots could be controlled, and the weaknesses of ready profiles are eliminated in this case.

Besides the different cross-sectional shapes of the span beam, there are different construction type as single-span (Figure 2) and double-span beam (Figure 4) construction. Main difference between them is construction way, load distribution specifics and structural consideration. Double-span construction offers an advantage of the smaller bending moments and deflections due to intervened intermediate supports in the structure and leads to the more cost-effective design. From another side, there is a chance of required extra structure elements and introduce some extra issue in the analysis in order to ensure desired load transfer and cover stability issues at the intermediate supports.

Below are presented the several options for the different girder design possibilities:

- Box beam: This presents as a closed square or rectangular cross-section (Figure 1), which is respectively lightweight, and the torsional stiffness of the profile is on the top level (Chen & Cai 2015, p. 10). According to Bredt's Theory rigidness is not an aspect to be considered in this case, this profile is mostly used as the base for the many utilized overhead cranes nowadays in the industry. Furthermore, considering the advantages of the box beam it has to be mentioned that greater lateral direction stiffness will effect positively on the crane movement along the crane track. Same comes to increased torsion rigidity, which is affecting on the better performance on the unexpected forces (such as rapid movement of the crane, along the crane span, acceleration, and deceleration).

Different ways for location of carriage truck will influence on the local stress and stiffness of the structure. Placing the carriage closer to the flanges will result on the bigger section's moment of inertia and as an outcome on the greater bending resistance which will increase safety in terms of static strength.

Figure 1. Example of the Box Beam girder (Yuantai crane 2023).

- I-Beam: One of the most popular structures for the overhead cranes is I-beam. This one could be quite easy for the manufacturing because there is a variety of the different ready-made profiles even though that it is not the best option for the girder construction (Figure 2). Taking into account warping stiffness is typically bigger in case of C-profile, at the same time the length of the beam should be considered also, it has an effect on the St. Vernant's torsional stiffness compared to warping stiffness The difference in current profile is also well known for the high load capacity which is making that one applicable in the heavy-load environment. In addition to that one due to the optimized shape it is easier to make the bolted connections for extension of the length on the profile or configuration the modular design (Gaylord, Stallmeyer, 2011, pp. 191-197). Considering the profiles presented above, the weight of this profile should be considerably smaller, what is considered as the huge benefit in the current application (Grondin and Wang, 2007, pp. 374-383).

Obviously, considering the benefits presented above there are some cons for the current construction. Biggest drawbacks are limited strength capacities of the current design, such as lateral-torsional buckling and twisting handicaps, as well as with the increasing load problem of deflection is appearing to be more critical. To the same outcome leads the shear force capacity lack. (Schmid and Talbert, 1983, pp. 67-73.) In addition to this fact the corrosion protective coating has to be utilized in any case for securing the strength level of the structure even after some time of utilisation of the structure. Visual representation of the beam is presented below. Comparing this design option to the box span beam structure carriage truck in this case could be attached directly to the web, what improve strength and stiffness performance and in theory torsional moment can be neglected due to main vertical loading.

Figure 2. Example of the I beam application in the Overhead crane structure (Alibaba 2023).

- C-channel girder: Is in a way similar construction to the I-beam structure, however due to the geometrical specifics, and considering same cross-sectional properties it has even less torsional stiffness comparing to the I-profile. Example is presented on Figure 3. Due to the same reason, stability issues are moving to the first plane. (Gao, Luo, Huang, 2017, pp. 1-10.) This design solution will require double-girder structure of the beam. In addition to that wrapping has to be considered in C-channel span beam cross-section due to the activated torsional loading. Even though carriage truck will be located on the web in this case, torsional moment will be created still based on the payload is not passing shear center of the cross section. However bending resistance is not changed and stays at same level with the I-beam. In addition to the drawbacks presented above, it needs to be added that the bolted connection for the modular solution is more difficult and therefore this option is not that profitable at least in the comparison with the I-Beam structure.

Figure 3. C-channel beam example for the crane (Ace industries 2023).

- Trapezoidal shape of the beam girder: This type of beam, presented on the figure 4 is usually lighter for the end product as well cross-sectional properties are much better and the forces it can withstand is a bit more. (Alzoubi, & Alkhaddar 2013, pp. 1-10.) This refers to the different concept that has been discussed earlier and considers different option for the longitudinal cross-section of the beam These factors are affecting on the overall costs of the construction. In addition to the facts presented below the flexibility of the design is playing a huge role, due to the different angles which could be utilized (Soares, 2007, p.27-31). Comparing with the box beam profile the joint process of connecting span beam to the end beams due to the smaller local height of the main girder will be easier. In addition to this distribution of the bending moment along the span beam as an outcome the overall structure could be light as well, due to the lighter ends.

  In addition to the presented benefits there are some drawbacks as well. Difficult fabrication process could be specified as one of those (Zhang & Su, 2019, p.21). However, stiffness properties are significantly better, shear strength of the observed structure is limited and therefore a bit tricky to be utilized in some applications. (Soares, 2007, p.27-31).

Figure 4. Example of Trapezoidal beam shape (Indiamart 2023).

1.8.2 Previous studies on the current topic

There has been plenty of different research done on the topic of the overhead cranes. Concerning the moving parts bearings, guiding rails, automation etc. One of those topics are girders themselves as well.

As prime example could be study of Cui and He (2015), which has been published in the Journal of Marine Science and Application. There has been considered different loading cases and derived calculations of deflection, shear forces and bending moment of the beam. In the mentioned work limit state design method (LSDM) has been utilized. In addition to the static loads fatigue strength of the structure has been investigated when the repeated load has been applied to the structure. LSDM has been utilized here has been opened from new perspective as a reliable tool for ensuring safety and reliability of the structure. As an end result it could be concluded that this is one of the very interesting and base work for the current application. (Cui, He 2015, p.6-8.)

Another interesting work for investigation is Wu and Lin study on the overhead crane girders. In this work FEM was widely utilized for figuring out effect of the different customer specific parameters such as cross-sectional area, material properties, etc on the deflection of the beam and stress. Based on the results these factors are very crucial and has to be considered thoughtfully for achieving the optimal solution in the observed design goal as well as their adjustment might be helpful for reducing the financial costs and achieving the required performance level. (Wu & Lin 2013, p.430.)

Going into deeper into the topic of the utilization of the FEM analysis the work of Coskun & İmrak & Kocabas about the Solid Modelling and FEA of the overhead crane bridge is seems to be very perspective. In the current work double girder model has been selected and case specific values for the 35 tons load capacity and 13 m span length. For the comparison purposes solid and surface elements were utilized and 4-node tetrahedral and 4-node quadratic elements have been observed and based on the results quadratic shell is more preferable for utilisation and providing more accurate results. (Coskun & İmrak, Kocabas 2004, p. 2-4.) Based on the information presented in the study above, current work has been utilized the results observed.

However, after figuring out the issue with the possible failure models in the bridges of the overhead cranes, failure probabilities have to be considered. This aspect has been discussed widely in the work of the Trinh Van Hai, Nguyen Huu Thu, Ha Dang Tuan, and Pham Van Hiu about the analysis of the different failure probabilities of the bridge girders under design parameters. By design parameters are concerned the material properties, loads and geometric tolerances, using some substitutions for those may lead to the low reliability of the setup. On the figure 5 the schematic representation of the beam is presented. As the outcome it has been stated that the geometrical tolerances appeared during the manufacturing state are affecting on the reliability of the setup and therefore have to be considered strictly. What is important for the current work that the rectangular profile has been observed for the current work. (Trinh, Nguyen, Ha, and Pham, 2020, p. 125–135.)

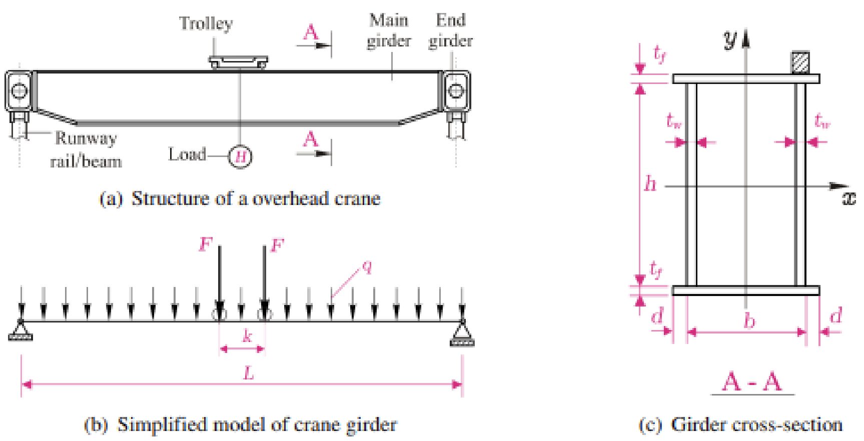

Figure 5. Crane configuration and schematic representation of the girder (Trinh Van Haia, Nguyen Huu Thua, Ha Dang Tuana, Pham Van Hiua 2020).

1.8.3 Different materials options

There are several different material options are utilized in girder construction. One of the key factors is the current application are the weight and the span length. Based on those factors the load carrying capacity which is required from the structure. Therefore, are available:

Structural steel is still one of the most utilised in current sphere due to the high durability performance. In addition, it is this option is widely available in world market. However, it still comes to the question what the most suitable steel grade for utilisation is. It is mostly connected to the price-strength relation, especially based on the yield strength of the material the load carrying capacity might vary, in other words saying weight of the beam structure could be saved and optimised.

Considering the influence of structure loading on the optimal grade selection, following can be concluded that the statically loaded structure can utilize the high steel grade directly. If the fatigue is the critical failure mode, the utilizing the high strength steels recall very high quality in terms of design and fabrication.

On the figure 6 presented graph of the price range difference based on the steel grade provided by the manufacturer.

Material / price €/tn

thickness	SSAB Domex 355MC D	SSAB Domex 420MC D	STRENX 650 MC D	STRENX 700 MC PLUS	STRENX 900 MC	STRENX 960 MC	STRENX 1100 MC
5mm	1300	1350	1500	1950	2300	2400	2550
ero 355MC		50	200	650	1000	1100	1250

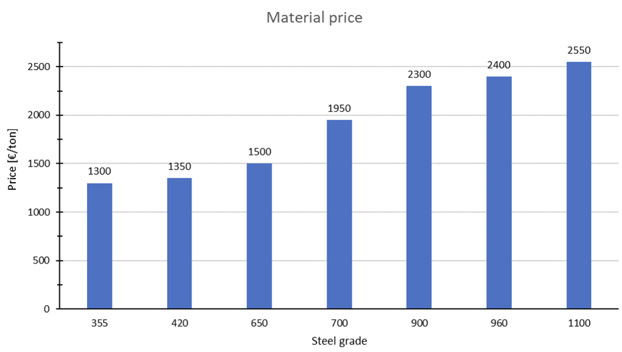

Figure 6. Material pricing (Tibnor, Heikki Kallioniemi 2022).

In the case of the structural steel thin plates the price could be calculated according to the volume. As it can be seen that there are two different price ranges (1300-1500 euro/ton) for the grades S355, S420 and S650. And the second price range is from (1950 – 2550 euro/ton) for the grades S700, S900, S960 and S1100. At the current stage of thesis work, the guess for the optimal price-strength ration would be grade S650 and onwards, due to the excessive weight of the girder with the less strong steel grades utilization.

Nevertheless, during the comparison process of the S355 and S700 it has to be noted, that the different between those grades is not only concluded in the price- stress relation, but also the manufacturing aspect is important to be mentioned. For the S355 there is no requirement for some special accuracy in the manufacturing methods, however for the S700 some special metal treatment processes are required as well as techniques in the welding processes.

In the final decision of the material selection process for the current application all the customer specific parameters such as, intensity of use, overall load capacity, span length and the environment conditions are taken in the consideration.

For the example there are some different options for girders such as aluminium and wood, but they are utilized in less demanding applications and with the load which is around 500 kg.

However, the final decision with calculations will be provided later in the methods and result sections of the thesis.

2 Methods

In the following chapter are explained methods utilized in design and manufacturing which are utilized in the current work.

2.1 Design methods

Topics connected to the design methods are covered in the chapter 2.1, in particularly design criteria of the crane, specification provided by the customer as well as standards for obtaining the reliable data.

2.1.1 Utilized standards.

For covering the scope of the current thesis work author has been using following standards presented on the table 1.

Table 1. Utilized standards in thesis work.

SFS-EN 1993-6	Eurocode 3. Design of steel structures. Part 6: Crane supporting structures.
SFS-EN 1993-1-3	Eurocode 3. Design of steel structures. Part 1-3: General rules. Supplementary rules for cold-formed members and sheeting
SFS-ISO 12482:2017	Cranes — Monitoring for crane design working period.
ISO 9001	System of the quality management

Due to the topic of the current work the most utilized standard would be the SFS-EN 1993-6 as the basis for the crane structure. Standard takes care of the special safety factors as well as the design approaches for the girders as far as the specific aspects of the cranes design procedure. It must be added that besides the design procedure is tis also supplies guidance for the design principles, material selection procedure, stability requirements and the fatigue design. Compliance with the current standard ensures reliability during the whole lifespan of the crane. As a supplementary standard the SFS-EN 1993-1-3 has been considered for the sheet metal design aspects which are not covered in the main standard of the scoped work. This standard mostly covers the fatigue design aspects and gives guidance on the influence of the varied factors on the fatigue performance of the structure. Considering the quality of the manufacturing the standard ISO 9001 is taking care of the case for confirming the best possible experience for the end user and acting as a quality management system. In addition to the stuff which has been mentioned above 9001 is needed to make sure that the product meets customer requirements and the ramping up of production with no harm to the quality of the product.

2.1.2 Specification of the crane

For the obtaining relevant information there have been held meetings with the customer and a set of questions has been asked in a way of the semiconductive interview to get the maximum necessary information and simplify the design process. Below are the presented results of the interview.

It has been figured out that the required load carrying capacity for the crane is 50 kN and the periphery structure is prepared for the desired load. It is considered as the medium-duty crane category. As well as span length has been specified as 15 m long and it is considered as a medium span crane. Different loading cases may not be considered as the crane is going to be installed inside the building what makes the design work easier in that perspective. The load carriage type would be hoist which is attached to the bottom flange, what make the design process a bit more straightforward with less iteration process. Operation time for the crane has been specified as 5 days week and 10 hours per day and supposed to be utilized daily. Seismic loads should not be considered as Thailand is in the moderate seismic active area. Temperature load also stays out of the scope as the workshop is equipped with the air conditioning unit (AC).

As can be figured out based on the provided replies to the environmental aspects could not be considered in this case, as wind and rain, and sun are no longer affecting the construction. As well as now there are specific requirements for the load capacity and span length it is easier to proceed forward with the methods. Below are presented some drawings and pictures of the 3D model of the probable location of the crane. On the figures 7 and 8 is presented visual representation of the workshop where the beam will be installed.

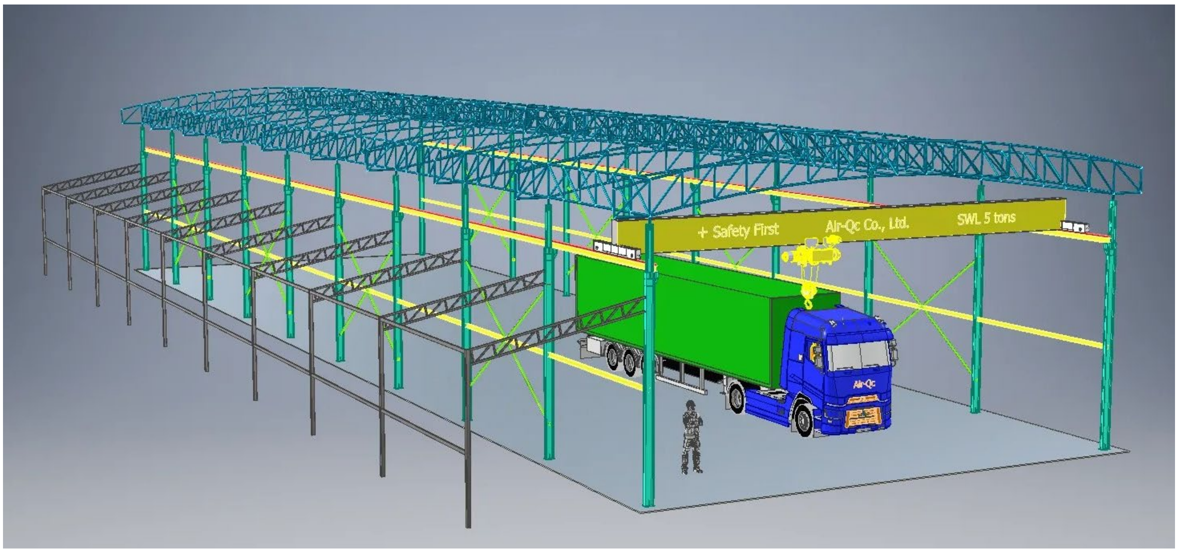

Figure 7. 3D Model of the location where the crane is supposed to be installed (Air QC).

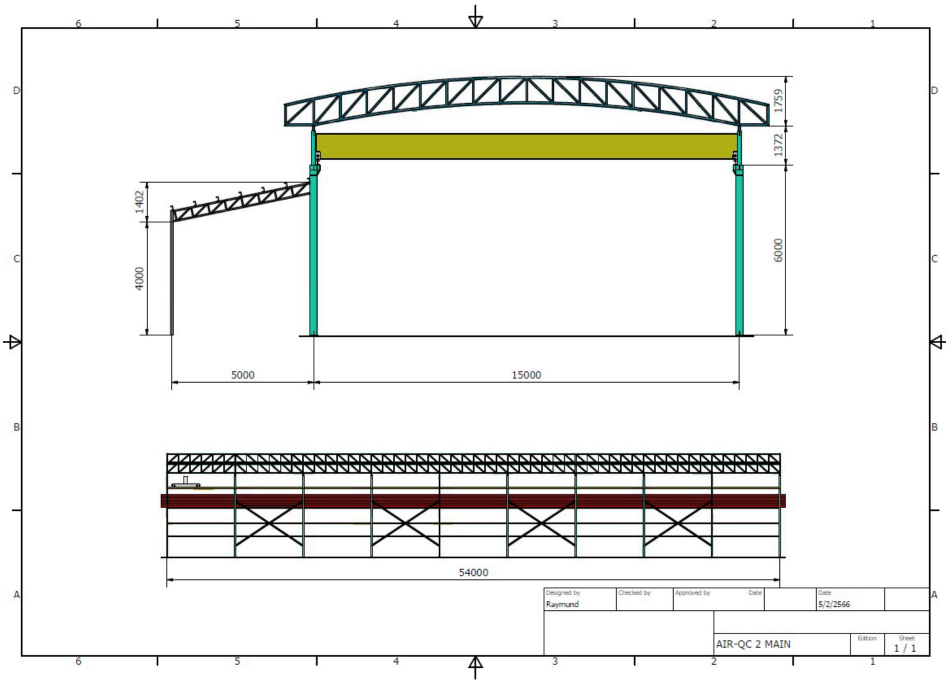

Figure 8. Schematic drawing of the crane (Air QC).

2.1.3 Design criteria of the beam

As has been mentioned before already, safety and structural aspects are important for the crane structure and therefore the design criteria are particularly important to be considered. Below are presented some common functional units for this case.

The beam is supposed to be designed in a way to secure the load lifting without any failure modes. Custom values such as span length and load carrying capacity are main design criteria. Next point for consideration would be stiffness phenomena. This is required for the deflection control within allowable limits as well as precise operation of the crane itself and reducing of the different kind of impact loads. It reflects at the same time the stability issues of the beam. Based on the different possible cross-section profiles the stability issue might be considered or not for our design case. This phenomenon refers to slenderness, lateral buckling, and effective length.

Considering the dynamic loads fatigue phenomenon is important to be considered. An important value to observe for this case are the number of cycles, stress ranges, specific material properties related to fatigue. Calculations are done based on the Eurocode 3.

In manufacturing there are some interfering steps in the integrated design process such as weldment and connection calculations. Desired factors are important for the structure of the beam, and they are supposed to be designed in a way to transmit the load from the beam to the support structures in a most desired way (Wang, 2019, p.13).

For some of these design criteria are summarized as follows:

- Ultimate limit state (ULS)
  - Ultimate load carrying (moment) capacity.
  - Stability
    - Local buckling
    - Lateral-torsional buckling
    - Flexural failure
    - Shear failure

        - Buckling
    - Fatigue
- Serviceability limit state (SLS)
    - Deflection (More conservative approach for the ensuring the safety aspects)

$$d_{max}=\frac{L}{1000} \tag{1}$$

    - Vibration

2.1.4 Consideration of the loads

During the design process of the crane girder different loads must be considered to ensure safe operation of the crane. Referring to the Eurocode 3 there are following type of loads to be considered:

- Dead load which is basically referring to the weight of the beam itself as well as considering the periphery equipment
- Live load considers all the different spectrum of load which is affecting the structure during its operation. It is always varying based on the current lifting weight and the type of the crane itself.

  To this can be added all the static load as well for the structure and can be represented as follows.

$$F_v=\gamma_L\varphi(Q_{LL})+(Q_{DL}) \tag{2}$$

where φ is dynamic coefficient, γ_L is safety factor for load, Q_{LL} is maxim live load and Q_{DL} is dead load which is equal to thickness of cross section multiplied by maximum life load.

- Impact load is the one which takes place during the high acceleration of the crane like starting and stopping of the crane. In the same section the fatigue load which is transferred to the beam from motor etc.

$$F_v = \varphi(Q_{LL}) + (Q_{DL}) \tag{3}$$

Other loads which will not be considered in this case, due to the case specific aspects:

- Wind load is irrelevant in this case due to the crane being installed inside the building.
- Temperature effects as well will not be considered the reason AC being installed in the workshop, so the temperature changes are minimal.
- Seismic load is more connected to the structure of the crane and not the beam directly, however according to the sources Thailand occurs to be in the low-moderate area, so should not be considered in this case. (Nakhorn, Pennung, Teraphan, Sutat, Phaiboon, Amorn, Chatpan, Panitan, 2018.)

2.1.5 Material selection procedure

The material selection procedure for the current work has been based on the load capacity of the crane. According to the information provided by the customer, the maximum load is 50 kN and the use of the device is set as 10 years. Since in a normal year there are 242 working days, the number of daily cycles is 96. According to S-N curves The FAT value can be determined as a stress range corresponding to fatigue life of 2 x 10^6 cycles and in current case is 80 MPa and slope parameter is set as 3, according to Eurocode 3 for the number of cycles less than 5 x 10^6. The safety factor is set as 3 as well because the crane is equipment that is used to deal with the people around and safety is one of the most important aspects which must be considered (SFS-EN 1993-6). The method which has been utilized for this calculation is based on the maximum moment created by the load.

$$M_{max}=i_{lift}G_{max}0,25L, \quad (4)$$

where M_{max} is the maximum moment without considering safety factors, i_{lift} is dynamic factor and G_{max} represents the maximum load which is applied to the crane.
Based on the FAT class and the required number of cycles, the equivalent stress (MPa). The equation is presented below.

$$\Delta\sigma_{eqv}=\sqrt[3]{\frac{2\cdot 10^6}{N_{req}}}\frac{FAT}{\gamma_f} \quad (5)$$

where $\Delta\sigma_{eqv}$ is equivalent stress, N_{req} is required number of cycles,γ_f is safety factor.

Based on the presented values above, the minimum allowable yield strength can be calculated for our profile. Numerical values will be presented in the Result section of the thesis.

$$f_y=\frac{M_{max}\gamma_L\gamma_{M0}\Delta\sigma_{ekv}}{\Delta M_{ekv}} \quad (6)$$

Where $M_{max}$is the maximum moment without considering safety factors, γ_{M0} is the material partial safety factor, $\Delta\sigma_{ekv}$ is equivalent stress and $\Delta M_{ekv}$is the equivalent moment.
It should be noticed that this is the minimum required yield strength, but materials with higher yield strength can be utilized if the FAT class for the cylinder bracket joint is increased, or the joint is located closer to the neutral axis of the boom, lowering the stresses in the joint.

2.1.6 Requirements for the section modulus

As far as the structure is utilized inside of the workshop, it must be safe to use, where all the deflections cannot affect the strength of the structure and cause some grounds for the further failure modes.

Minimum requirement for section modulus can be obtained through static or fatigue analysis. Fatigue analysis will set a lower limit if the selected material has a greater yield strength than the minimum yield strength. Minimum section modulus for the structure is calculated through fatigue analysis as described in the equation below:

$$W_f = \frac{\Delta M_{ekv}}{\Delta \sigma_{ekv}} \tag{7}$$

On the equation above ΔM_{ekv} represents the equivalent moment on the structure and the $\Delta\sigma_{ekv}$ represents the equivalent stress affecting on the structure.

2.1.7 Selection of the cross-section dimensions

Dimensions were set so that the entire structure will fall in cross section class 3 as described in Eurocode 3 part 1. For simpler designs, the optimal dimensions are solved analytically. For more complex designs the dimensions are obtained using Solver. The solver is set to minimize the area of the cross section, while satisfying the following constraints for the dimensions:

- Height to width ratio must follow cross section class 3 for all plates.
- Sheet thickness must be a minimum of 3 mm for manufacturing reasons.
- Section modulus must meet the minimum requirement.

Below are presented some equations for obtaining initial values for the geometrical values as an example for the box beam structure.

$$h = \sqrt[3]{\frac{3M}{4f_d}\eta} \tag{8}$$

where h is mid-plane height of the beam, M is moment, which is influencing on the structure, f_d is designed yield strength and η is ratio between height and thickness of the web. (η is equal to 74,9)

The thickness of the web is calculated as follows in equation 8. It can be noted that the minimum value obtained must be rounded to obtain standard thickness value for the sheet metals.

$$t_w \geq \frac{h}{\eta} \tag{9}$$

The equation for the width of the beam represents below:

$$b = \sqrt{(\beta_b + 2\beta_c)(\frac{M}{f_d h} - \frac{t_w h}{3})} \tag{10}$$

where b is mid-plane width of the beam, β_b and β_b are ratios between width and the thickness of the flange.

Based on that minimum requirement for the thickness of flange (eq.10) could be obtained

$$t \geq \frac{b}{(\beta_b + 2\beta_c)} \tag{11}$$

The values obtained from the solver are rounded to closest numerical solutions.

2.1.8 Finite Element Analysis

FEA stands for Finite Element Analysis. It represents numerical method which is utilized for the solving complicated engineering tasks by dividing the problem into smaller sections, called elements. The Finite Element Method is utilized in different engineering spheres, especially in conducting structural analysis. The outcome of this method is an approach to solve tasks that are hard or impossible to obtain by analytical calculations. (J.N. Reddy, 2005).

The software which has been utilized for currently work for conducting the FEA for the final design for the current work has been Simcenter FEMAP. It is considered a progressive tool of pre- and post-processing for editing models and is especially good for complex products (Siemens FEMAP).

Geometry has been created in Solidworks CAD software and then imported into the FEMAP for the analysing.

Solidworks is a world-wide known software for fast creation, validation, and transformation of sketches and ideas into the design of parts and assembly (Solidworks).

2.2 Manufacturing methods

Moving forward from the Design aspects, which have been already described, the next aspect for consideration is the manufacturing procedure.

2.2.1 Description of the manufacturing processes

On the same level of importance as design aspects are located manufacturing aspects as well. This is based on the matter that in some cases design solutions that are provided could not be manufactured or manufactured that easily and the effort would be worth it. In some cases, it refers to the expenses of the manufacturing methods. Essential manufacturing processes would be cutting, either thermal cutting or mechanical cutting processes, as well as welding. Some optional methods could be utilized as well specifically such as bending and beveling.

Inside of those methods are also many different options and they are mostly connected to the number of parts which are subject to be manufactured.

In the case of the different difficult manufacturing shapes, machining could be utilized as well. It includes processes such as drilling, grinding, milling. This method could be quite difficult and expensive for utilization therefore some simple holes and slots are preferred to be manufactured by laser cutting for example.

After assembly of the beam, the beam is supposed to have treated surface. It requires blasting and painting of the manufactured surfaces to ensure corrosion protection performance and provide an improved aesthetics view.

However, if we have a look at the case specific values such as span length of the beam, it could be highlighted that the specific machinery must be utilized for cutting. Since from a design point of view it is important to avoid various kinds of welds in the transverse direction. And it makes perfect sense to outsource the production of the pieces to some subcontractor.

Below on figure 9 is presented an example of a suitable laser cutting device for the current beam. This device can cut pieces up to 20 meters long and the cutting table is around 30 meters long. (Trumpf.)

Figure 9. Example of the laser cutting device (Trumpf, 2023).

2.2.2 Value analysis

Considering the methods utilized in the ensuring the validity of the manufacturing aspects results following have been considered. For the ensuring of selecting the optimal cross-section based on the different factors value analysis table has been utilized. It is a universal tool for justification of the correct selection of the option out of the full variety of those. Example is presented below on the figure 10.

		Option	
Criteria	Weight factor	1	2
Weight (kg)			
Ease of design (estimate, 0=simple, 10=very difficult)			
Number of parts			
lenght (meters) of welds			
number of bends			
Misc. Fabrication related items (0=easy, 10=difficult) (seam preparation, large machinery, difficult work steps etc.)			
Total cost			
Finishing			
Transportation			
	Score	0.000	0

Figure 10. Example of the value analysis table

2.2.3 Static strength capacity of the welds

Welding is known as the most common joining method for structures. Most of current span beams are manufactured with welding if those are not made of rolled profiles.

The design requirement of full penetration fillet weld is connected to the weaker of the parts which are connected. In addition to that correct consumables must be selected to achieve the strength of the weld equal to the strength of the parent material. (Eurocode 3)

The throat thickness of the fillet weld could be calculated with the following formula:

$$a = \frac{\beta_w \gamma_{M2} t_b}{2 f_u} \sqrt{2\sigma_x^2 + 3\tau_{xy}^2} \qquad (12)$$

where a is throat thickness of the weld,β_w is correlation factor, γ_{M2} is partial safety factor for joints: welds, t_b is thickness of base material, f_u is ultimate strength of weakest base material.

2.2.4 Manufacturing chart

It is also well known as a production flowchart and is a visual representation of all the steps which are included in the manufacturing process. It represents the transformation of the raw material to the product.

The manufacturing chart usually includes different shapes and symbols to depict various process tasks, operations, inspections, transportation, and requirements. Arrows connect these symbols to provide. Some extra info might be added to the steps, but at the same time the balance must be kept in order to keep the document still readable and clear for understanding.

The goal of a production chart is to give a systematic overview of the production process of the specific product, helping to figure out potential bottlenecks and try to find out some more efficient way of the process if it is possible to be implemented (Schey,1999).

Figure 11 represents an example of the manufacturing chart, what could be utilized as a template for the current work.

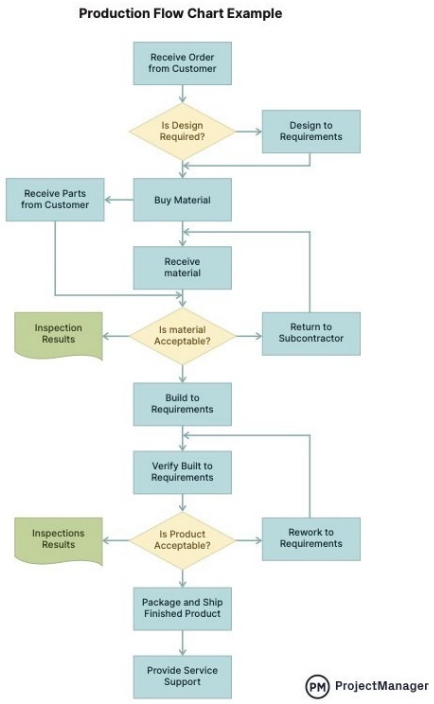

Figure 11. Example of the manufacturing chart (ProjectManager, 2023).

2.2.5 Prices estimation for the manufacturing

Considering the price estimation, it is important to take all the manufacturing costs into consideration as well as make a comparison between the in-house production and making an order from the subcontractors. In addition to that, batch size makes a difference in the selection of the specific manufacturing methods, meaning more automated ways or mechanical solutions would be enough. Most important criteria are presented below:

- Material prices: Balance must be selected between performance and costs. All the mechanical properties have to be considered versus price.
- Selection of the processes: Evaluation of the different processes and assessment of the influence of them on different cost referred aspects.
- Supply Chain Management: Optimizing this aspect will lead to the minimization of the material costs and lead times without compromising quality.

- Process efficiency: By eliminating different principles of manufacturing less waste could be achieved as well as optimization of the production time.
- Evaluation of the suppliers: Evaluation and comparison of different parameters, such as reliability, pricing, quality of the supplier.

Figure 12 represents the example of the manufacturing consideration.

Process	Place of processing	Price	Time	Sum
Employee	Own shop	40 eur/h	12h	480 eur
Laser cut	Subcontractor	20 eur/h	1,6h	32 eur
Working time	Subcontractor	100 eur/h	1,6h	160 eur
Bevelling	Subcontractor	10 eur/h	0,8h	8 eur
Working time	Subcontractor	100 eur/h	0,8h	80 eur
Bending	Subcontractor	10 eur/h	1h	10 eur
Working time	Subcontractor	100 eur/h	1h	100 eur
Mechanized Welding	Subcontractor	10 eur/h	8h	80 eur
Working time	Subcontractor	100 eur/h	8h	800 eur
Material	Subcontractor	1300 eur/t	213kg	276,9 eur
Post processing	Own shop	10eur/h	8h	80 eur
Cylindrical bracket	Subcontractor	11.8eur/pcs	2pcs	23,6 eur
End bracket	Subcontractor	36eur/pcs	1 pcs	36
Total cost				2166,5 eur

Figure 12 Example of the cost evaluation table

3 Results

In the following chapter the results of the current work will be covered and prepared for analysis.

3.1 Results of the steel grade calculations

Based on the input values and the requirements for the crane, S700 grade of steel has been obtained considering the structure has to be safe to use as well as the weight of the structure should not be excessive. This will effect on the price of the raw material for the crane in a negative way, as well as will create some difficulties for the manufacturing process such as weldability issues, as it is worse in comparison with the low strength steel, and therefore require specific welding methods and consumables. Stress concentration have to be avoided for avoiding of the brittle facture phenomena. However, considering the benefits durability, resistance to fatigue and better design flexibility are treated on the elevated level (Bjorhovde, 2010). Since the current design is oriented towards the lower weight structure the solution is considered a desirable choice.

3.2 Results of the analytical calculations for the single beam structure

Analytical equations presented in chapters 2.1.5, 2.1.6 and 2.1.7 following results have been obtained in the as a cross section of the single beam for the overhead crane structure. On figure 13 is presented cross-section of the span beam for the single beam structure Thicker bottom plate has been selected for attachment of the loading carriage for the crane. The weight of the span beam with this set-up is 1,763 tons. However, deflection has not been considered at this stage and will be covered after FEA is conducted. At that stage, some reinforcements might be added for improving the stability performance.

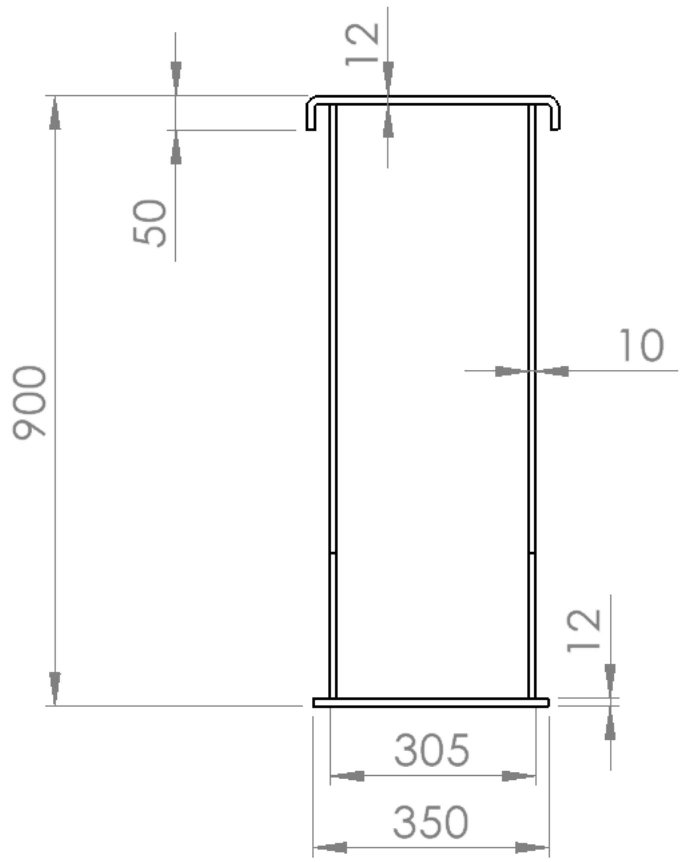

Figure 13. Cross-section properties of the single beam girder

3.3 Results of the analytical calculations for the double beam structure

Based on the same principle as presented in chapter 3.2 the cross-section dimensions have been obtained. Results are presented in figure 14. The own weight of the structure in this case is 1,958 tons. Like the case with the single beam, further calculations will be presented after comparing two different options.

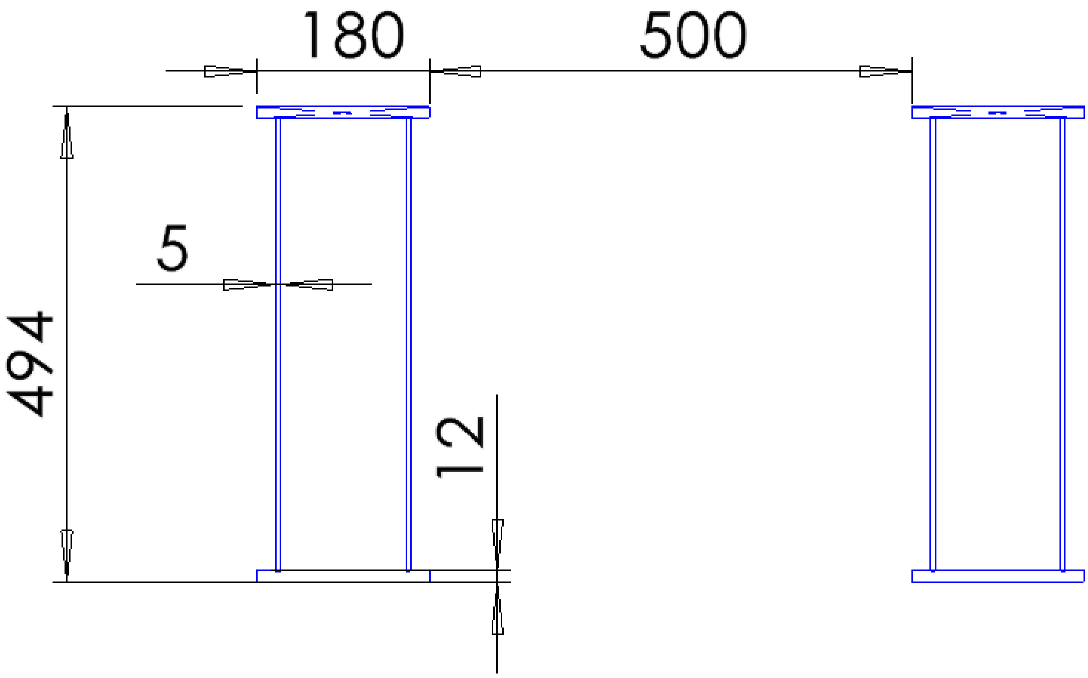

Figure 14. Cross sectional calculation for double-span girder structure

3.4 Results of analytical calculations for the I beam profile.

According to the similar procedure that have been utilized in chapters 3.2 and 3.3 cross sectional dimensions have been calculated for the I beam shape of the span beam; calculations are presented on figure 15.

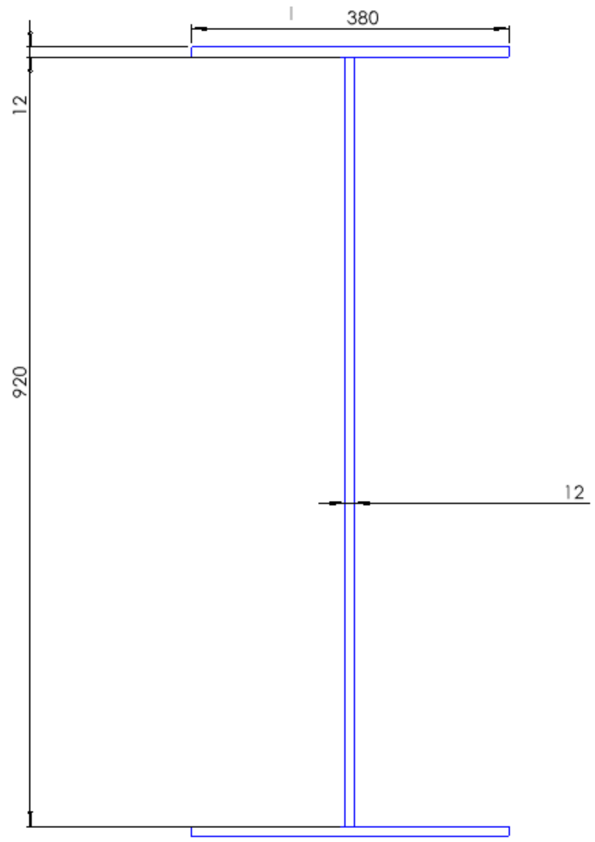

Figure 15. Cross-section values for the I profile.

The total weight of the structure is 2359 kg in case based on the steel density. The comparison of the selected profiles will be done in the following chapter.

3.5 Comparison of the result and selection procedure

One of the most efficient ways of considering the results is the value analysis table. According to the results presented in sections 3.2 and 3.3, comparison between single-span and double-span beam can be conducted. The results are presented in table 2 below.

Table 2 Value analysis table

Criteria	Weight factor	Option					
		1 (double beam)		2 (single beam)		3 (I beam)	
Weight (kg)	0.5	0.83	1993 kg	0.9	2130 kg	1	2359 kg
Ease of design (estimate, 0=simple, 10=exceedingly difficult)	0.05	0.3		0.1		0.1	
Number of parts	0.05	0.4	8	0.2	4	0.15	3
Number of bends	0.02	0	0	0.2	2	0	0
Length (meters) of welds number of bends	0.08	0.96	120	0.48	60	0.48	60
Misc. Fabrica-tion related items (0=easy, 10=difficult) (seam prepara-tion, large ma-chinery, de-manding work steps etc.)	0.05	0.3		0.2		0.1	
Total cost	0.2	0.9142		0.8609		0.8715	
Finishing	0.03	1		0.5		0.5	
Transportation	0.02	1		0.86		0.86	
Total	1	0.775		0.742		0.762	

Into consideration have been taken all the crucial factors, which are affecting on the decision making as weight of the structure, ease of the design process, number of parts which are utilized for assembling the beam, number of bends, length of welds, fabrication items, total cost, finishing and transportation. All these criteria have been assigned to the weight factors for those based on the importance of it for the entire process and they are 70% of all the weight factors. As an outcome the biggest weight factors have been assigned to the weight of the beam and total costs of the structure, as based on the selected design approach these are assigned to be the most important ones. All the biggest values have been assigned to one and others have been calculated, respectively. The least key factor has been selected to be the number of bends due to the small effect on the total cost of the structure and the transportation costs, as far as it has been covered partially in the total costs. Overall, the result of the comparison can be seen that the preferable choice is with the smaller value. The smaller final value is considered as the better option for manufacturing. Based on the results it would be single-span beam construction. Further calculations and the FEM analysis will be conducted for the current profile and cross-section provided in section 3.2.

3.6 Numerical calculations result for the selected structure.

The model has been imported to the FEMAP as a Parasolid format from Solidworks and the geometry is presented below in Figure 16. Reinforcements have been added to improve the deflection performance.

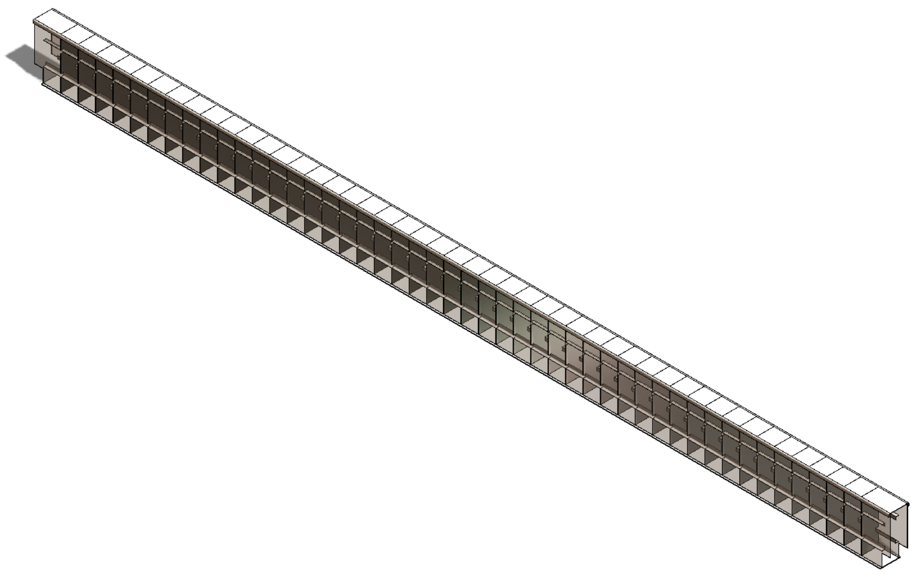

Figure 16. Model of the single-span beam

Following material properties have been applied for the model in FEMAP are presented on the table 3:

Table 3. Utilized material properties.

No	Name	Value	Unit
1	Young's modulus	210	GPa
2	Yield strength	750	MPa
3	Poison ratio	0.29	-
4	Shear modules	82	GPa
5	Density	7800	Kg/m^3

The plate element model with quadrilateral 4-noded linear elements meshing has been utilized in this model. Initial size was coarse but after the mesh convergence the final size is about 25 mm. Since the model is quite long due to that fact, the selected size is fair enough for results calculation. Meshing results are presented in figures 17 and 18. In addition, in figure 18 is depicted that the transversal plates are connected to webs and bottom flanges.

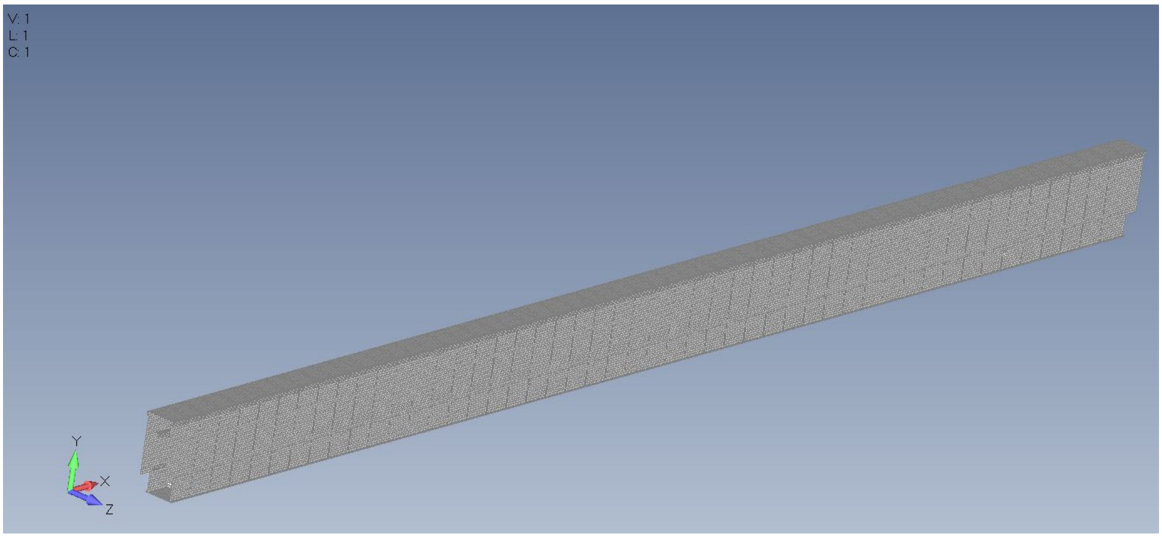

Figure 17. Meshing of the model #1

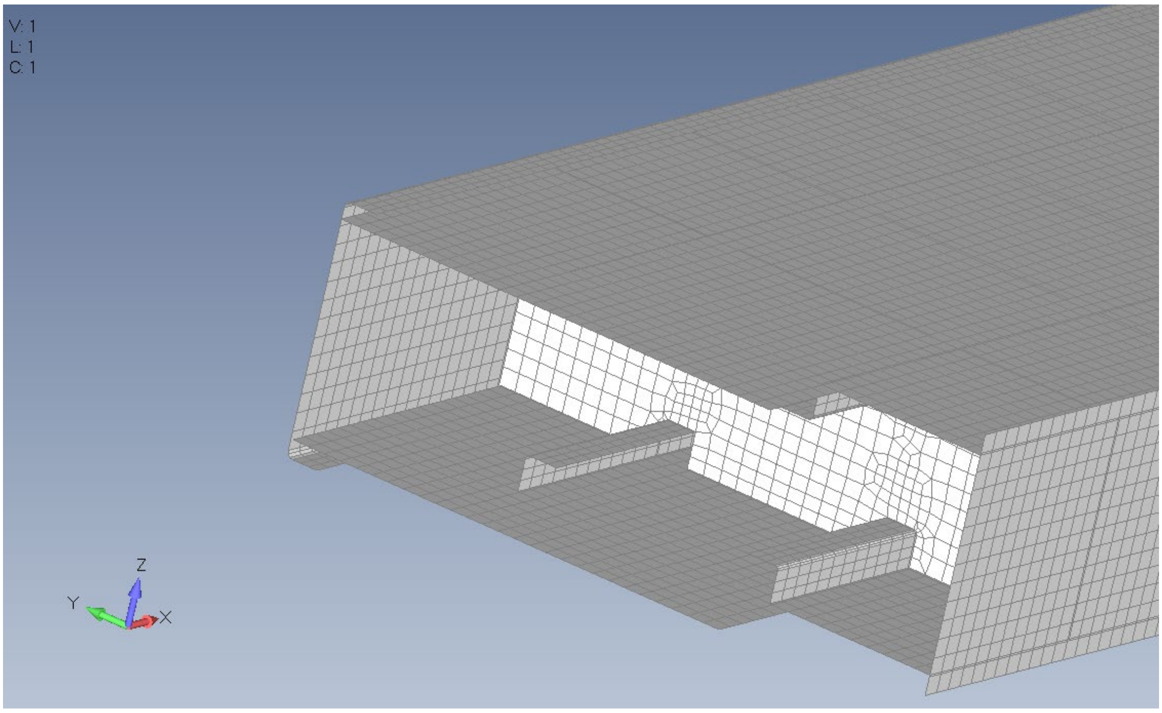

Figure 18. Meshing of the model #2

To the model where applied pinned boundary conditions (BC) as presented below in figure 19.

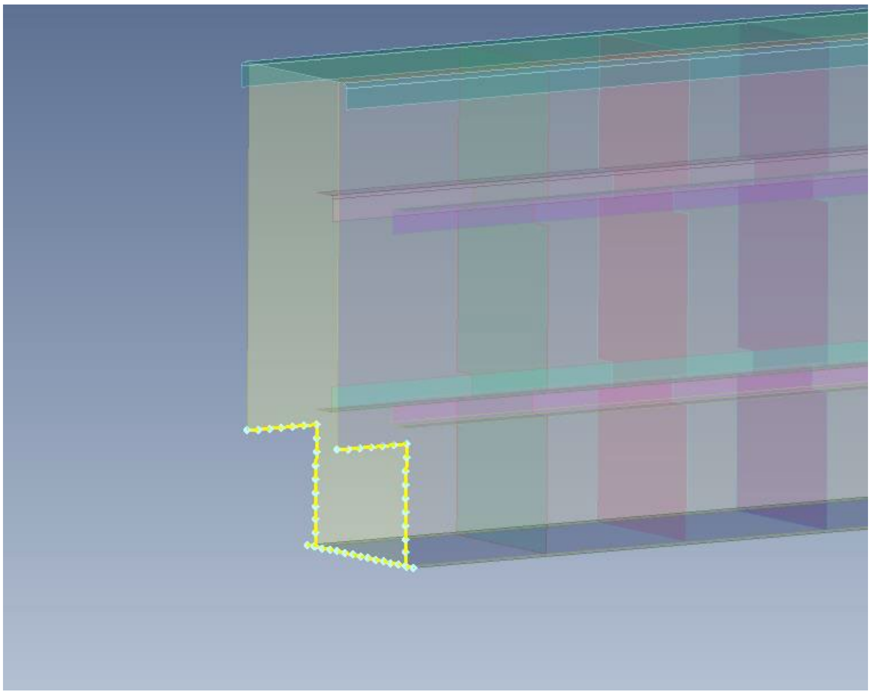

Figure 19. BC of the model

For a static analysis of crane, different configurations can be made like the load can be towards one end (left) or other (right). According to beam theory for a fixed beam on both ends, the most critical case of the load is when it is applied at the center of a beam as shown on the figure 20

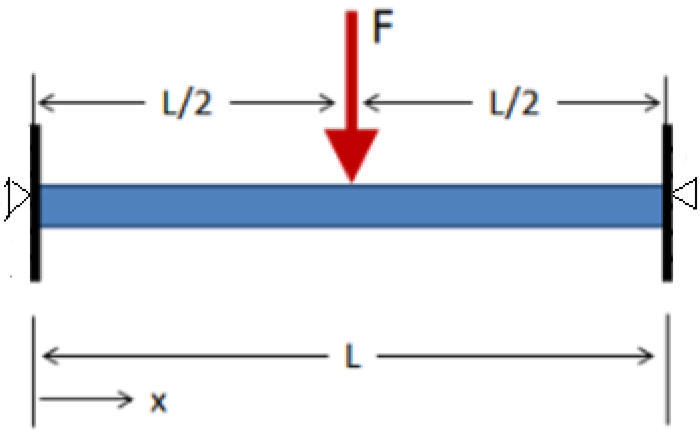

Figure 20. Maximum deflection in a case of the fixed beam

Hence, the load will be applied at the center of the crane for analyzing the most critical case, as shown below. The load value is 5 tons. Since on crane, the load bearing members are more than one pulley. That is why it applied as distributed load on some area of the middle of crane. Figure 21 represents the force appliance on the structure

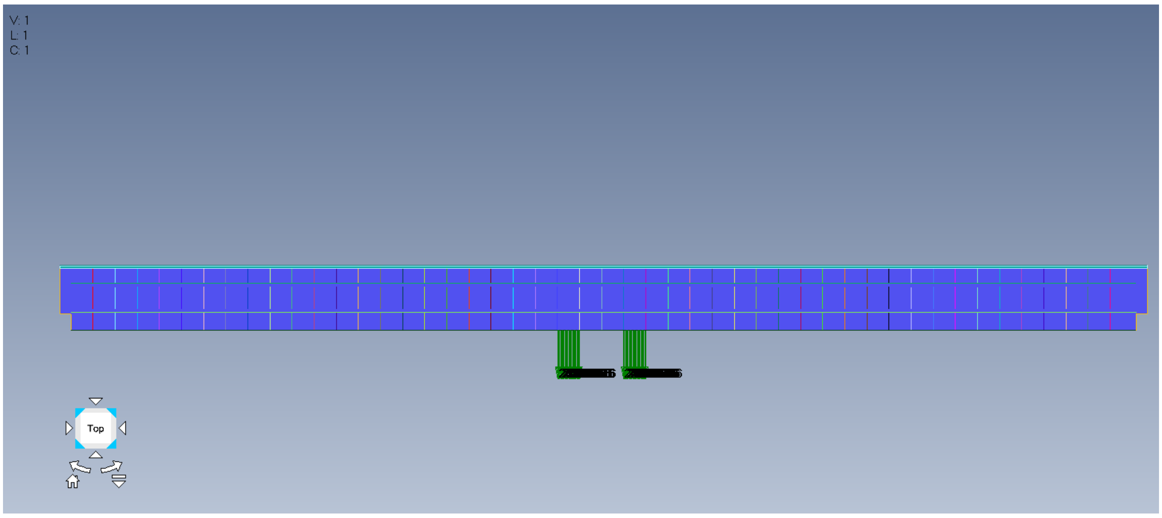

Figure 21. Force appliance on the structure

Based on the presented modelling aspects the analysis could be conducted. Based on that, total deformation of the model is calculated as 3.7903 mm. Figure 22 shows the contour of the model in total deformation. In order to observe representation of the contour, deformation has been scaled in times.

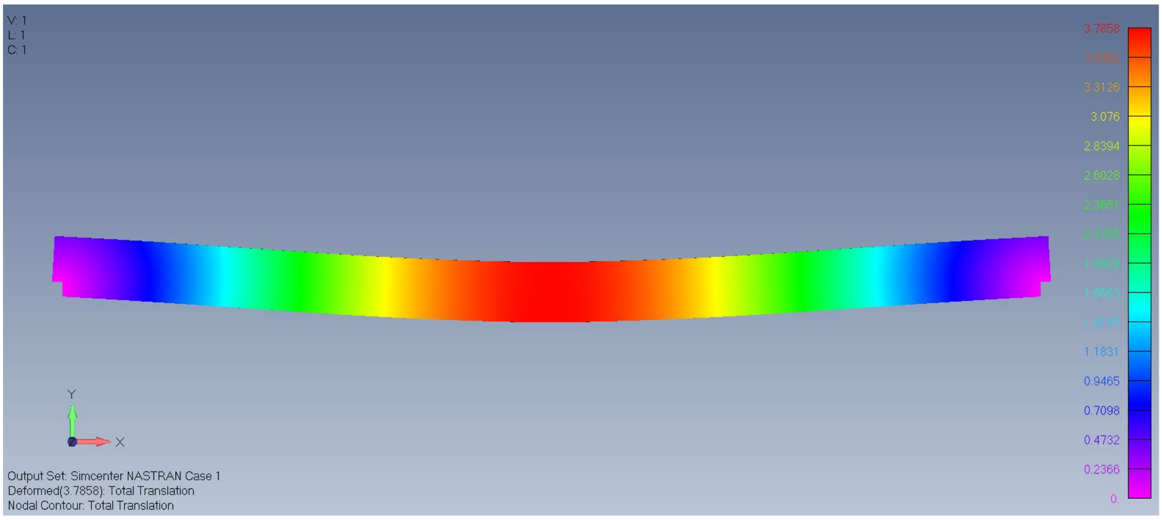

Figure 22. Total deformation in mm

Von-Mises stress has been obtained as well from the analysis and the maximum von-Mises stress calculated is 212.05 N/mm^2. Figure 23 shows the contours of the data. To better represent the contour, it is scaled times.

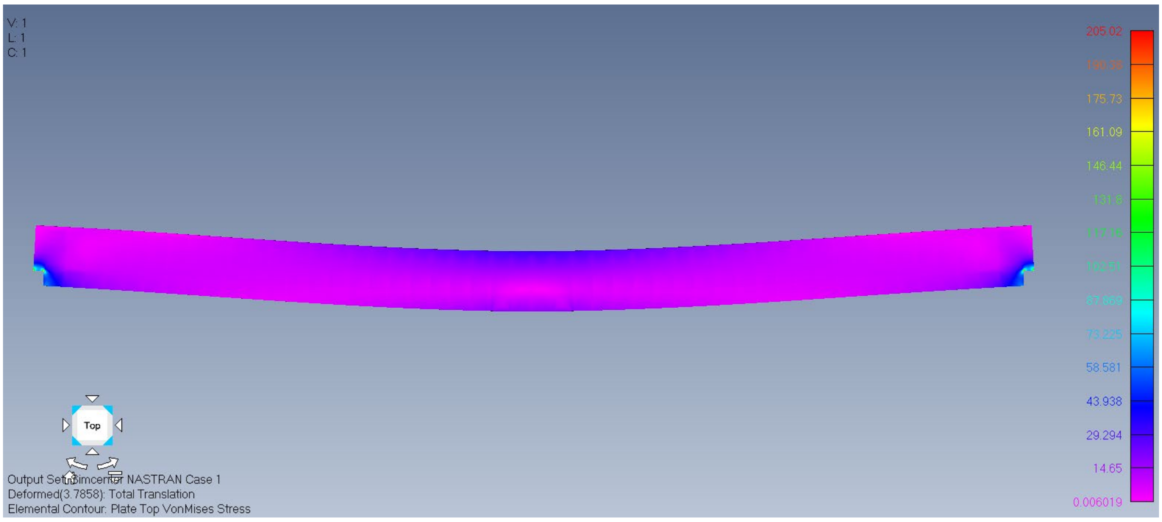

Figure 23. von-Mises stress in crane model under applied loads

On the figure 24 is represented the ultimate load carrying capacity in the representation of the safety factor withstanding of the structure. The blue colour represents the partial safety factor of 15. The minimum safety factor has been obtained at the edges of the span beam with 5.9 value.

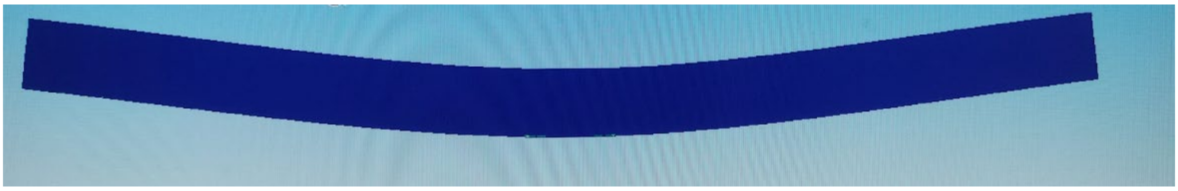

Figure 24. Safety factor representation around the structure

Next thing to be considered is the global stresses in the area of mid-span and the ends. It can be concluded that the stress in the mid-span area is not the biggest one as it is only 52 N/mm^2 and the stress in the ends is equal to the 212 N/mm^2 and figures 25 and 26 serve as a graphical representation of the global stresses.

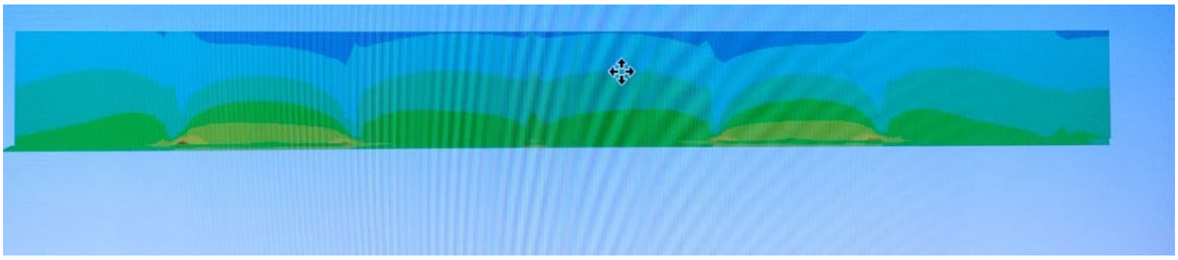

Figure 25. Global stresses in mid-span area

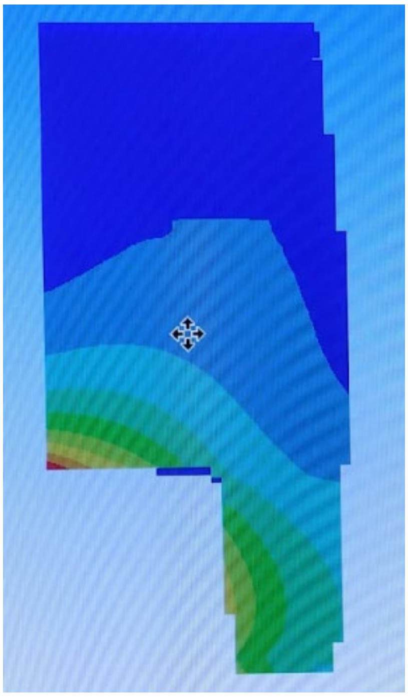

Figure 26. Global stresses in the end of the span-beam

3.7 Weldments calculation

Based on the equation provided in the section 2.2.3 the fillet welds for the different structural pieces are presented in table 4:

Table 4. Weldment table

Number on picture	Joint location	Type of weld	Throat thickness
1	Bottom flange to webs	Fillet weld	2,6 mm
2	Top flange to webs	Fillet weld	3 mm
3	Middle reinforcement plates to the walls	Fillet weld	2,1 mm
4	Angle beam to the reinforcement plates	Fillet weld	3,3 mm

As a part of the welding procedure specification (WPS) following parameters are specified for welding in table 5.

Table 5. WPS

Base Material	S700
Material thickness	6 mm
throat thickness (desired)	3 mm
Welding type	single pass
I (planned)	200-230 A
Voltage (planned)	28 V
feed rate	11 m/min
Welding speed	30 cm/min
Heat input	1.03 kJ/mm
Interpass temperature	60 degrees
Welding position	PB

3.8 Manufacturing aspects and procedure

Continuing forward to the manufacturing procedure several steps must be considered:

- Manufacturing will be happening in the own shop at the AIR-QC facility.
- Mechanized welding equipment will be utilized from the welding of the span beam.
- Parts will be ordered from the local supplier.

Below on figure 27 is presented a production flow chart for the provided beam.

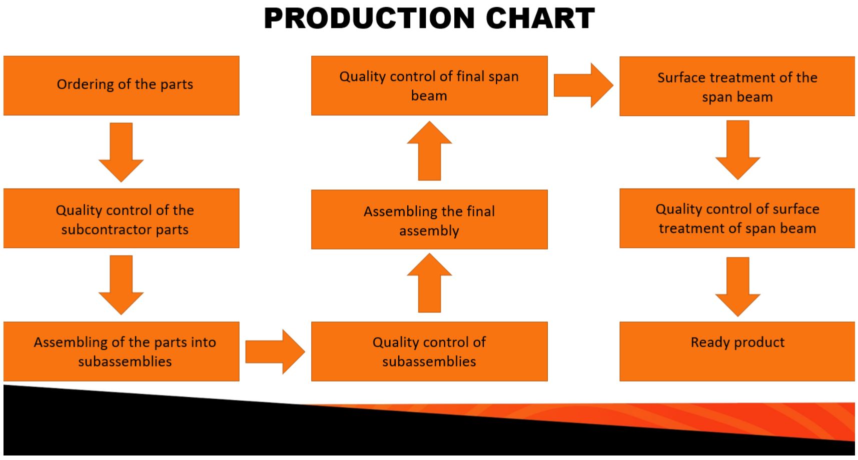

Figure 27. Production chart for the beam

Based on the figure above the general image about the production process can be generated and below the detailed description of the production process is presented.

Subcontractor will provide following parts which are presented on the table 6:

Table 6. List of parts to be ordered from subcontractors.

Name of the part	Amount (pieces)	Dimensions	Laser cutting	Bending
Beam walls	2	882x14850x5mm	Yes	No
Beam top flange	1	423x14850x6mm	Yes	Yes
Beam bottom flange	1	350x14550x12mm	Yes	No
Reinforcement angle irons	4	50x50x14550x6mm	Yes	No
Reinforcement plate	47	290x892x6mm	Yes	No

All parts would be manufactured from S700 steel grade as it was presented in the section 3.1. Based on the drawing's walls, bottom flange, and the reinforcement plate will be just laser cut pieces. Beam top flange will require as well bending.

For the welding the mechanized MIG welding process has been selected. Furthermore, the surface treatment could be depicted in the picture 28 for ensuring the proper aesthetic look of the surface and improving corrosion-resistance performance.

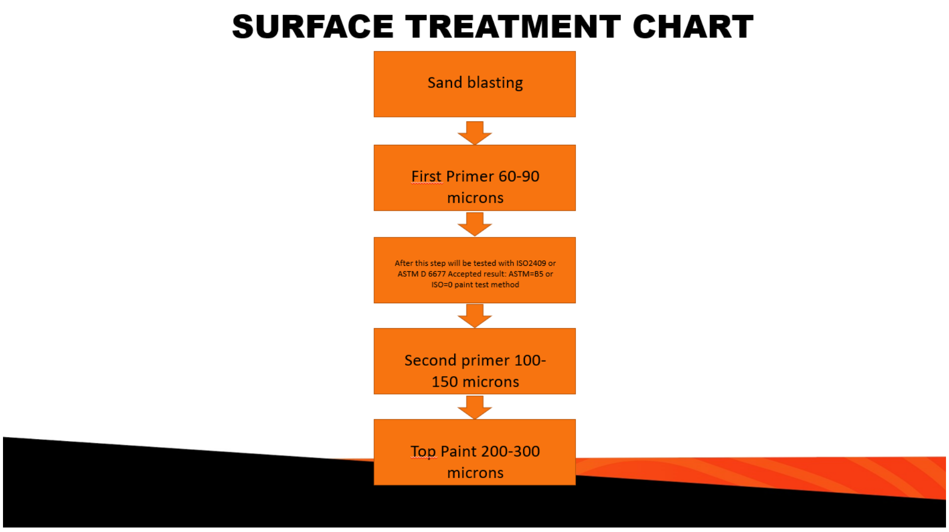

Figure 28. Surface treatment chart

3.9 Price estimation

Price estimation has been done based on the subcontractor quotations for the following parts. The results are presented in the table 7.

Table 7. Price estimation table

Process	Processing location	Price	Time (hours) or Mass (kg)	Sum
Employee	Own shop	20 euro/ hour	20	400
Laser cut	Subcontractor	20 euro/ hour	4	80
Working time	Subcontractor	50 euro/ hour	4	200
Bevelling	Subcontractor	20 euro/ hour	2	40
Working time	Subcontractor	50 euro/ hour	2	100
Bending	Subcontractor	20 euro/ hour	2	40
Working time	Subcontractor	50 euro/ hour	2	100
Mechanized welding	Own shop	10 euro/ hour	12	120
Working time	Own shop	20 euro/ hour	8	160
Material	Subcontractor	1950 euro / ton	2663 kg	5193
Post processing	Own shop	20 euro / hour	20h	400
Total cost				6833 euro

As it is presented in the table above the total estimated price for the beam is 6833 euros with considering that manufacturing and the subcontracting parts will be manufactured in the Thailand and the manufacturing batch is one beam therefore the prices are relatively high based on the average market price

4 Analysis

As the outcome of the current study the ready design and manufacturing procedure of the single span beam. Beam transportation will be done as a separate piece to the Air-QC facility, after that they are assembled in the ready beam. It will be time consuming process due to the multiple quality control procedures as it has been mentioned in the Figure 25. Following the presented guidelines will provide the reliable structural member with the ability to withstand loads without failures.

The design has been done according to the standards presented and have been validated with the FEA. In the beginning requirements list have been created based on the interview with the customer and based on that following calculation aspects and limitations have been considered

The final design meets the demands of the customer and ready-made CAD models and drawings are included. The span beam is ready for manufacturing, even though modifications to the manufacturing process might be required, due to the tight schedule of the preparation work. Especially if the manufacturing of the beam needs to be expanded.

In the following subsections, the most important reflections on the results are presented.

4.1 Quality of the design

Considering the quality of the design it has to be mentioned that the design meets the requirements provided by the customer. However, some important points could be analyzed based on the provided results.

Considering first the results of the FEA it can be emphasized that the structure of overhead cranes is made for hard applications in terms of load bearing capacity. They usually are designed to be used for years, that's why their high strength is compulsory. The resulted deformation of 3.8 mm is very small and can easily be compensated. Secondly the von-Mises stress also very small being 205 N/mm^2. The yield strength of the material is 750 N/mm^2. Hence the failure under static loading not that possible to happen. The overall safety factor is 3.7. Hence the structure is quite safe. It is good to add that the reinforcements, to control the deflection (Figure 31) which have been added to the structure for the ensuring the minimal deflection requirements are reached, the structure have been overdesigned what might bring extra weight to the structure, nevertheless considering the timeframe for the work the result might be considered as adequate, even thought that is affecting on the moment of inertia of the structure.

Checking out the weldment calculations, it must be said that extra effort for the calculation has been brought with the introduced different thicknesses for the beam web and flanges. The bottom flange thickness has been selected to 12 mm due to the load carriage attachment position. However, the main task during the calculation of the throat thickness is to assure that the failure will not happen in the weld root, what is achievable with the values presented in the result section.

4.2 Manufacturing and assembly work

Based on the requirement of the expensive and specific machinery the utilisation of the subcontractor is important in order to ensure the quality of the end product and exclude any welds of the main beam in the transverse direction. Considering the production procedure, based on the figures 29-32 the following notes for the steps can be made:

1. Angle profile welding to the webs of the beam

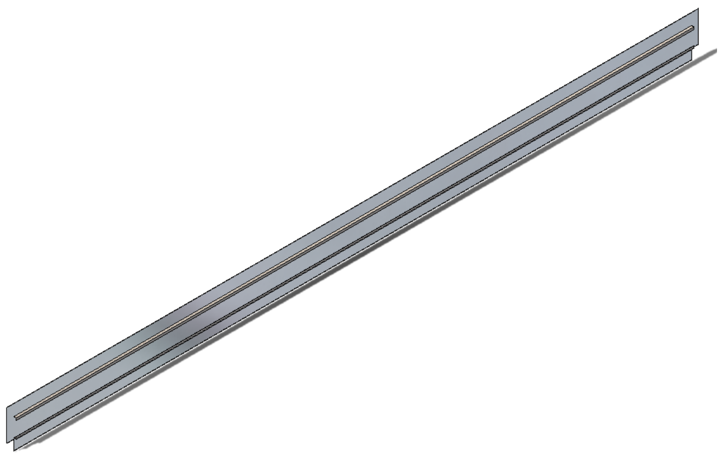

Figure 29. First welding step

2. Welding bottom flange and the webs together

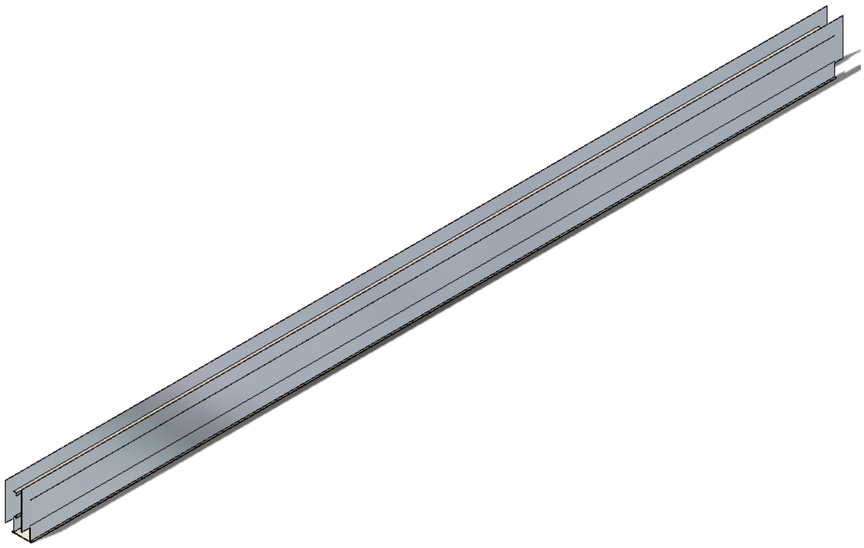

Figure 30. Second welding step

3. Welding reinforcement plates to the flange+ plate structure

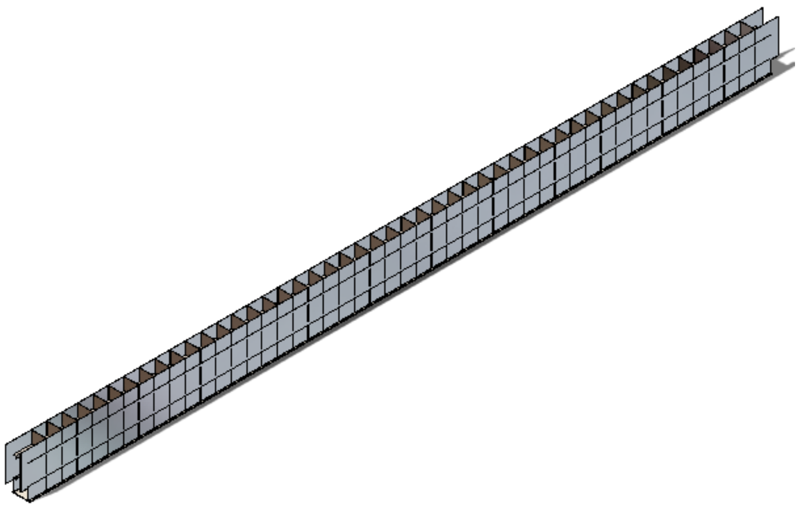

Figure 31. Third welding step

Transversal plates are attached to both the webs and flanges. The positioning of the transversal plates with the small distance between those is needed for preventing of the distortion in case customer willing to put the carriage on the web, however this will not increase the capacity of the axial, shear, bending, torsion or warping.

4. Welding the top flange to the structure

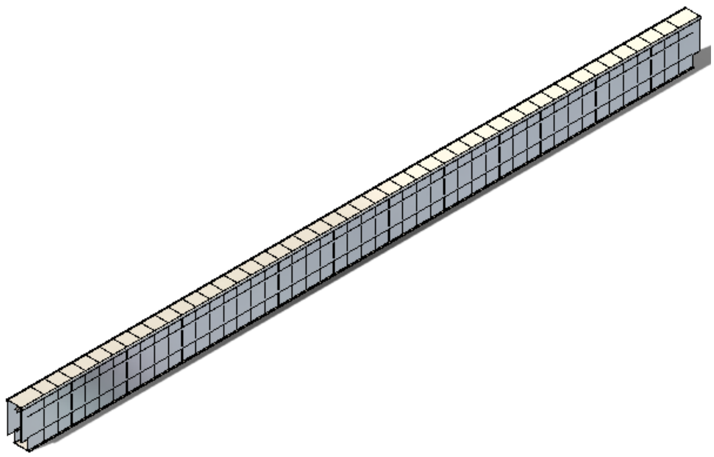

Figure 32. Fourth welding step

The weldment alignment must be checked carefully and therefore fixtures have to be utilized. In case the beams are manufactured in bigger scales the design and manufacturing of the jigs might be considered for improvement of the time efficiency and ensuring quality. In addition, the temperature of the weld has to be considered and welding should not happen in the same place in order that heat affected zone (HAZ) is not getting larger. The interpass temperature should not be higher than 60^{o}.

4.3 Price analysis

Considering the results obtained in the previous section it is extremely important to get the comparison of the price range and several pinpoints for justification of those. First of all, it has been considered that for manufacturing of one position of single span-beam does not make sense to hire workers as well as buy specific equipment for the manufacturing of this setup, therefore it is straightforward that presented solution is reasonable. Especially considering that for the assembly work the own workforce can be utilized what will most likely result on the better result based on the well-known quality standards inside the company as the manufacturing process as well. The prices are based on the quotations provided by the Air-QC Ltd. sales department. At the same time, it is safe to assume that the manufacturing price for the 1 piece as well as 100 pieces will not change dramatically, therefore 10% discount is added for the 100 pcs manufactured with the subcontractor. However, it is fair to say that the amount of the customization in the current product is relatively high, it is hardly possible to find similar workshop based on the span length or load carrying capacity. The prices which have been utilized for the structure are not connected to the selling of the beam as far as the first model is manufactured for the own production purposes.

Definitely it would make some sense to purchase, or lease required machinery, taking into account that it would be utilized for the other projects at the same time. In that case the prices for the subcontractor work could be decreased from 50 euro to 20 euro per hour, therefore the saving amount are presented below in the table 8

Table 8. Comparison of the work price

Amount	Own shop manufacturing (euro)	Subcontractor (euro)
1	400	160
100	40000	16000

As can be seen, manufacturing at the own shop of bigger amount of the units will save 24000 euros for some investments in the machinery and can increase the manufacturing range of products.

5 Discussion

In this section different results observations will be covered in particularly such aspects as reliability, objectivity and validity of results.

5.1 Objectivity

Due to the fact that author of the work has not had much experience in designing structural elements, the results might be very objective. Despite of the fact mentioned above, the work also used knowledge based on previous knowledge there is a chance of introducing negative effect into objectivity, but based on the fact that team included in supervising the research and the development process the objectivity was improved by more opinions were considered before making decisions.

5.2 Reliability and validity

Current work can be considered as quite reliable due to the different material sources have been utilized for research work. Information can be accurate relying on previous research. The data obtained from sources can also be counted as trustworthy. As an addition, various studies have been done, and their results were checked many times referring to those. Obtained info from those is considered as reliable due to the iteration of reviewing in order to minimize miscalculations and errors.

The research is relatively valid because the research used different methods to gather data. Fact that different methods have been utilized due to the different aspects to review.

5.3 Sensitivity

The data obtained at work can be considered reliable and checked for the sensitive as far as all the environmental factors have been considered in the work, however the practical arrangement of the physical test was not done the real behaviour in the operational environment cannot be proved by the results of the current thesis and has to be conducted separately afterwards.

5.4 Utilization of results

There is not much of scientific value in the results of current thesis work, but it can be used as a prototype of structural design in the future research when similar product is going to be designed based on the results. This research contains valid and utilized research methods. Based on those, reasonable results were obtained, as an outcome structural member could be tried to be manufactured as a prototype. The system can be installed in different locations, however, will require the study of the place and modification of customer specific values and some extra calculations based on the environmental factors.

6 Summary

The main reason why span beams for the overhead cranes needed to be designed was that there was that the case optimized solution for the customer has been required. Beam is needed for ensuring the safe and failure less function. From this analysing results it is possible to tell achievements for the current beam design as well as improvements in them manufacturing aspects and optimized price calculation. Product itself is useful and customer is planning to implement the current design in the manufacturing.

The subject of this thesis was to develop beam and the process for its manufacturing that is relatively light and strong and can operate in the provided by customer environment. The timeframe caused the issue of the design process and some problems left for further investigation. Design procedures provided by Eurocode 3 standard were followed to ensure that all the aspects are considered. Material selection, analytical calculations, value analysis table, finite element analysis and collaboration with the current manufacturing places were used in the designing process.

Work itself can be considered as relatively successful, based on the fact that it was completed with desired results, and ready product was designed, however might require extra work within the scope. Product itself fulfilled all crucial requirements.

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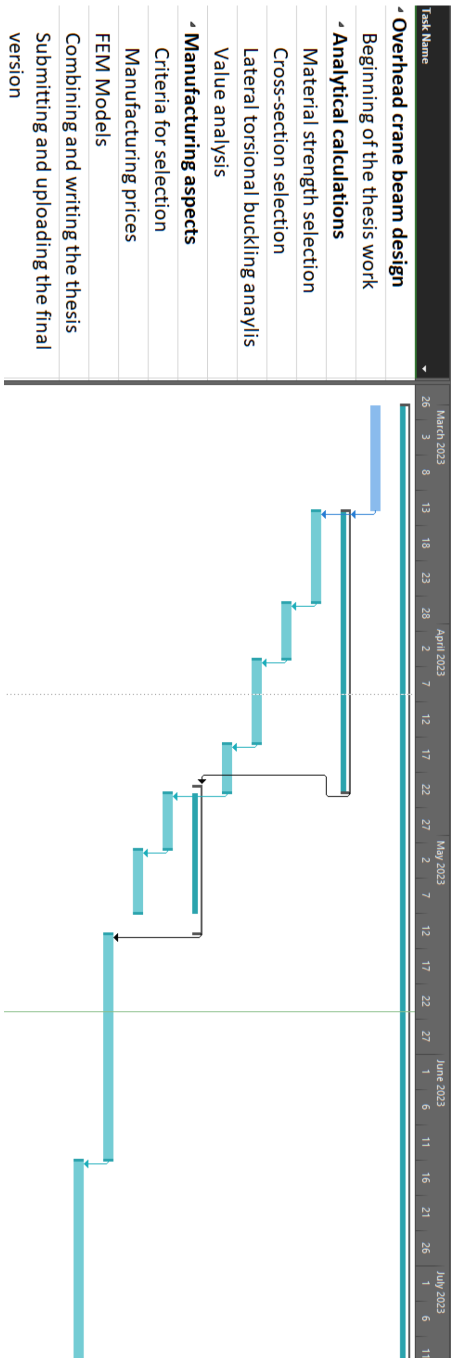
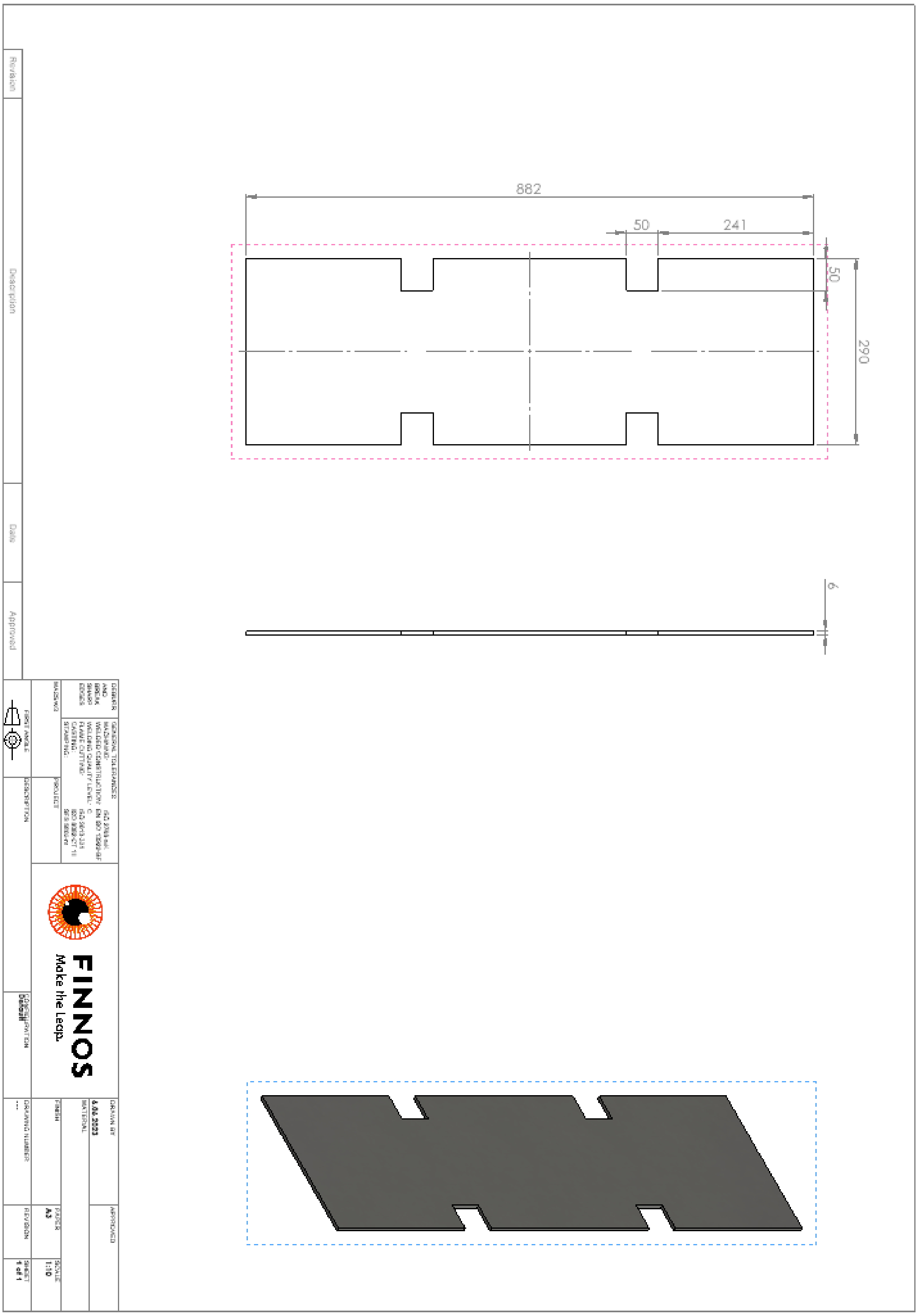
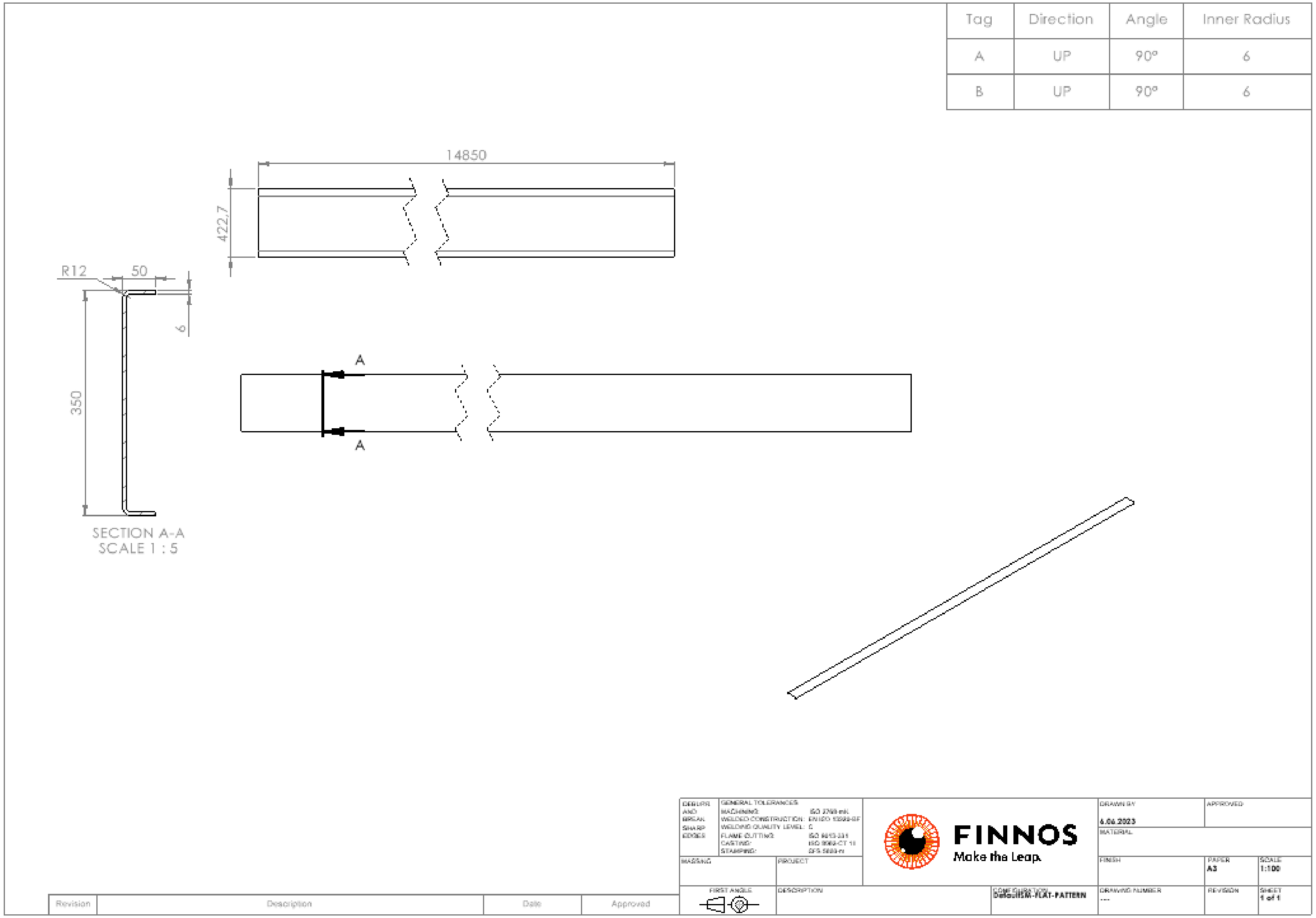
Appendix 1. Timetable of the project



Appendix 2. Mechanical drawings

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WELDED CONSTRUCTION: EN ISO 13920-BF
WELDING QUALITY LEVEL: C
FLAME CUTTING: ISO 9013-331
CASTING: ISO 8062-CT 11
STAMPING: SFS 5889-m
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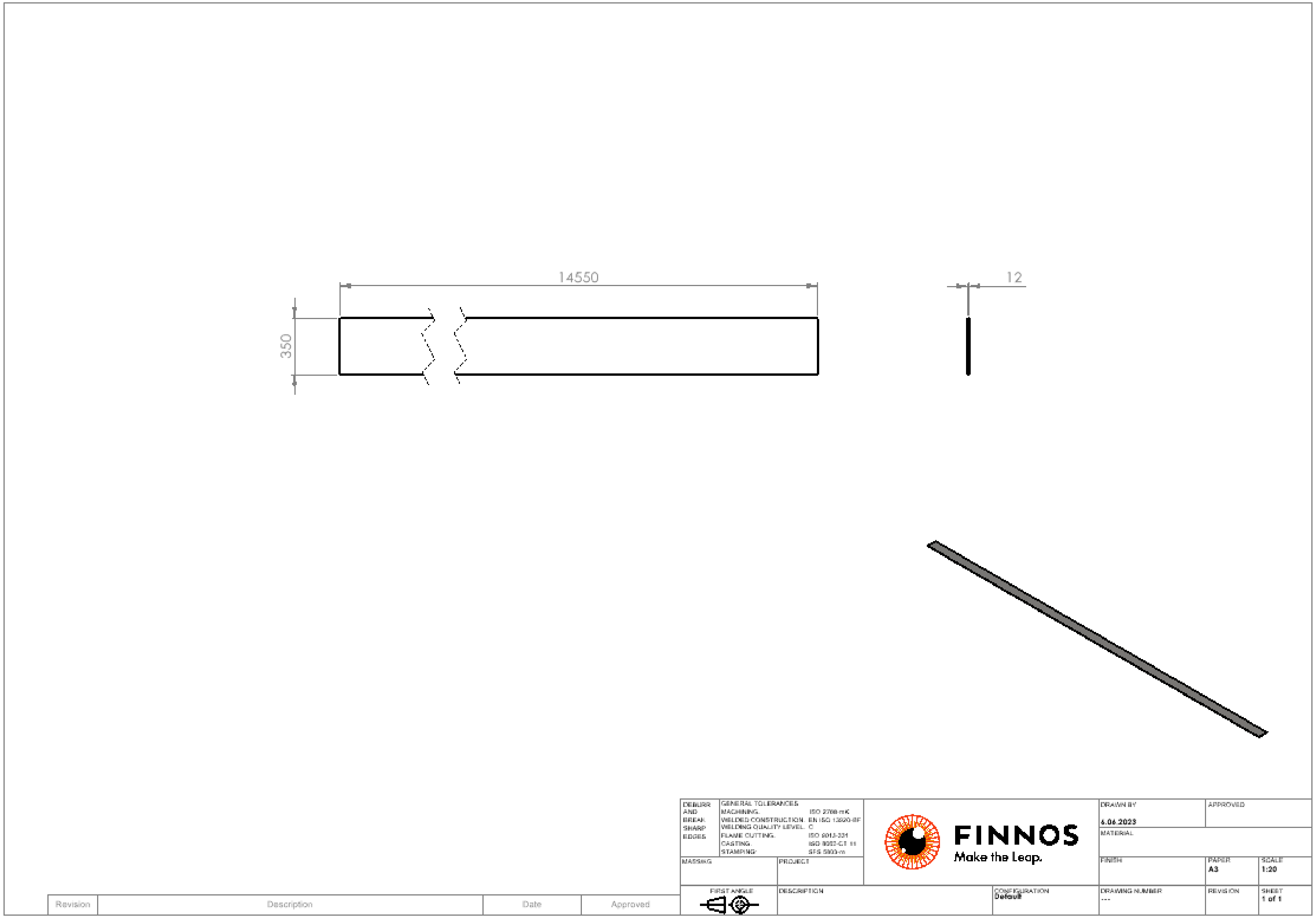

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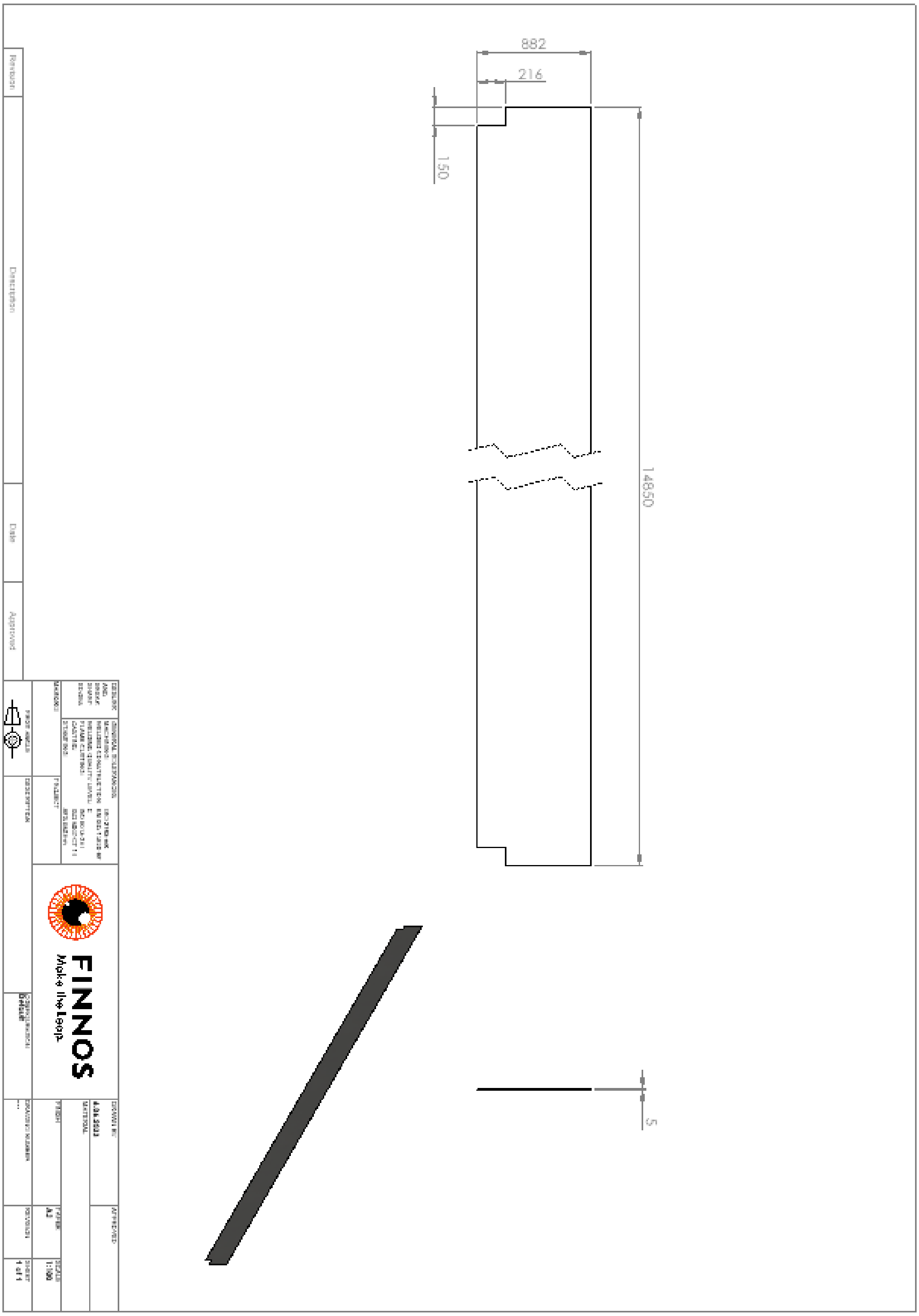
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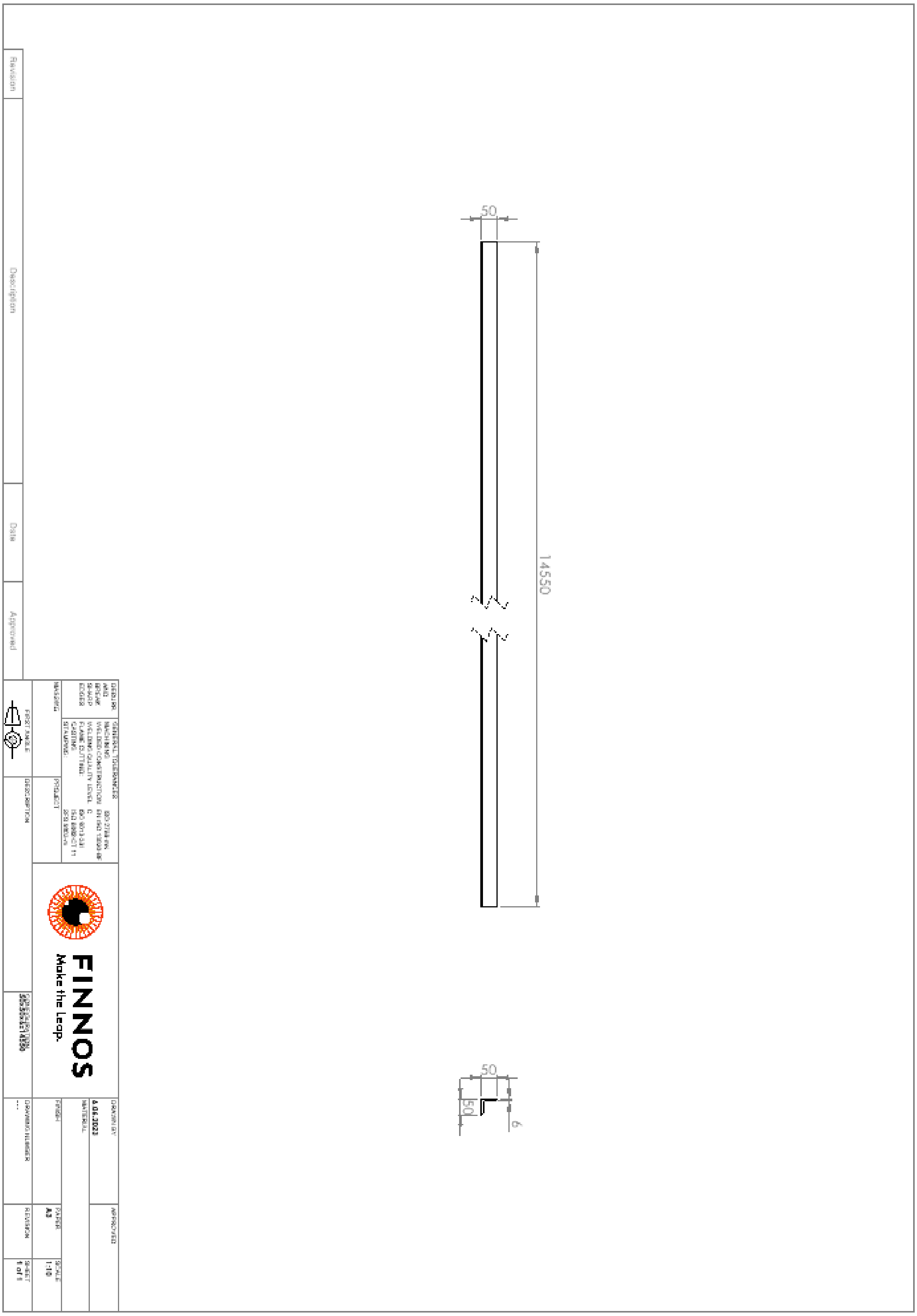

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