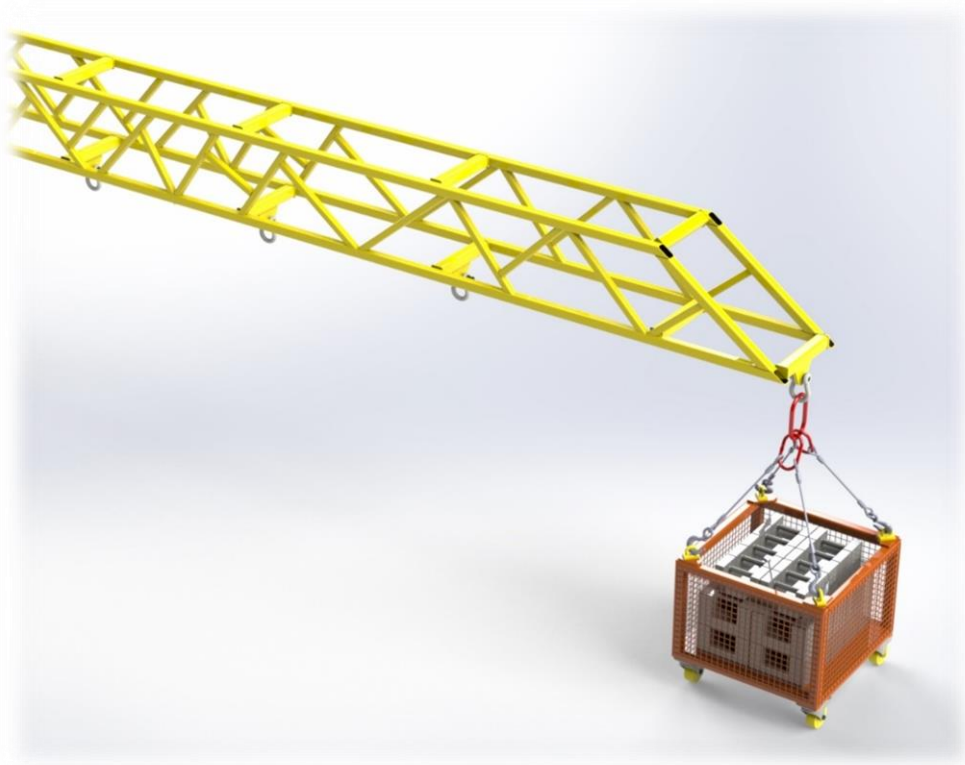




Dissertation – Design of a Counterbalance Lifting Beam

Naeem Noor – Beng Mechanical Engineering -2023

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Abstract:

The present study has been investigated on the request of a client, where a customer have raised a need of a lifting beam with a minimum tare weight possible at their ongoing project site. As per their specific request the beam should consist of several lifting points & also a counterbalance basket with calibrated weights. Customers require 10 to 12 lifting beams at their different sites.

In a market there are number on lifting beams, but every lifting equipment is not suitable for everyone's needs. After researching such a specific beam is not available in market, to increase our market value this beam is designed with a minimum tare weight with a span of 10 meter.

Aim is to minimize the mass of the current beam which is getting used where steel beam S 275 is over 1 tonne (1078kg) in weight and the aluminum beam is 780 kg in weight. The model which has been designed is just hold a tare weight of 413 kg with a safe working load of 2 tonne.

To reach minimum mass in respect to stiffness ratio topology optimization has been used in **Solidworks** where the model has gone through the analysis several times, and to make sure the load it can take, it has gone through a (FEA) finite element analysis at proof load which is twice the (S.W.L) safe working load.

Model have been symmetrically constrained in order to get the best possible results as the same loads have been applied at both out most lifting points which are at 5 meters from the fixture (top Lifting Point) giving a lifting center of 10 meter.

After going though all the possible processes to reach the set goal of minimizing the mass of the asset has been achieved, it has been proved that the structure will perform well under the applied load of 2 tonne which also puts the asset to a working load limit (WLL) of 2 tonne.

Introduction:

To design a lifting beam to carry loads from point A to point B. The lifting beam will allow for a safe lifting during use. Optimization techniques will be used to reduce the mass of the machinery lifting beam which will allow a lower lifting capacity crane or lifting device to be

utilized. Also bring in the consideration of increasing the load on the beam that could be lifted by the same or existing crane as the weight of the beam will be less than the original beam.

Project objectives:

- To design a lifting beam to transfer machinery from A to B.
- Gain a good understanding of equipment design.
- To optimise the structure to reduce the weight of the beam, so a smaller capacity crane can be used while maintaining the stiffness required to take the load.
- Gain a good understanding of relevant optimisation techniques that can be used for rigging equipment.
- Further skills in Finite Element Analysis.

Aim of the Project:

The aim of the project is to design a counterbalance beam which will lift balanced loads to move from point A to point B or to be used by working needs. The beam designed optimisation techniques are utilised to reduce the overall mass of the structure and it is possible to increase the load as the structure or the designed beam will weigh less. This will then allow to be able to use smaller capacity cranes to be used as well as balanced out loads with providing it with several lifting points.

While designing a lifting equipment's it is extremely necessary that to keep in mind the self-weight of lifting equipment. Which will then allow you for what safe working loads to be used that is crane capacity slings loads consideration, shackles & lifting component connectors etc.

In Italy, a crane was lifting heavy concrete and ended up in a catastrophic situation which made the crane to fall. Find the image below for the incident.



IMAGE - 1 INCIDENT 1

[Mail Online Videos: Top News & Viral Videos, Clips & Footage | Daily Mail Online](#)

On another occasion a person died in lifting operation, below is the image with the date stated in it.



IMAGE - 2 INCIDENT 2

[OSHA Cites SGL for Accident Where I-4 Ultimate Worker Died \(mynews13.com\)](https://www.mynews13.com/story/news/local/2019/09/28/osh-cites-sgl-for-accident-where-i-4-ultimate-worker-died/561111000270001)

ORLANDO, Fla. — The U.S. government is fining two contractors for exposing I-4 Ultimate workers to safety hazards, OSHA announced Wednesday.

- SGL cited for incidents where one worker was killed, 2 hospitalized.
- Universal Engineering cited for exposing employees to hazards.
- Both companies are contractors on the I-4 Ultimate Project

SGL Constructors is facing \$188,913 in penalties for two separate incidents involving workers at I-4 Ultimate construction sites which led to one person's death and put two others in the hospital.

SGL was cited in a September 28, 2019 incident where a concrete beam struck an aerial lift. Two people were working on the lift. One died from his injuries while another was hospitalized.

So, in the end it is the responsibility of the engineers to keep the design and structure safe by not over kill the beam (means in engineering term not to use a designed beam which is extremely over weigh for the required lifting load). While designing it is important to keep the mass low which then allows to use smaller capacity beam or to be able to lift more load.

Background study:

The 10 m long beam, with a self-weight of 780kg, was made by engineering company RSS for Efinor, which was recently acquired by the French company Framatome. This was done primarily to improve the industrial welding skills of the nuclear industry supplier.

Based on the concept and requirements provided by the client, the whole scope of work also included design analyses and feasibility studies. A conventional cantilever beam was not an option because of logistical problems and limited headroom.

The beam will be used to provide maximum coverage for the installation of equipment plates, floor and wall frames, and ancillary items within an in-containment refueling water storage tank (IRWST) pool, a cylindrical tank filled with water at atmospheric pressure. The beam has a 1t capacity chain hoist at each end. A motorized hoist will lift the beam while being supported by a curved monorail beam that has been erected in the middle of the ceiling above.

"In accordance with the requests of the client, we used this basket/rigging method. Wire rope slings were the lightest option for the application because the balance beam assembly's total mass requirements were extremely strict.

As aluminum cannot be welded to steel, the beam also has lifting points which are bolt able, allowing for the separation of the two components.

To become widely used, they must be low-cost but high performing. Designing a lifting equipment which is suitable for extensive needs will increase its value in market. There are always competitors in every field not just engineering, but in order to get the product out in the market or making the first step & offering it to customers will lead to several beams to manufacturing. A lifting equipment like this will be used to increase our market share. The use of expensive motors and speed reducers, which are the main causes of their high price. These components are required to produce enough torques to support the robot mass and payload. In order to address

these issues, a multiple-degree-of-freedom (DOF) balancing mechanism were created in a prior study. These devices can offset the gravitational torque brought on by the mass. In this study, we proposed to build with the flexibility to separate the counterweight once the initial load had been set down. The counterweight basket's wheels make it easy for workers to pre-load the necessary counterweight before moving into position at the beam's tail end for connecting to equalize/ balance the load.

The design and construction of major nuclear facilities require a significant amount of planning, expertise, and attention to detail to ensure the safe and efficient operation of the facility. One critical component of these facilities is the counterbalance beam, which is essential for the smooth and safe movement of heavy objects within the facility. In this paper, we will discuss the design and construction of a custom counterbalance beam for the installation of a major nuclear facility. Counterbalance beams are used in a variety of applications, including cranes, lifts, and other heavy machinery. In a nuclear facility, the counterbalance beam is used to support and move heavy objects, such as nuclear fuel rods, in a safe and controlled manner. The design of the counterbalance beam must take into consideration several factors, including the weight and size of the objects being moved, the height and distance they need to be moved, and the safety requirements of the facility. It was as chosen as the material for the counterbalance beam due to its high strength-to-weight ratio, corrosion resistance, and ease of machining. The design of the counterbalance beam was developed using Computer-Aided Design (CAD) software, which allowed for precise calculations and simulations of the beam's performance. The design was optimized to minimize weight while maintaining sufficient strength and stiffness. The counterbalance beam consists of two main components: the beam itself and the counterweight. The beam is a long, narrow structure that extends horizontally over the area where the heavy objects will be moved. The beam is supported on either end by bearings, which allow it to rotate freely. The counterweight is a heavy mass that is attached to the beam at one end, which provides the necessary counterbalance to lift the heavy objects. The counterweight is typically made of lead or concrete, which provides a high density and low volume.

One critical aspect of the design of the counterbalance beam is the selection of the bearings. The bearings must be designed to handle the weight and movement of the beam, while also maintaining a high level of precision and reliability. The bearings are typically made of high-strength steel or bronze, which provides excellent durability and resistance to wear and tear.

Another important consideration in the design of the counterbalance beam is the control system that operates it. The control system must be designed to ensure the safe and accurate movement

of the heavy objects. The control system typically includes sensors, actuators, and controllers that work together to control the movement of the beam and counterweight.

The construction of the custom aluminium counterbalance beam requires an elevated level of precision and expertise. The beam is typically machined from a solid block of aluminium using Computer Numerical Control (CNC) machines. The machining process is carefully monitored to ensure that the dimensions and tolerances of the beam are accurate and precise. Once the beam is machined, it is carefully inspected for any defects or imperfections that could affect its performance. The counterweight is typically cast in place using a high-density material, such as lead or concrete. The counterweight is carefully positioned and attached to the beam to provide the necessary counterbalance. Once the counterweight is in place, the entire assembly is evaluated and calibrated to ensure that it meets the required performance specifications.

Background Design study:

After researching on design side of the structure, originally the client need was to have a counterbalance steel beam. Due to the weight of the beam engineers offered the client with a solution of aluminium beam and a basic concept. Although aluminium is lighter than steel, but steel is harder compared to aluminium, aluminium alloys dent, scratch, or ding very easily while steel is strong and less likely to deform its original shape, bend & it perform very well under the allowed applied load.

Most importantly it is a lot cheaper than the aluminium. By designing a lifting beam which is made of material steel, it will be a cheaper than the aluminium beam, by having it at affordable cost it will push the company in competitive market and open doors to think out of the box. Which then will progress towards future orders of the lifting beam.

Looking at the original lifting beam with steel material it gives a tare weight of approximately over one tonne 1050kg, this weight of the beam is on its own which excludes any rope, slings, shackles, cage & the calibrated weights.

Looking the weight above it will take the total weight around 2 tonnes?

See below the beam and the mass in solid works.

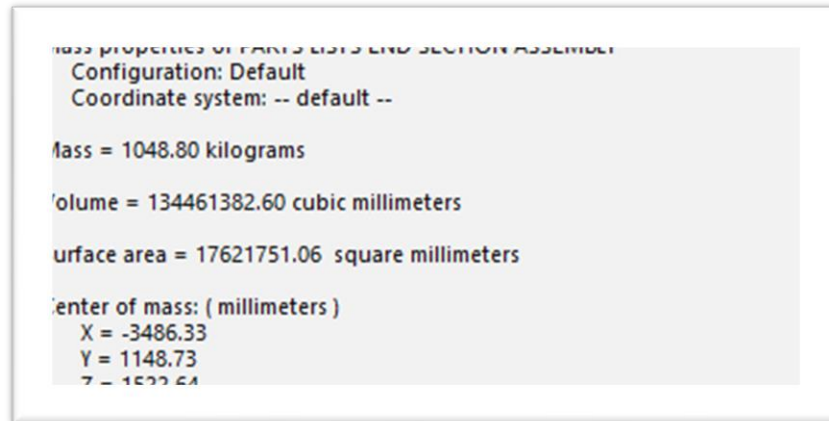


IMAGE - 3 STEEL BEAM MASS PROPERTIES

ORIGINAL DESIGN STEEL BEAM

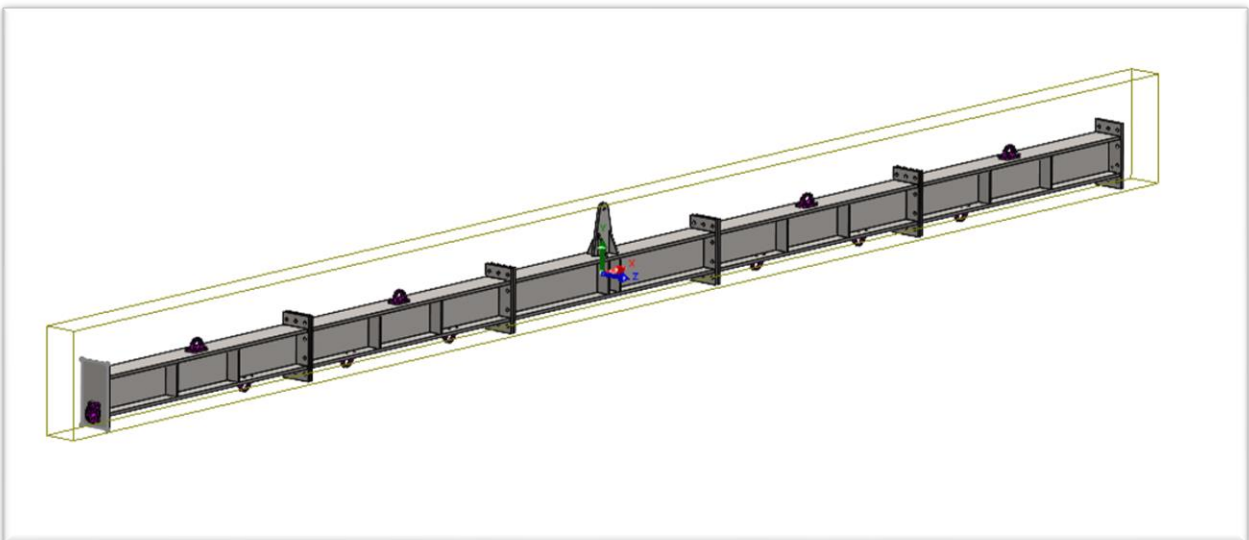


IMAGE - 4 STEEL BEAM SECTION

In the above image of beam a concept design can be seen, as mentioned above about the weight of the beam, there are also a lot more to consider, 4 NO top lifting points in pink colour are there just to lift the beam in small sections beam was designed to be able to be bolted because 10 meter long span of aluminium beam would have been impossible to achieve, a larger beam could have been selected but then it would have took the cost to extreme level as well as the tare weight although it will be less then steel but achieving that mass and by selecting aluminium would be a unsuitable choice.

As well as minimum of 50 M20 grade 8.8 bolts, nuts and washers will also be required just to bolt the beam together.

Basic Concept of Counter-Balance beam:

The basic concept of the Counter-Balance Beam is to use variable amounts of counterweight to offset the weight of the targeted lift. By traversing the counterweight along the length of the beam, the target item is smoothly lifted from its location.

A counterweight lifting beam is commonly used in a construction environment to lift/install an item underneath an overhang.

Facilities required:

For the project to be successfully software will be needed to help carry out complex calculations to improve existing structure.

Solid works – several areas of solid works will be needed – 3D modelling, sheet metal design, weldments for structural elements, finite element analysis, and topology analysis in solid works.

Lifting Beam requirement:

- ✓ To design the counterbalance, beam some critical requirements are needed to ensure the lifting beam will be fit for the purpose.
- ✓ Load capacity of counterbalance beam 2 tonne. To be tested at proof load, which is 2 times the safe working load.
- ✓ Not to exceed the maximum stress, due to BS EN 13155, stating that the factor of safety of 2 is needed to satisfy the standard without permanent deformation occurring & factory of safety of 3 with permanent deformation. (What is BS EN 13155 standard: BS stands for British National Standard & EN stands for European Committee, where as EN 13155 is a standard for a non-fixed loading attachment, which can include cranes, hoists & also manually controlled load manipulating devices.)

Available at www.en-standard.eu/csn-en-13155

- ✓ Beam needs to be sufficient size for cranes to lift.
- ✓ To only lift balanced loads.
- ✓ The Lifting Equipment Engineers associated: LEEA. LEEA are an accredited training courses which are specially designed for the end users of lifting equipment.
- ✓ LOLAR (Lifting Operation & Lifting Equipment Regulations, 1998) is a legal requirement, it places duties on competent person or people & companies who operate or own control over lifting equipment.

Lifting Operations and Lifting Equipment Regulations (LOLER) ([hse.gov.uk](https://www.hse.gov.uk))

- ✓ Machinery Directive 2006/42/EC2006/42 – S.W.L, Type of equipment, safe for us, DOC (Declaration of Conformity), Marking.

Here Machinery Directive 2006 42 EC it focuses at the market circulation on machinery & at the protection of the consumers or employees who uses the equipment. It explains the necessary health & safety requirement for certain categories of machinery.

[Directive 2006/42/EC - new machinery directive | Safety and health at work EU-OSHA](#)
(europa.eu)

Specifications:

1. The purpose and function – what will your product do?

The main function of the product is to safely lift balanced loads from A to B, as well as lift balanced counterweight loads.

- ## 2. Performance requirements

The counterbalance beam will need to be robust and operate correctly for at least 10 years, The client had requested a lifetime of 10 years to ensure buying them was commercially viable must be easy to maintain.

The life span of the lifting equipment's is generally anywhere between 8 to 10 years generally, but it all depends on the amount of hours its getting used it can also be reduced down to 6 years. In a height and safety manufacturers article it was mentioned that a lifting equipment can have a life up to 10 years depending on regular inspections and not loading it more than its safe working load.

3. What materials will product be made from?

The final design of the lifting beam will be manufactures from Mild Steel S 355 which has the material property of 355 MPa, other material could have been considered for example aluminum can be used to manufacture the lifting beam but to keep the asset cost effective and to work well under the applied load.

Steel S 355 is a medium tensile, low in carbon & manganese metal which a high strength to weight ratio. This material is easily weldable, resilient & robust material which contain good weather & impact resistance, even in extremely cold temperatures.

[Steel Fact Sheet: S355 Grade \(buyabeam.com\)](http://buyabeam.com)

4. The market or user requirements?

Must be suitable for engineers to use. Must be used by authorized person.

5. Values and issues that may influence design.

Balanced loads in order to lift using the most suitable lifting points located on the beam. Mass reduction is one of the main customer's need which makes it a self-weight of the beam.

6. Consideration for the manufacturing process?

Must be easy to use and maintain & be able to be manufactured.

7. Finish of product?

Beam will be self-finish with no painting required although lifting points will be painted for them to stand out and the cage which will be designed which will work as a weight basket will be finished powder coated RAL (1003) which is yellow color code for lifting equipment's.

8. Scale of production?

Number of clients will be willing to have this beam manufactured for their ongoing projects, currently a client want a concept design which possibly will lead to manufacture it. Currently a client require 10 to 12 of lifting beams at different sites for a long term on going project.

9. Quality and safety issues

Beam must be safe and easy to use. Welds will be magnetic particle inspection. A load test will be carried out on the beam after completion to ensure it meets deflection limits. Beam will also go through proof load test.

Must conform to BS EN 13155, manufactured to BS EN 1090 EXC 2 (BS EN 1090 Execution class is entitled as “technical requirement for the execution of steel”).

10. Ergonomic and Anthropometric dimensions?

Must be easy to use and user friendly.

11. How long will it take to make?

An estimation of 2 weeks per beam, this is confirmed from a prototype model being fabricated, with took 2 weeks to complete from start to be finished.

12. Cost restraints?

There is potential order of 10 beams at minimum and maximum to 12, the lifting beam will cost to customer at £17722.00 with generating a profit of 8861.00 per lifting beam.

So a total profit of $8861 \times 10 = £88610.00$ is expected.

13. Lifespan?

The device must last 10 years for it to be commercially viable.

14. Recyclability?

Once the beam has reached its end of life it can they be fully recycled.

LITERATURE REVIEW:

Xiaoqing Kang, Tao Ren, Wentao Qu used conventional counterbalance mechanism featuring a fixed counterbalance torque is to balance the nonuniformity of polished rod load. Therefore, it cannot satisfy the demand of polish rod load which changes with well-condition and then leads to increase of power cost for decreasing quality of balance. This paper presents a new dynamic adjusting mechanism of counterbalance in beam-pumping unit that can adjust the counterbalance torque automatically without stopping the unit according to the new balance parameters derived by analyzing the variation of well-condition and increase productivity at the same time. A data comparison based on the corresponding kinetic model of transmission mechanism is also discus.

A.L. Podio, J.N. McCoy, F. Collier used a systematic study was undertaken in order to establish a procedure by which the effect of operating conditions on the efficiency of beam pumping systems can be determined with a minimum of expense. The study concentrated on the effect of easily controllable parameters such as direction of rotation, counterbalance effect. Motor selection, torque mode for variable torque motors. Tubing back pressure, stuffing box friction and motor slip on the energy usage. This literature paper describes the instrumentation, data acquisition and processing system which allows accurate measurement of instantaneous motor power during a pump stroke. This measurement was correlated with dynamometer measurements in order to determine the surface system efficiency. Calculation of the downhole pump dynamometer allows determination of the effect of operating conditions on the volumetric efficiency of the pump. From these measurements. an overall efficiency can be established as a means of comparison, that is, the overall work output at the pump versus the work input at the motor.(Podio, McCoy and Collier, 1994)

Zhao Guo and Gao Yu used the Beam pumping unit is the uppermost artificial lifting equipment in the oilfield exploitation. In order to reduce its energy consumption and to cut down the oil production costs; many manufacturers have developed a lot of types of the energy-saving pumping unit. With different energy-saving principle, the energy-saving effects are quite different. It is becoming very important how to justly and reasonably evaluate the energy-saving effect of a pumping unit. Hydrodynamic simulated experiment well is used to compare the energy-saving effects of four types of pumping units. In the process of the experiments, water is taken as the

medium, offset pumping unit is as the reference body, system efficiency and electricity-saving ratio is as the evaluating goal and all the experiments are executed at the same condition. The relative curves of the lifting height with the system efficiency and the electricity-saving ratio are drawn for the four types of the pumping units. Testing results indicate that the double horse-head pumping unit has the best effect, and then the compound-balanced pumping unit with downward beam balance weight. According to the comparative results, it is put forward the pumping unit selecting suggestions.(Guo and Yu, 2008)

Fengshan Wang, Liu He, Zhou Wanfu, Shi Guochen, Cao Gang, Chang Ruiqing, Zhang Deshi, Lin Dingming used the Daqing Oilfield is the largest continental oilfield of China. And beam pumping system was the main artificial lift method of the oilfield. Till the end of 2008, the number of producers has reached more than 48,000 in the whole oilfield, in which 80% wells applied beam pumping system. Statistics indicated that, the averaged efficiency of beam pumping systems was only about 25% for the whole oilfield resulted in large quantity of power waste. Moreover, the power consumption of beam pumping wells was about one third of the total power consumption of the oilfield development which was the largest part of operation cost.(Fengshan *et al.*, 2009)

In the past ten years, Daqing Oilfield invested huge funding to improve beam pumping equipment's energy-saving techniques. And a series of energy saving rebuilding techniques were developed including two innovative beam pump units, three energy-saving motors, and two new control designs. This paper presented these energy saving techniques in details. Application in more than 2,000 producers indicated that the efficiency of beam pumping systems was improved considerably after using these innovative energy-saving rebuilding techniques.

According to Matt Permintella, mechanical design engineer with RSS, "mass was further lowered by having many circular cut-outs along the beam web and aluminum construction, as this is approximately three times lighter than steel.

For a different client, Efinor, lifting and rigging assurance is offered by Jason Govier, a lifting engineer at Notus Heavy Lift Solutions. Since the establishment of Notus Contract Lifting, a member of the Notus Group of enterprises that also includes Notus Heavy Lift Solutions and Notus Training, RSS, a lifting and rigging specialist, has been a preferred partner.

According to Govier, "This beam is a noteworthy engineering achievement. Based on the load to be raised, lift point position along the beam, counterbalance positions along it, and finally equipment/accessories used, 82,000 variations are available."

After purchasing the Gemmak Company in 2019, which is close to the headquarters in South Wales, Permintella emphasized that the project was yet another illustration of RSS's enhanced engineering capabilities.

Topology analysis has been widely used in the design of mechanical structures for optimal performance. Topology optimization is the process of optimizing the layout of a structure to achieve the desired performance. In this literature review, we focus on the topology analysis of a counterbalanced aluminum beam. The aim is to find the optimal topology that can provide maximum stiffness while minimizing the weight of the structure.

A counterbalanced beam is a type of structure used in various engineering applications, including cranes, bridges, and aerospace vehicles. It comprises two arms, with the weight of the load distributed between them. The counterbalancing effect minimizes the bending moment and shear forces on the beam. Aluminum is a lightweight material with high strength-to-weight ratio and is widely used in structural applications.

Several studies have been conducted on the topology optimization of a beams. In a study by Zhang et al. (2018), the authors used topology optimization to design a lightweight aluminum beam for use in a UAV wing. They used a density-based method and finite element analysis (FEA) to optimize the topology of the beam. The results showed that the optimal topology provided a weight reduction of 37.5% compared to the original design. In another study by Huang et al. (2019), the authors used topology optimization to design a lightweight aluminum beam for use in a motorcycle frame. The objective was to minimize the weight of the beam while maintaining its stiffness. They used a topology optimization method based on the level set function and FEA to optimize the topology of the beam. The results showed that the optimal topology provided a weight reduction of 31.4% compared to the original design.

In a study by Chen et al. (2020), the authors used topology optimization to design a lightweight aluminum beam for use in a robotic arm. They used a bi-directional evolutionary structural optimization (BESO) method and FEA to optimize the topology of the beam. The results showed that the optimal topology provided a weight reduction of 52.1% compared to the original design.

In a recent study by Kole et al. (2022), the authors used topology optimization to design a lightweight aluminum beam for use in a crane. They used a topology optimization method based

on the level set function and FEA to optimize the topology of the beam. The results showed that the optimal topology provided a weight reduction of 40.6% compared to the original design while maintaining its stiffness.

Counterbalance beams are used to offset unbalanced loads in various applications, such as robotic arms, cranes, and balancing mechanisms. The choice of material for counterbalance beams is critical to ensure adequate strength and stability while maintaining low weight. Aluminum is a popular choice due to its high strength-to-weight ratio and corrosion resistance. However, the topology of the beam affects its mechanical properties, including its stiffness, strength, and buckling behavior. In this literature review, we examine the effect of topology on the mechanical properties of aluminum counterbalance beams.

1. Topology optimization of a counterbalance beam:

A study by Wang et al. (2020) used topology optimization to design a counterbalance beam for a robotic arm. The authors used a genetic algorithm to optimize the topology of the beam while considering constraints such as stress and displacement. The optimized beam had a unique topology with fewer material clusters, resulting in a lower weight and higher stiffness compared to the original design. The authors concluded that topology optimization can significantly improve the performance of aluminum counterbalance beams.

2. Analyzing buckling behavior of counterbalance beams:

In a study by Razavi et al. (2019), the buckling behavior of a counterbalance beam was analyzed under different loading conditions. The authors used finite element analysis (FEA) to investigate the critical buckling load and buckling mode of the beam. The results showed that the topology of the beam affected its buckling behavior, with beams with larger cross-sectional areas being more resistant to buckling. The authors recommended that the topology of counterbalance beams should be designed to minimize the risk of buckling failure.

3. Effect of topology on the vibration characteristics of counterbalance beams:

In a study by Xu et al. (2017), the vibration characteristics of aluminum counterbalance beams with different topologies were investigated. The authors used FEA to simulate the natural frequency, mode shape, and damping ratio of the beams. The results showed that the topology of the beam significantly affected its vibration characteristics. The authors concluded that topology optimization could be used to design counterbalance beams with desirable vibration characteristics for specific applications.

4. Topology optimization of composite counterbalance beams:

A study by Zhu et al. (2020) used topology optimization to design aluminum composite counterbalance beams with enhanced stiffness and strength. The authors used FEA to simulate the mechanical properties of the optimized beams and compared them to conventional aluminum beams. The results showed that the optimized beams had significantly higher stiffness and strength than conventional beams while maintaining a similar weight. The authors concluded that topology optimization could be used to design lightweight and high-performance aluminum composite counterbalance beams.

5. Analyzing stress and strain distribution in counterbalance beams:

In a study by Gupta et al. (2021), the stress and strain distribution in an a counterbalance beam were analyzed under different loading conditions. The authors used FEA to investigate the effect of different topologies on the stress and strain distribution in the beam. The results showed that the topology of the beam significantly affected the stress and strain distribution, with optimized topologies having a more uniform stress and strain distribution. The authors concluded that topology optimization could be used to design counterbalance beams with improved stress and strain distribution.

Topology analysis has been proven to be an effective method for designing lightweight and stiff aluminum beams for various applications. The studies reviewed in this literature review have shown that topology optimization can significantly reduce the weight of a beam while maintaining its stiffness. The results of these studies can be used as a basis for future research on the design of lightweight structures using topology optimization.

In conclusion, the topology of aluminum counterbalance beams affects their mechanical properties, including stiffness, strength, buckling behavior, vibration characteristics, and stress and strain distribution. Topology optimization can be used to design lightweight and high-performance counterbalance beams with improved mechanical properties. The studies reviewed in this article provide valuable insights into the effect of topology on the mechanical properties of counterbalance beams and can inform future designs for optimal performance.

The vector Debye integral was used to determine the focusing characteristics of a Gaussian beam that was circularly polarized. The simulation outcomes demonstrated that, when the incident Gaussian beam was focused through an aplanatic lens, a helical term was created in the longitudinal component of the beam corresponding to the handedness of the circular polarization.

An optical partial intrinsic-to-extrinsic angular momentum converter functions in this case as the aplanatic lens. The NA of the lens has little effect on the conversion effect itself, but it does cause a significant decline in the amplitude of the longitudinal component. According to our theoretical simulation it is possible to drive the orbital motion of a highly scattering particle by focusing a circularly polarized Gaussian beam. Separating the particle should be maintained distant from the beam axis to allow orbital motion to be observed due to absorbing optical orbital angular momentum due to the influence of intrinsic spin angular momentum. The direction of orbital rotation should match the circular polarization's sign. For different circular polarizations with the same trapping power, same trapped particle, and similar environment, all other orbital motion characteristics including orbital frequency, diameter, and trajectories should be identical.

[Custom%20Counter%20Balance%20Beam.docx](#)

Gap of the study:

In order to position the beam above additional loads, something built with the flexibility to separate the counterweight once the initial load had been set down. The counterweight basket's wheels make it easy for workers to pre-load the necessary counterweight before moving into position at the beam's tail end for connecting to equalize/ balance the load. Topology analysis on the asset is performed by redefining the mass of the model as well as increasing its safe working load in result less cost to the beam and also less cost on the cranes or hoist which will be used for lifting as small capacity crane will be able to perform the lifting procedure.

As generic lifting beam is not an option by designing a beam which is suitable for many lifting purposes will increase its market value and will suit the client's needs.

Methodology:

In order to provide a safe lift operation, the project's goal is to create a lifting beam or lifting frame that support the balanced loads and not to exceed the safe working load. Utilizing the designed beam, optimization techniques will be used to lessen the structure's overall mass. Due to having a target of a lifting beam to be as light in weight as possible, this will then enable to use a smaller capacity crane, as well as by using material steel **S 355** it will also allow to lift more loads as working load limit will exceed by not using the aluminum beam.

It is also important to keep in mind about the counterbalance loads to be balanced out when lifting, as it can lead to a catastrophic result, in the early stages of the report it have been explain how it can affect the working environment as well as human life can be in danger. Lifting beam have become unstable on several occasions, as a result of the incident all the work has halted until an investigation was carried out, which cost time and money.

Companies in the UK have taken this into consideration as a result of the tragedy and have chosen to utilize a new, safer method of lifting beams, which is why the lifting beam was designed. In order to avoid using a crane with a larger lifting capacity, the companies have stated they aim to utilize the lightest structure possible. In order to identify the best potential size and shape for the platform structure parts, optimization techniques will be used to lower the overall mass of the developed platform.

Software use for analysis:

Software will be required for the project's success in order to carry out the difficult calculations necessary to upgrade the current structure.

- Solid Works - Solid Works in a variety of areas, including 3D modelling, sheet metal design, weldments for structural elements, finite element analysis & topology analysis will be used in solid-works.

Benefits of using Solid works:

Solid works is a software which allows you to design, run analysis as well as many other features & lets you get you design and your concept ideas to the clients or the market. Solid works is a user-friendly software which allows engineers & the designers for a quick amendment, solve design problems, and lets you design in a cost-effective manner as well as errors are detected automatically in early stages.

[CAD / CAM Services with Advantages of SolidWorks 3D Models \(cadcam.org\)](http://cadcam.org)

AutoCAD could have been used but solid works offers more features & fully developed 3D modeling then AutoCAD. Also, CATIA is a designing tool, but it is more on Aviation side while solid works is for mainly structural side of designing.

Engineers prefer solid works as it helps them create the 2D & 3D models, drawings (concept or manufacture drawings etc.), assembly & simulation quickly and more easily. It also lets

engineers & designers to be able to design components & assemblies in 3d modelling more accurately.

[Why Should Mechanical Engineers Learn SolidWorks? Skill-Lync Blogs](#)

FEA Analysis & Results of Aluminum Lifting Beam:

Boundary Conditions Load & Fixtures:

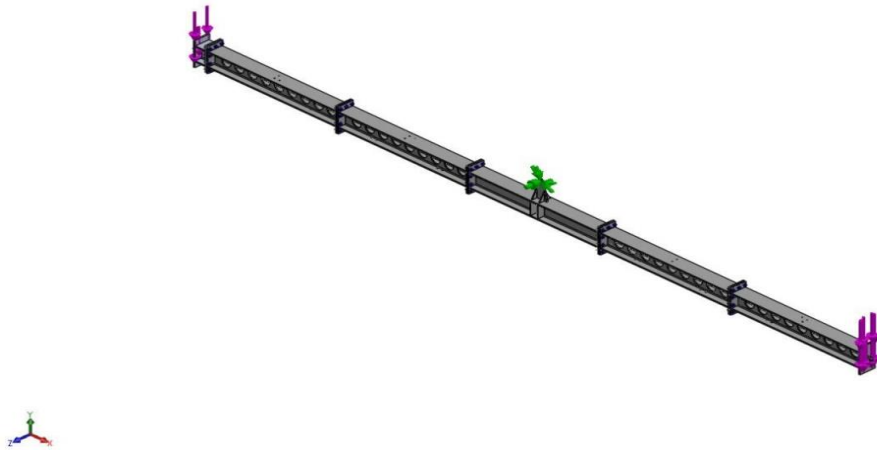


IMAGE - 5 BOUNDARY CONDITION & FIXTURE

The image above shows the boundary conditions of the beam where the top lifting point is the fixture and the load is applied on the two bottom lifting points.

Displacement:

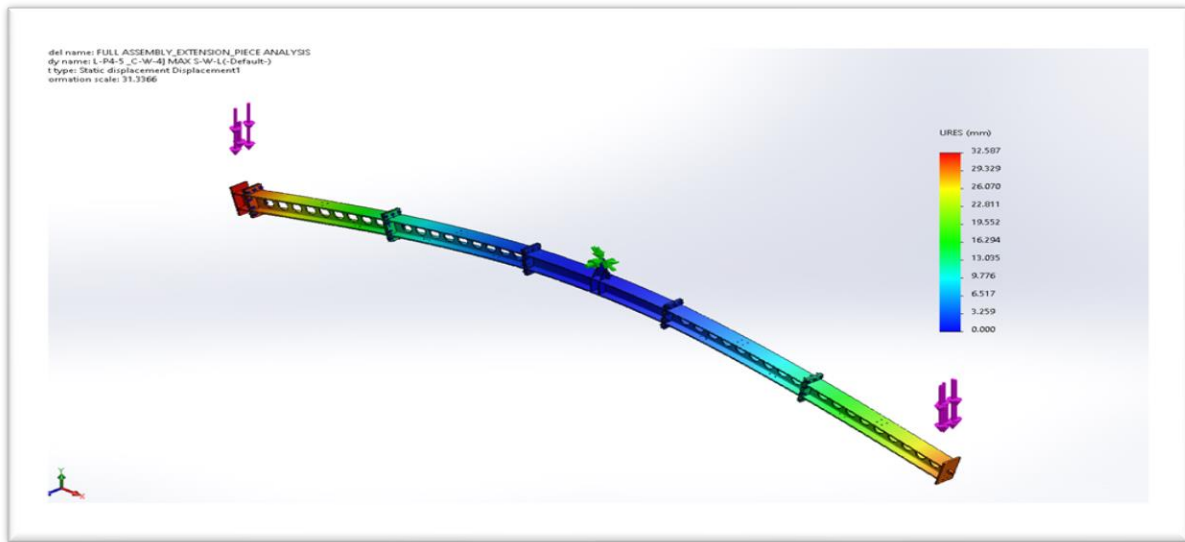


IMAGE - 6 MAXIMUM DEFLECTION

In the image above you can see the deflection limit which is 32mm.

Strain:

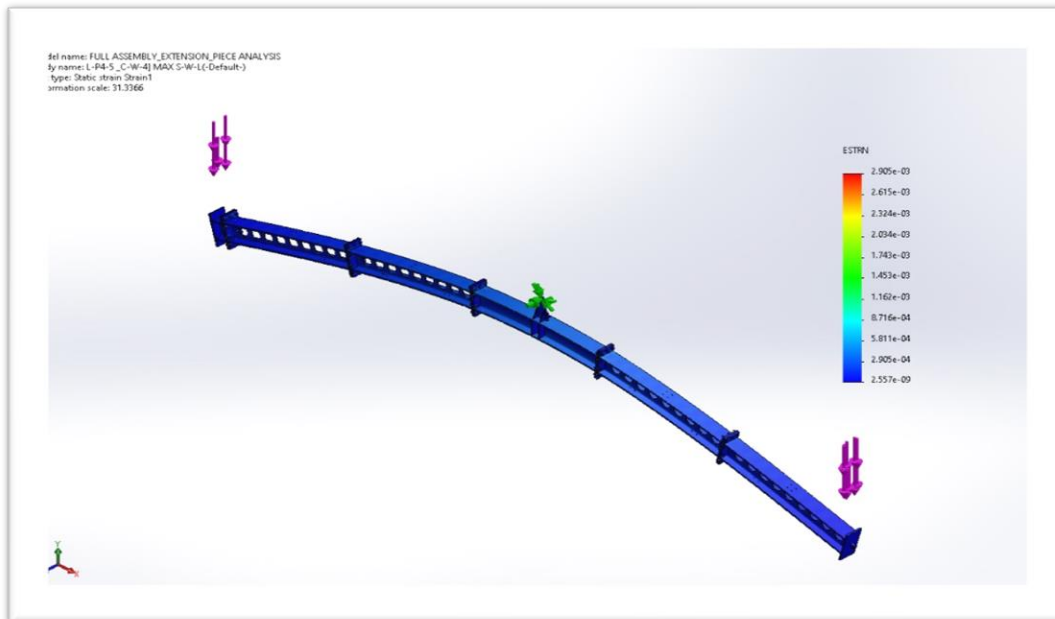


IMAGE - 7 STRAIN VALUE

Image above shows the strain value of the model.

Bolt Check:

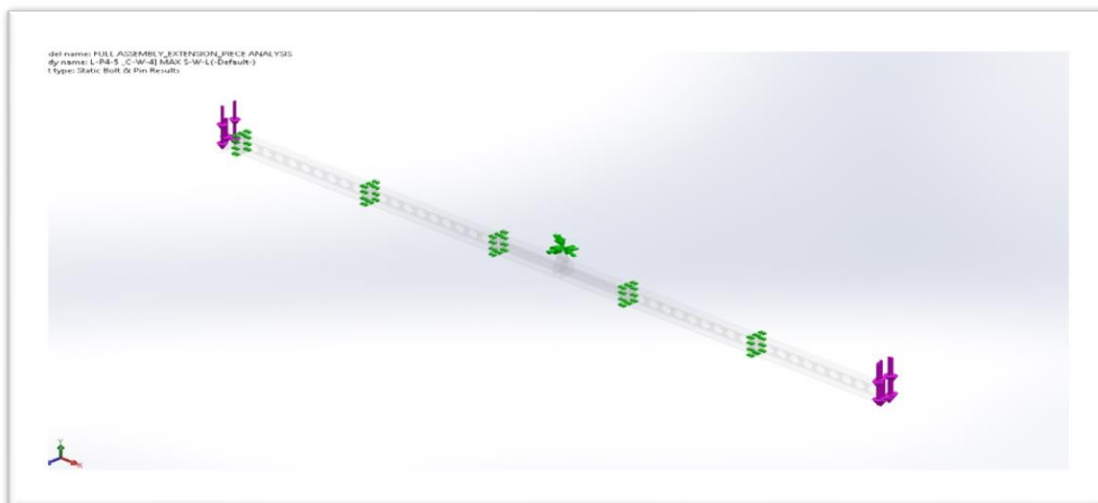


IMAGE - 8 BOLT CONNECTION

Above shows the bolted connection where the bolts will be in place in the model. As the model also have bolted connection it is important to add them to the model to get the results that how the model will react realistically.

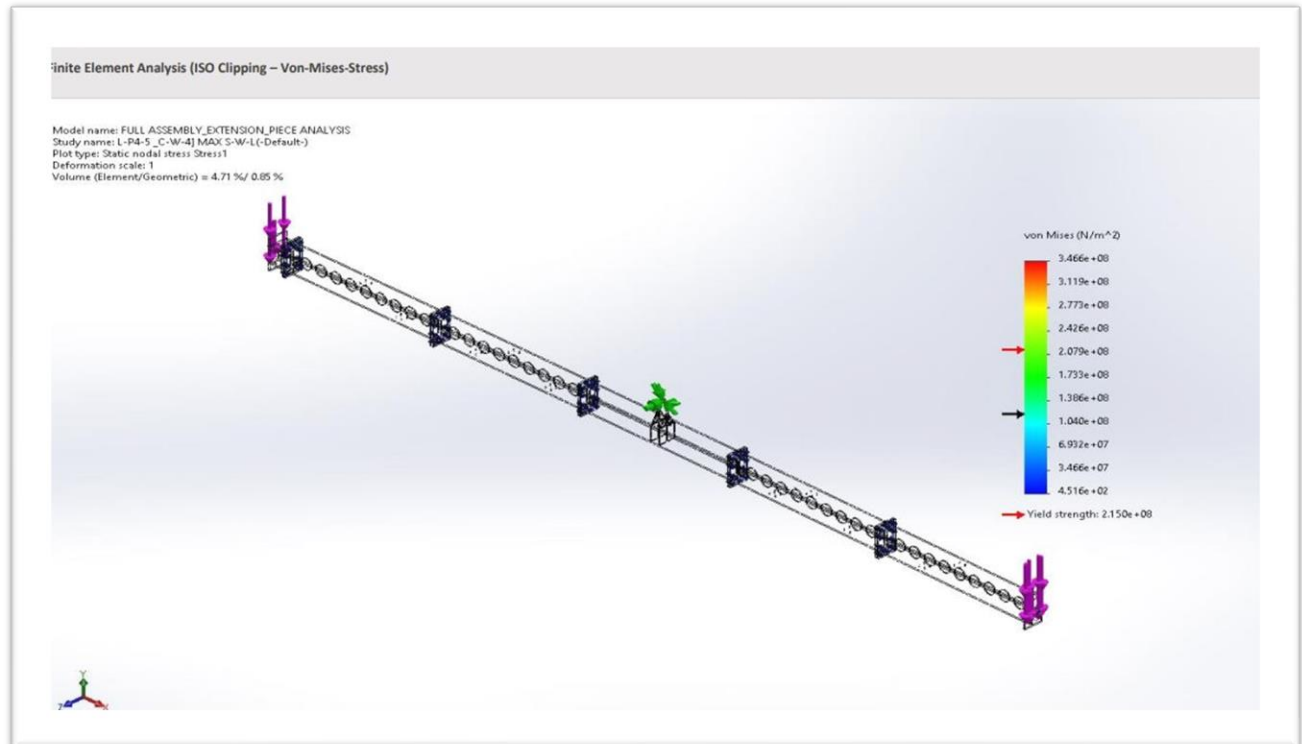


IMAGE - 9 STRESS VALUE

The above shows the maximum stress value a model can take before it reaches the permanent deformation.

Optimization Techniques:

Topology Optimization:

A mathematical method that is used during the concept level of design phase, the goal of this method is to spread the material into critical areas of the model (optimal solid-void pattern) the design engineer will set specific boundaries conditions along with an applied load and limitation of space in the design. In its most basic understanding, topology optimization takes the given 3D model and displaces and removes material to make the design the most effective it can be

(maximum stiffness in structure with the least amount of material, minimizing the strain energy to its lowest energy state) (Topological Optimization with FEA | Finite Element Analysis (FEA) Blog – LEAP Australia & New Zealand, 2020). The objective of the function does not consider ease of manufacturing neither take into consideration the aesthetics of the finished geometry. (Topology Optimization | Benefits & Disadvantages | Software, 2020).

Topology optimization can focus on an entire component or elements of it. TO uses a finite element analysis to use a mesh on the design space. The model undergoes stress and strain analysis to find how the structure performs this allows the optimization run to know where to put the material within the design space. With each iteration material is removed if this removal affects the stiffness the process will stop, and material will be retained in this area. A weight objective is set before the optimization run is performed (e.g., 50%), other objectives and constraints can be set such as buckling, frequencies. (Topology Optimization | Benefits & Disadvantages | Software, 2020).

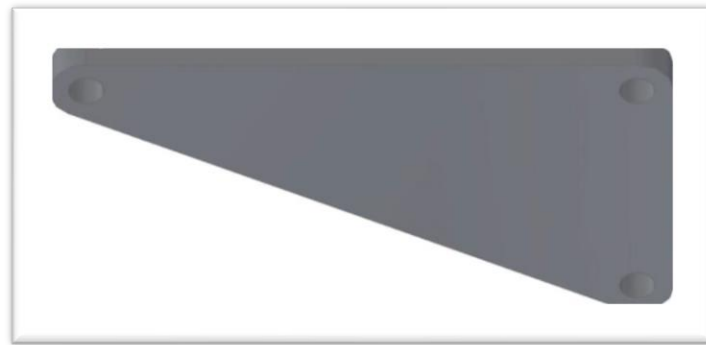


IMAGE - 10 GEOMETRY BEFORE OPTIMISATION (TOPOLOGY - BENEFITS & DISADVANTAGES - SOFTWARE 2020)

The above shows the existing designed geometry before optimization has been completed.

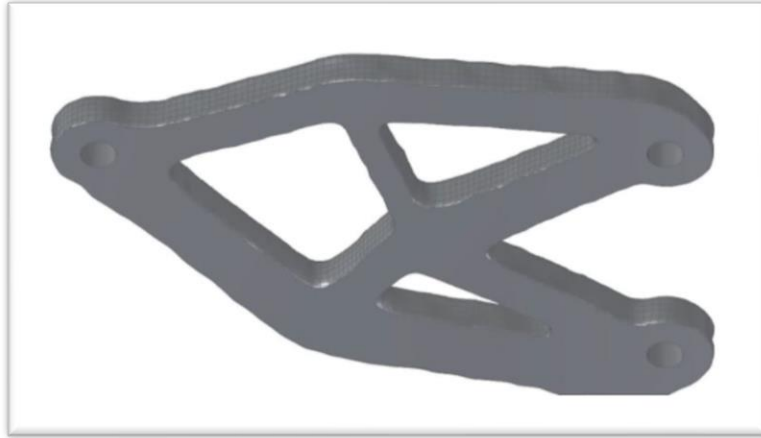


IMAGE - 11 OPTIMISED GEOMETRY (TOPOLOGY OPTIMISATION- BENEFITS & DISADVANTAGES- SOFTWARE 2020)

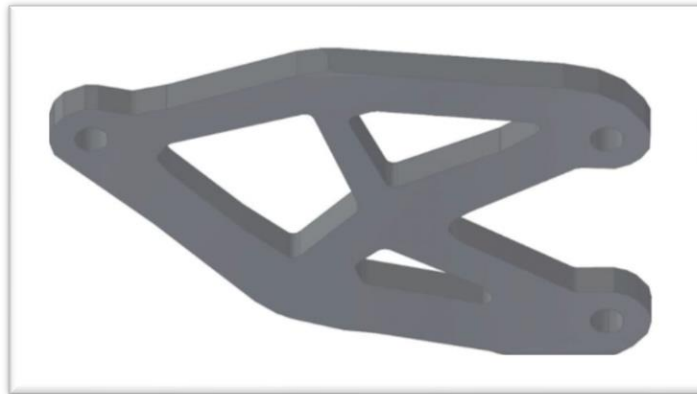


IMAGE - 12 FINAL OPTIMISED GEOMETRY AFTER POST PROCESSING HAS BEEN DONE- (TOPOLOGY OPTIMISATION BENEFITS & DISADVANTAGE - SOFTWARE 2020)

During the optimization run the structure undergoes several changes, with each iteration the material is displaced into each critical location. The below shows this process.

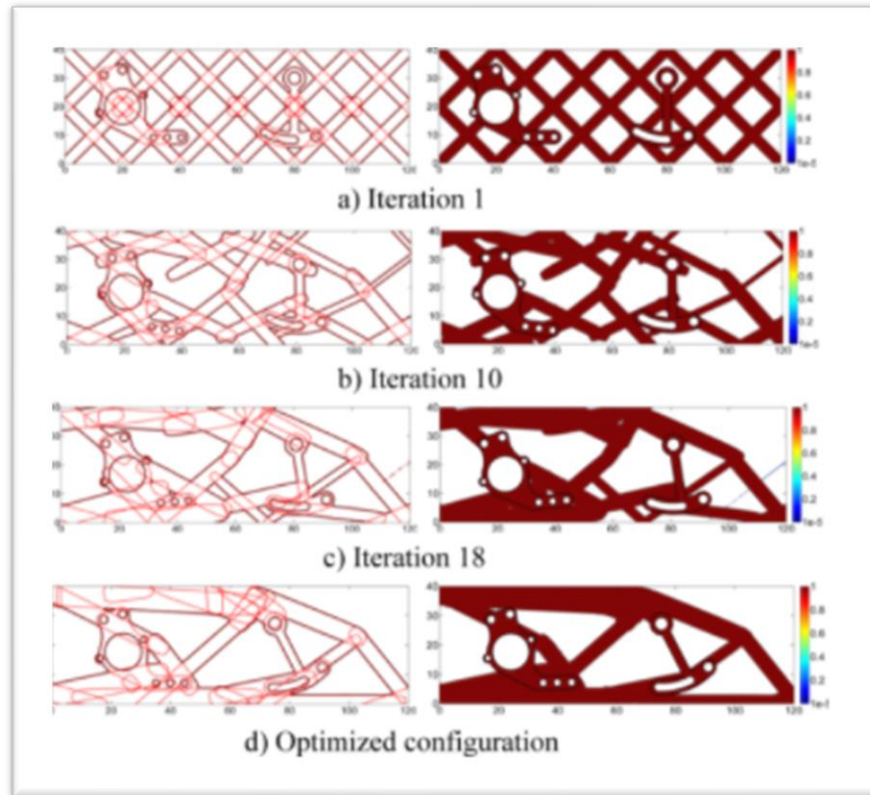


IMAGE - 13 SHOWS ITERATION 1 TO 18 & THE FINISHED OPTIMISATION CONFIGURATION - TOPOLOGY OPTIMISATION WITH FEA - FINITE ELEMENT ANALYSIS (FEA) BLOG - LEAP AUSTRALIA & NEW ZELAND 2020

Image (13) Shows iteration 1 to 18 and the finished optimization configuration. (Topological Optimization with FEA | Finite Element Analysis (FEA) Blog – LEAP Australia & New Zealand, 2020).

Sizing optimization:

Sizing optimization seeks for optimum geometry size of complex structures with various load cases, without changing the generalized shape it finds an optimum relation between stiffness and weight, sheet thickness is changed to find the dynamic behavior of the given model (Systems, 2020). Sizing optimization finds best dimensions for composites, shells, and bar

elements. (Topological Optimization with FEA | Finite Element Analysis (FEA) Blog – LEAP Australia & New Zealand, 2020).

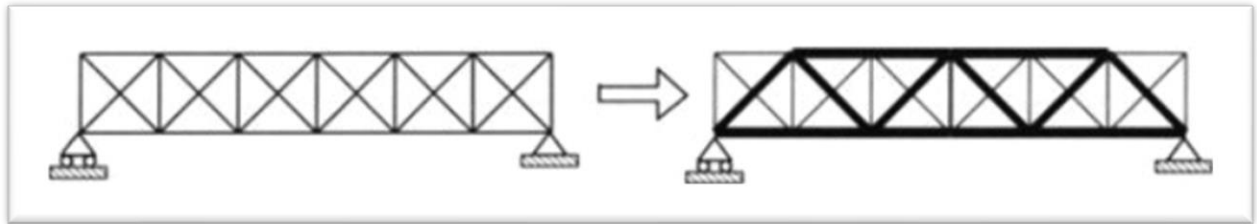


IMAGE - 14 SIZING OPTIMISATION (THE THREE CATEGORIES OF STRUCTURAL OPTIMISATION OF A TRUSS 2020

Shape optimization:

Shape optimization capability which allows the user to find the best shape possible. The software finds the best location of the finite element nodes, which define the shape of the structure. (Topological Optimization with FEA | Finite Element Analysis (FEA) Blog – LEAP Australia & New Zealand, 2020).

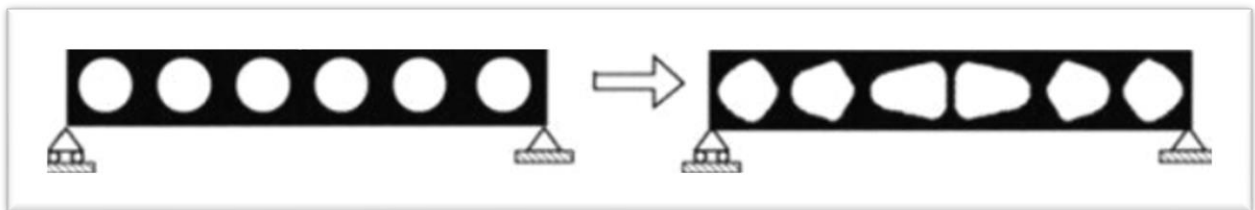


IMAGE - 15 SHAPE OPTIMISATION (THE THREE CATEGORIES OF STRUCTURAL OPTIMISATION A SIZING OPTIMISATION OF A TRUSS 2020

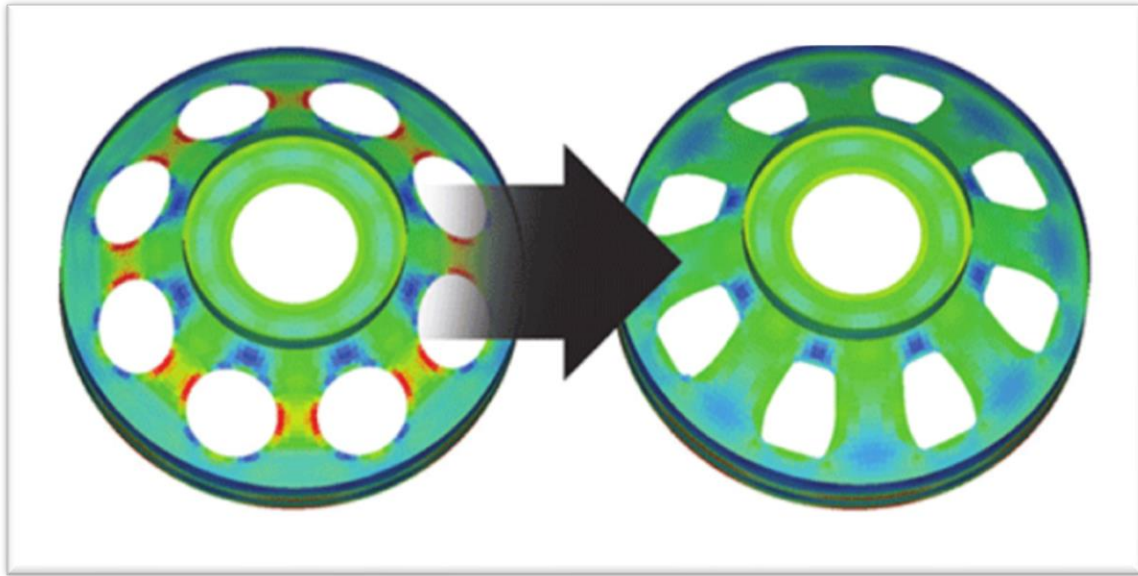


IMAGE - 16 SHAPE OPTIMISATION OF CUT OUTS IN A THIN-WALLED STRUCTURE

[1: Comparison of size optimization, shape optimization, and topology... | Download Scientific Diagram \(researchgate.net\)](#)

As seen in the above image (16) the shape has been changed to mitigate the high stress regions observed (left side). The optimized shape (right side) has stress distributed evenly within the structure.

Topography optimization:

Topography Optimization is a more advance form of shape optimization is giving the engineer the capability of generating bead patterns and swages on the model these are used on panel/shell like structures (university, 2020). This is ideal because it will maximize the stiffness on the same overall geometry without increasing its mass, therefore gaining a lighter stiffer structure. It may also be utilized to maximize the frequency of the geometry; this is governed by the objective given by the user. (Structure > Run > Optimization > Topography Optimization, 2020).

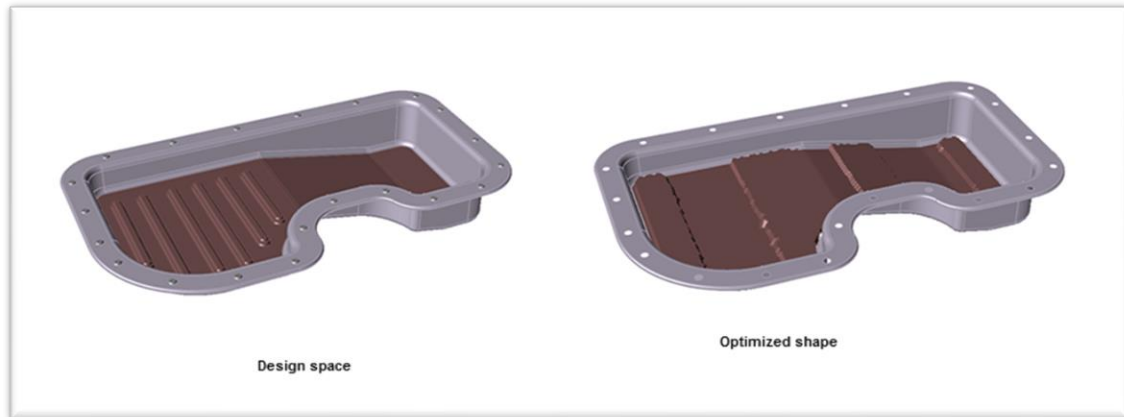


*IMAGE - 17 TOPOGRAPHY OPTIMISATION OF A SHEET METAL PARTS
(STRUCTURE>RUN>OPTIMISATION>TOPOGRAPHY OPTIMISATION, 2020)*

Topometric Optimization:

Topometric optimization is a unique technique, it allows the engineer to find the optimum distribution of elements in the design space (Tonometry Optimization: A New Capability to Perform Element by Element Sizing Optimization of Structures, 2020). Like topology this technique is used to take material out of the model, however unlike topology it can also add material to the design space, typically the user can define thicknesses of each element as a design variable. This technique can be utilized simultaneously with shape, size, and topography optimization. (Topological Optimization with FEA | Finite Element Analysis (FEA) Blog – LEAP Australia & New Zealand, 2020)

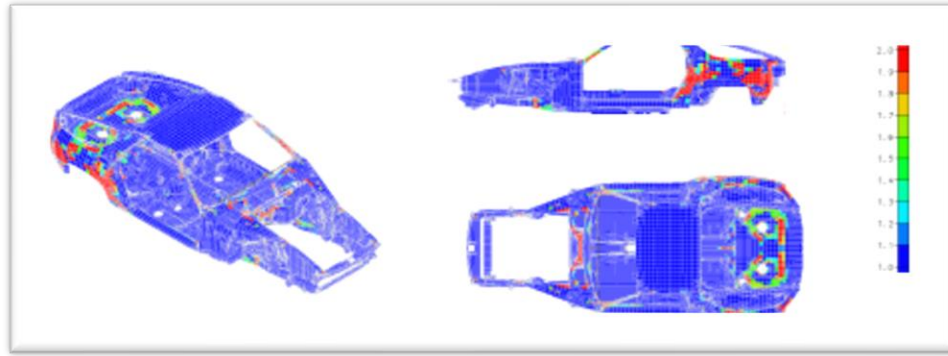


IMAGE - 18 Thickness distribution, Tonometry optimization. (Tonometry Optimization: A New Capability to Perform Element by Element Sizing Optimization of Structures, 2020).

Freeform Optimization:

Freeform optimization is a new variation of shape optimization it allows the user to find the best shape of rib patterns that allow structures increased stiffness, even within solid. Shape optimizations were performed whole vector whereas in free optimization these vector are split so each grid or sets of grids can have their own single variable, this allow greatly flexibility within the optimization to find an even more optimum shape. (Freeform Optimization: A New Capability to Perform Grid by Grid Shape Optimization of Structures, 2020). It has been given the name freeform optimization this could be a generalized version of topography as it can achieve the same results, however freeform optimization can be utilized on shells, trusses, and solids giving it more freedom to be utilized however it needs to be, topography is mostly used with shell type geometry. (Freeform Optimization: A New Capability to Perform Grid by Grid Shape Optimization of Structures, 2020).

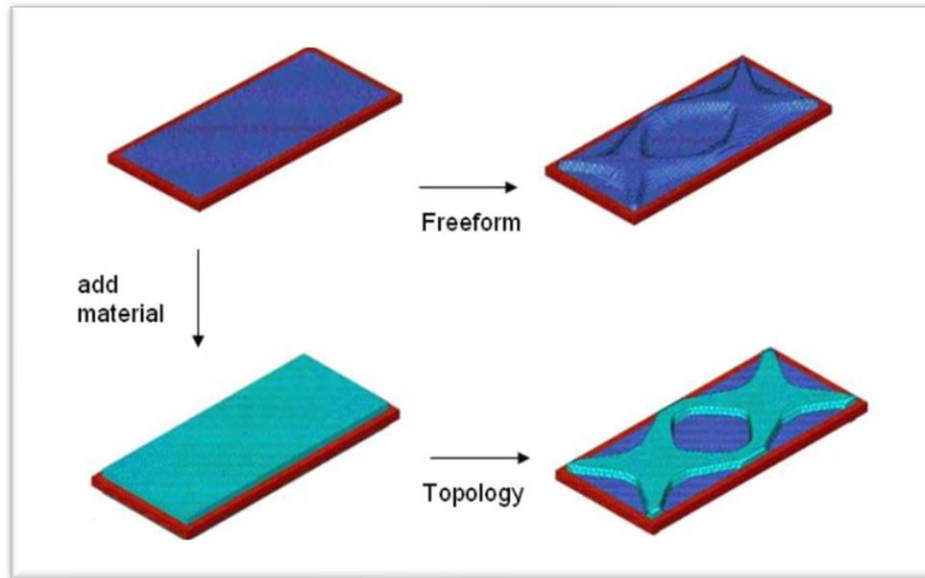


IMAGE - 19 freeform optimization of sheet metal part. (Freeform Optimization: A New Capability to Perform Grid by Grid Shape Optimization of Structures, 2020).

As you can see by the above topology adds material into new shape whereas freeform will change existing geometry into a stiffer shape.

Composite Optimization:

Composite optimization is being used in many areas of engineering it offers high stiff and low mass, long fatigue life, it also has superior thermal properties and are corrosive resistance.

Within composite optimization optimum thickness for each layer can be obtained, optimum ply angles and optimum stacking of plies. Below show possible routes for composite optimization.

(University, 2020)

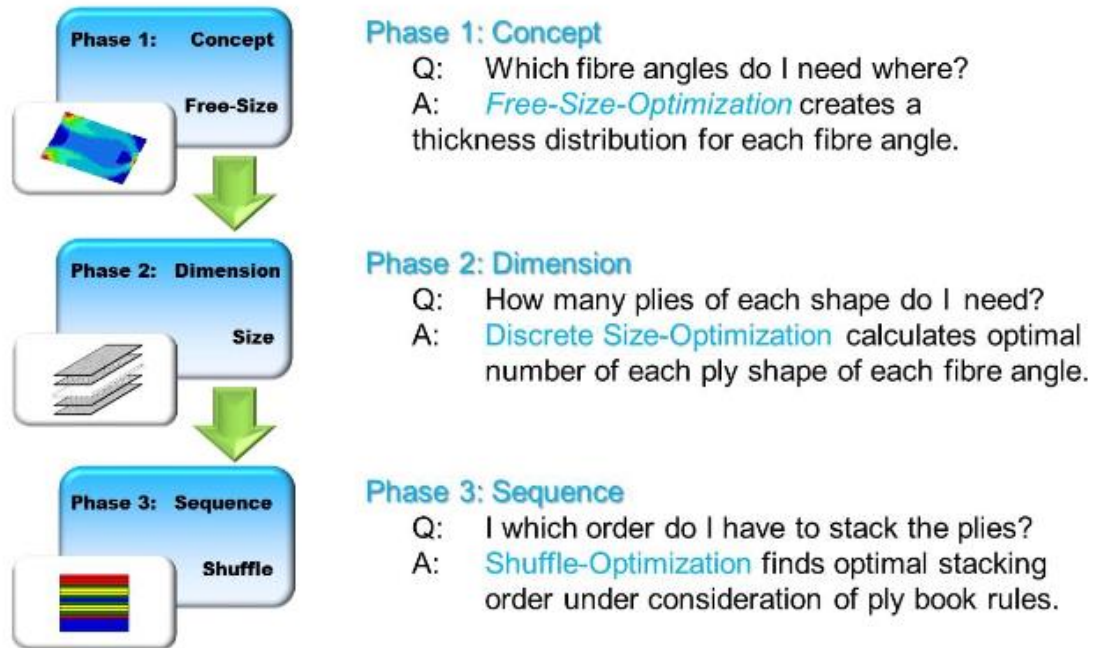


IMAGE - 20 Shows composite optimization routes. (University, 2020)

Benefits of using FEA optimization:

The benefits of using finite element analysis optimization techniques during the design phase, can greatly influence the design process and gain desirable results needed in today industries.

- Reducing weight due to needing less material to achieve the same stiffness.
- Reduce cost due to these weights saving, without compromising on stiffness.
- Prevent stress concentrations within the model or mitigate them completely.
- Attain desirable performance attributes, such as frequency maximization, stress, or displacement constraints. Using optimization techniques will ultimately avoid huge amount of manual design iterations. (Xia, 2016)
- Remove bottlenecks.
- Can reduce engineering time during the design phase using optimization techniques.
- Optimization can lead to design geometry not thought off normally, very robust design can come to life due to a huge amount of design variable, so the user can explore the

entire design space with several different optimization techniques available. (Topological Optimization with FEA | Finite Element Analysis (FEA) Blog – LEAP Australia & New Zealand, 2020)

- Increased sustainability due to less materials being used. (Querin et al., 2017).

Extensive research has been carried out in-order to determine the most relevant optimization techniques which were ideal to achieve the mass goal of 3 Tonne. Basic topography will be carried out in-order to find the critical load paths. It is determined that shape optimization will achieve an optimum shape of the structure, and size optimization will help in determining the optimum size of members and optimum thicknesses to give the lowest mass possible with the required stiffness needed to ensure the structure meets relevant standards of safety.

Design in Solid works:

To run the topology analysis and design the beam, beam length is entered in the solid works 2d sketch and then set the length, height & the width. And by selecting the sketch it was extruded to required length of the beam.

In the below image a solid block can be seen with the plane set as a mid-plane, which will allow us to create a lifting point (top lifting point), it is important to make it all in the same sketch as a one solid body otherwise topology will not run the whole structure which will then not allow you to include the lifting points in the analysis as they are not attached to the existing structure.

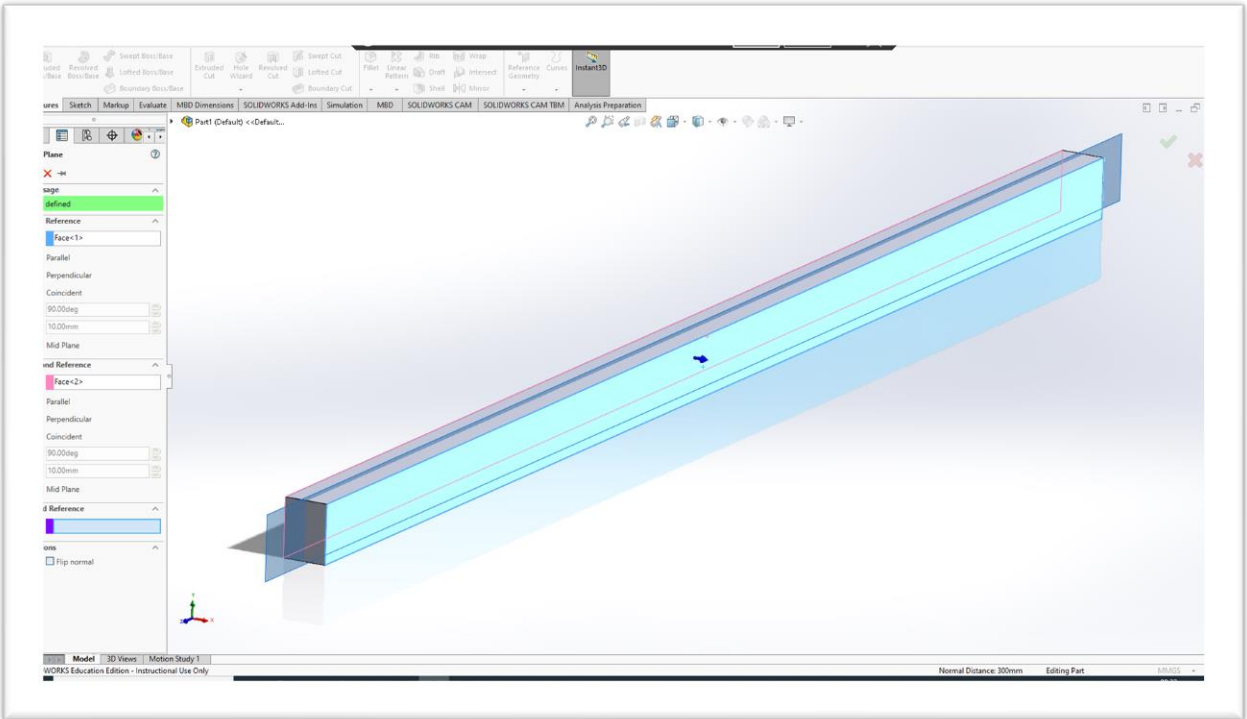


IMAGE - 21- SOLID BLOCK EXTRUDED FOR TOPOLOGY

Below you can see the block with top lifting point.

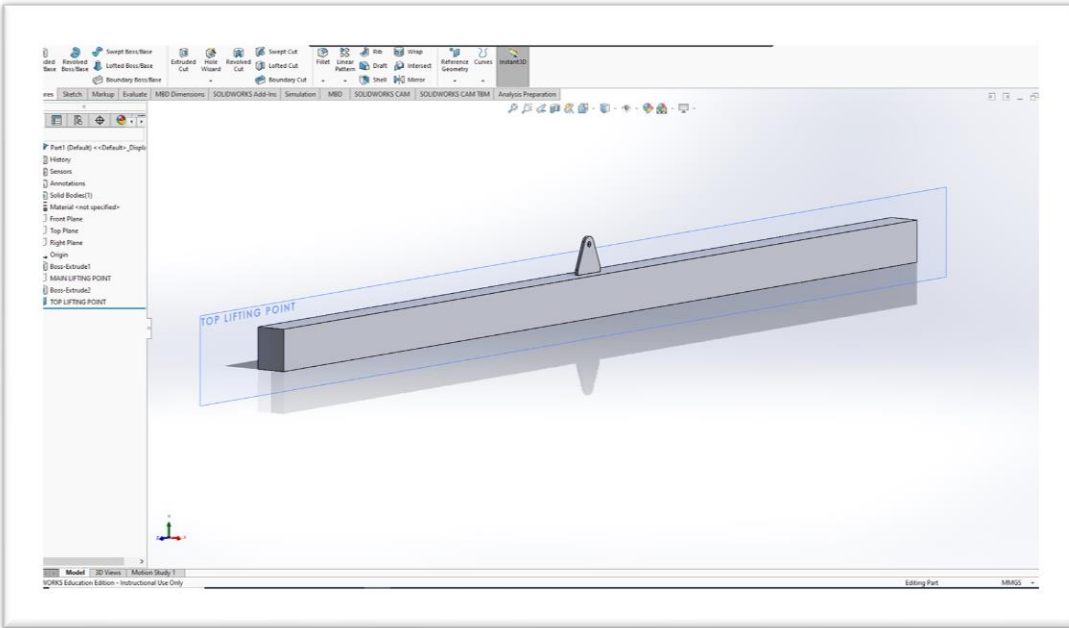


IMAGE - 22- TOP LIFTING POINT FOR TOPOLOGY

Each plane is set to make different lifting points locations as it allows to amend or make changes without interference to other constraints.

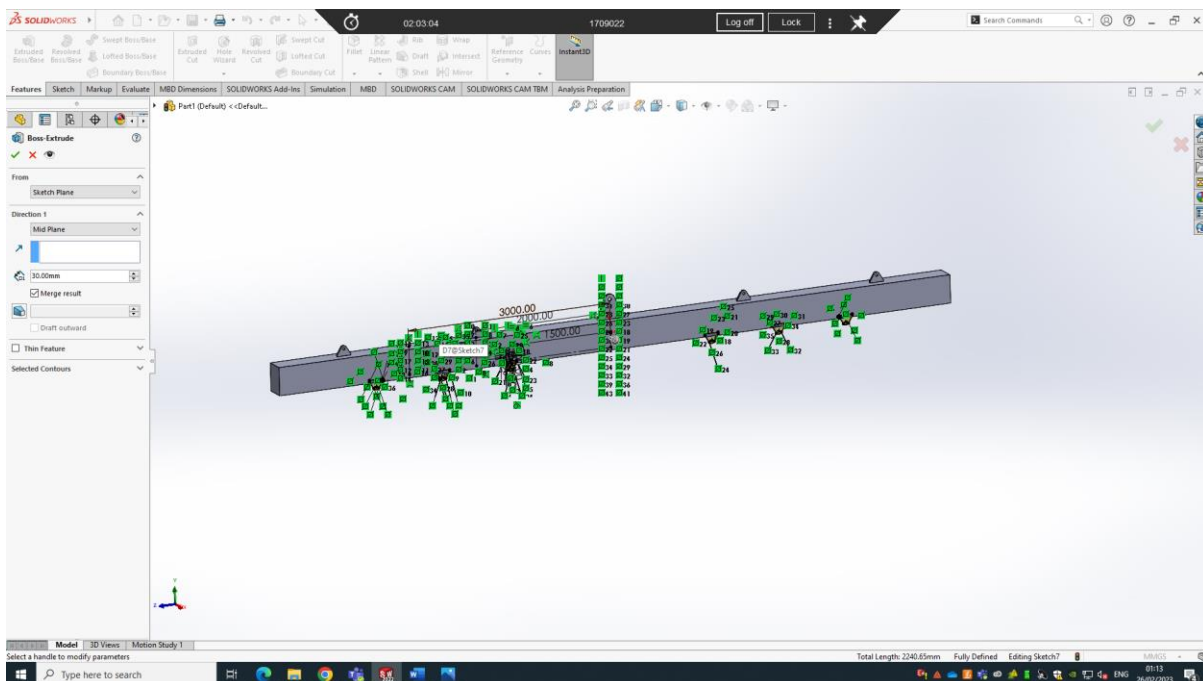


IMAGE - 23- COMPLETE LIFTING POINTS

Now that all the lifting points are created, it is important when creating all the parts when extruding them to click the option for merge results.

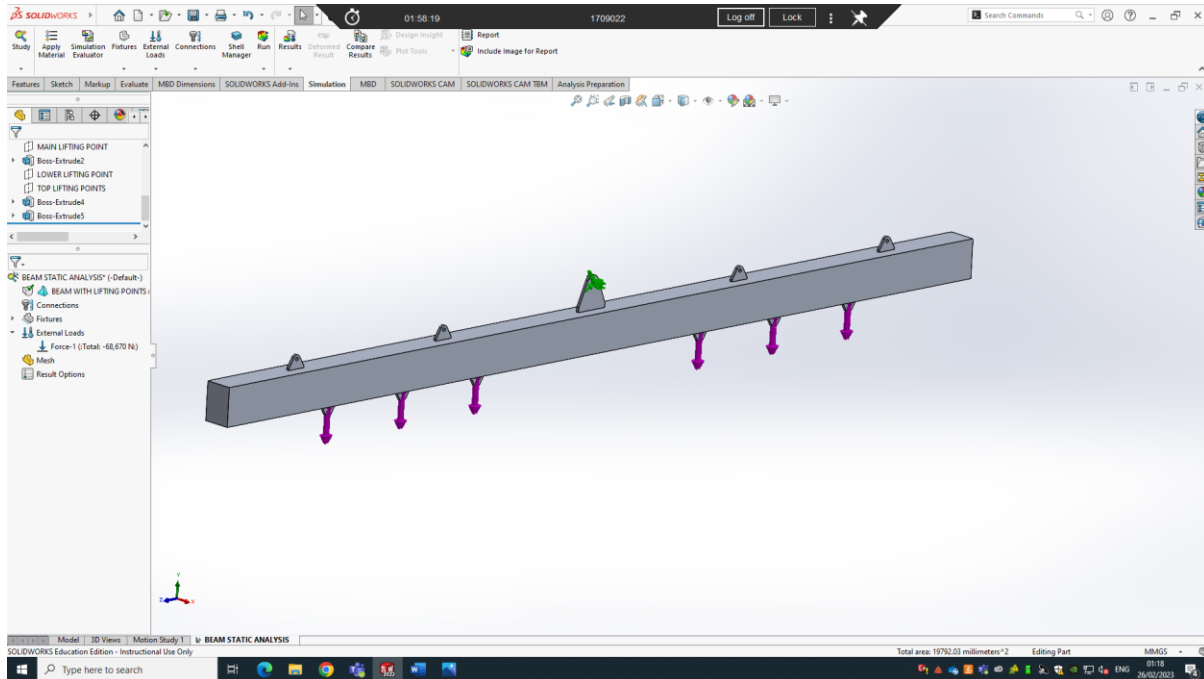


IMAGE - 24- SOLID BLOCK LOADING & FIXTURES

To run topology, it is required to run the FEA first which will then allow the component to consider all the stress and strain and the goals to reach.

In the image below mesh is applied on the design.

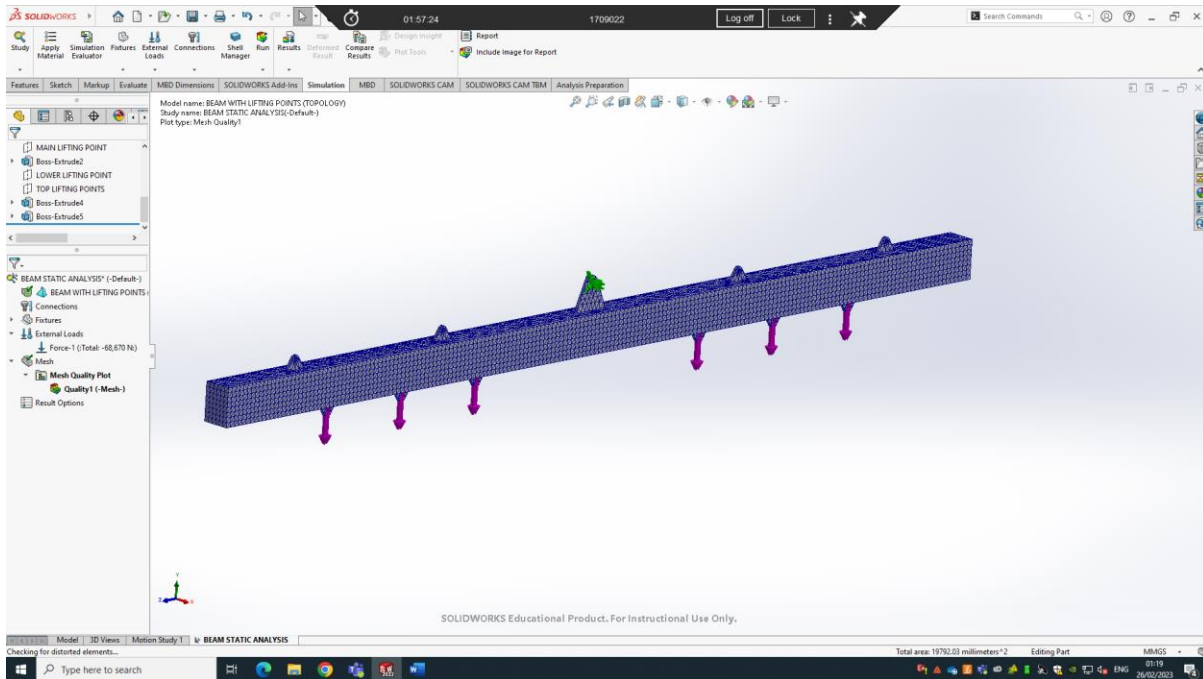


IMAGE - 25 SOLID BODY APPLIED MESH

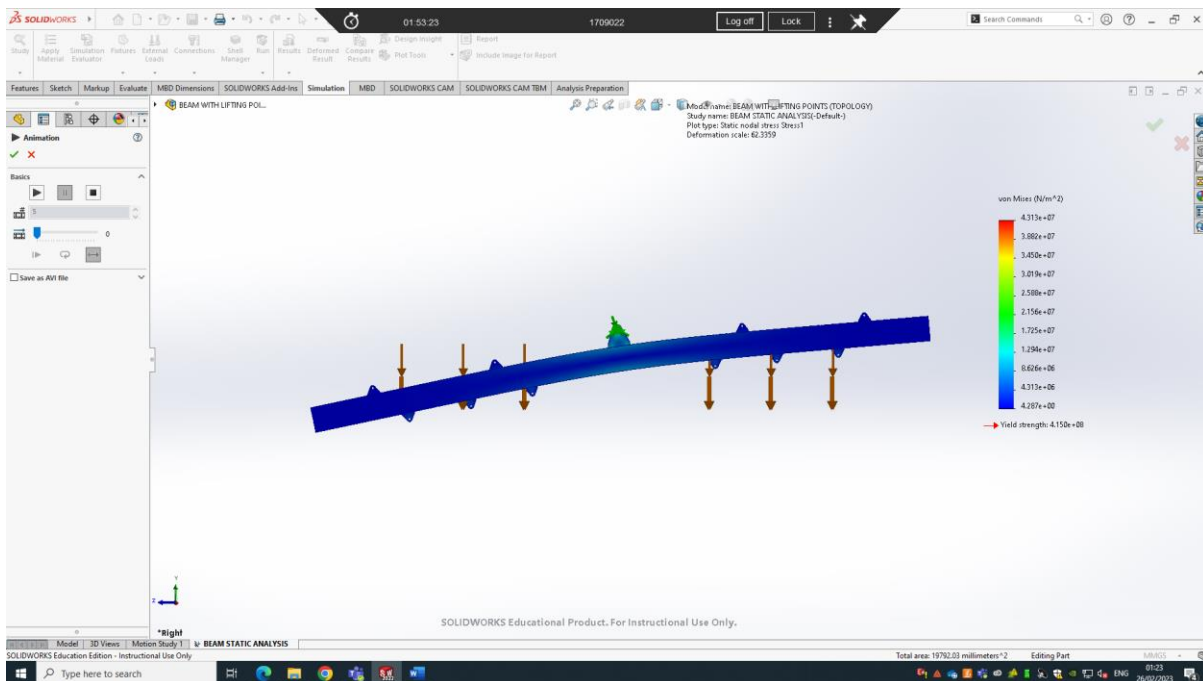


IMAGE - 26- SOLID BLOCK FEA ANALYSIS

To see the FEA results in few different constraints 6 degree of freedom was allowed to see what results we can get. And then as you can see about the model is not stable and have moved which gives then higher value of displacement.

See below FEA results.

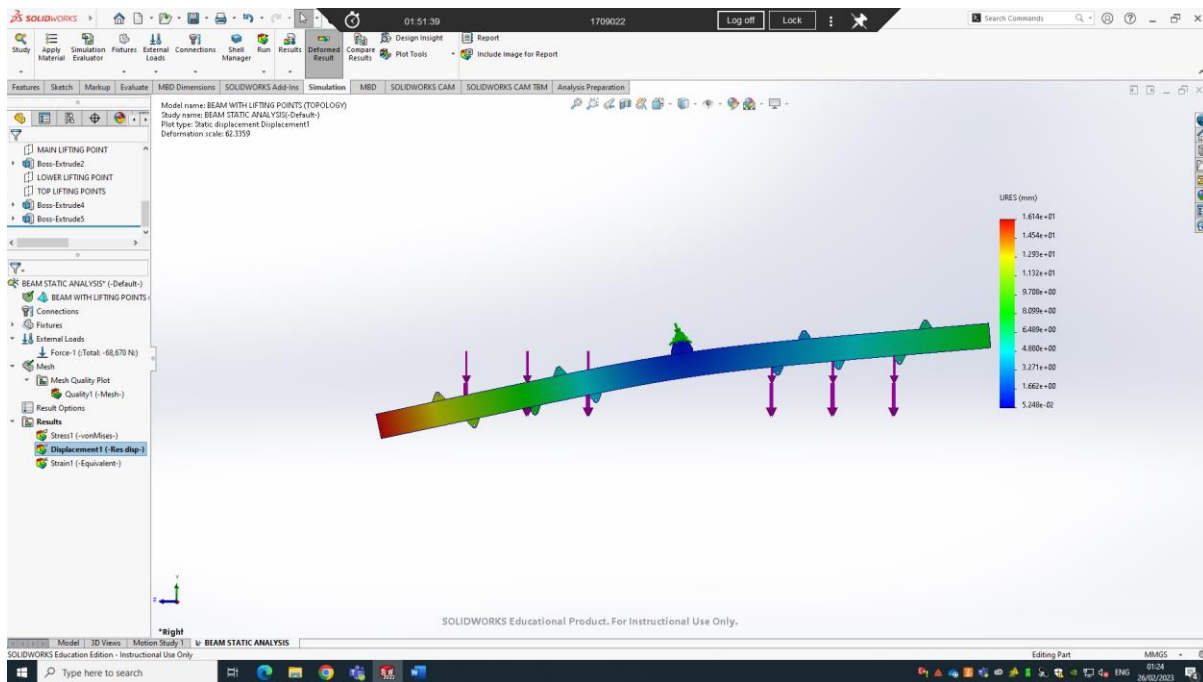


IMAGE - 27- SOLIDBLOCK DEFLECTION

Below images shows when the top lifting point was fully fixed so that we can get accurate results. The model then become stable and provided with results it is then a user as an engineer's responsibility to verify the results. FEA gives you results but that does not beam that they are correct we then have to check all the forces, fixtures & the connections are accurate and are set as a model will be used in real life.

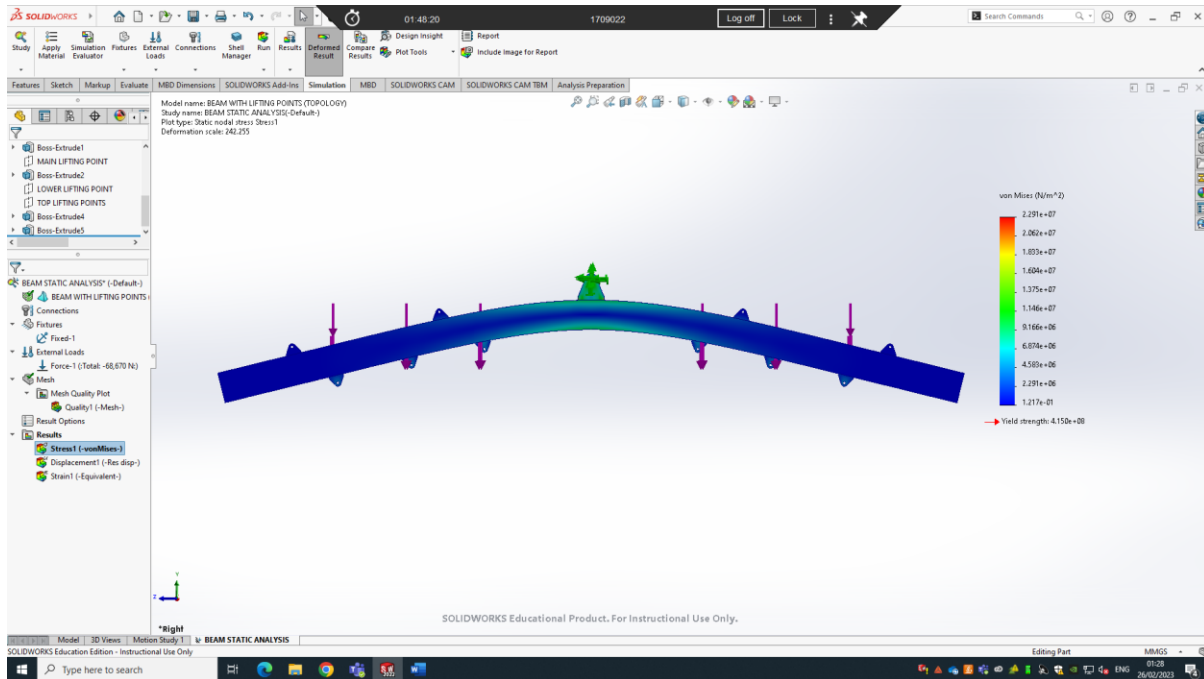


IMAGE - 28- SOLID BLOCK STRESS VALUE FULLY FIXED

For a product to be safe for use, it is required to consider running the analysis on the worst-case scenario to get the worst results possible. In their below images the analysis were run to get the results for the worst-case scenario.

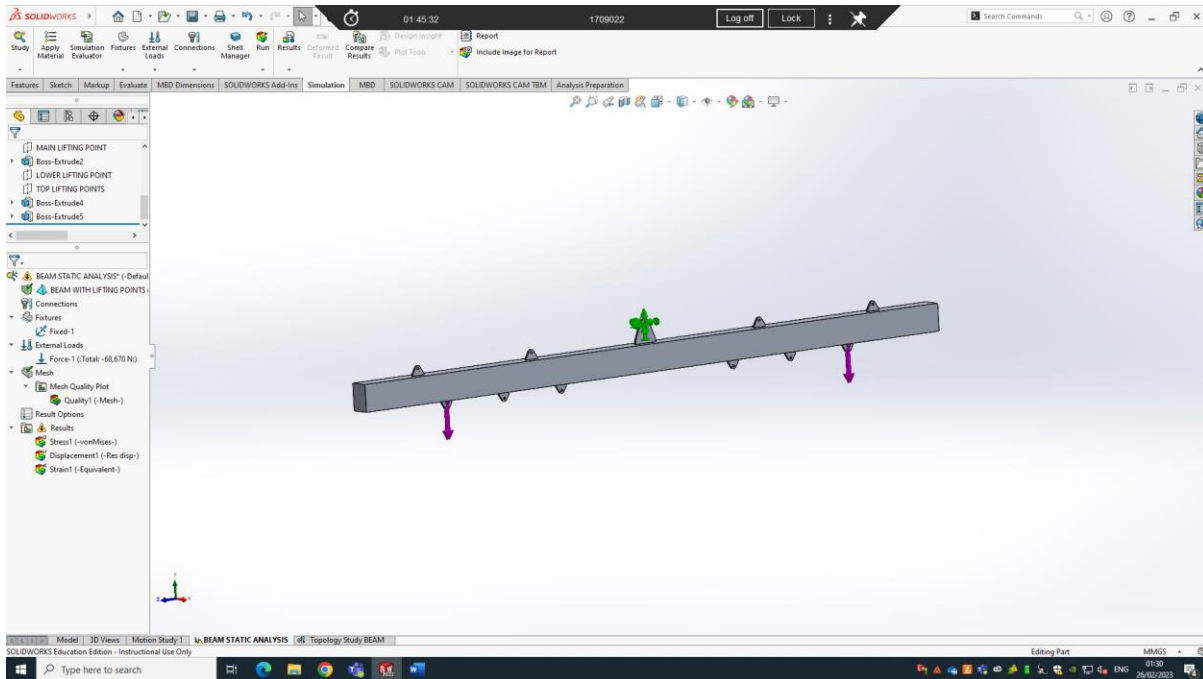


IMAGE - 29 FEA SECOND RUN

Below shows the stress value.

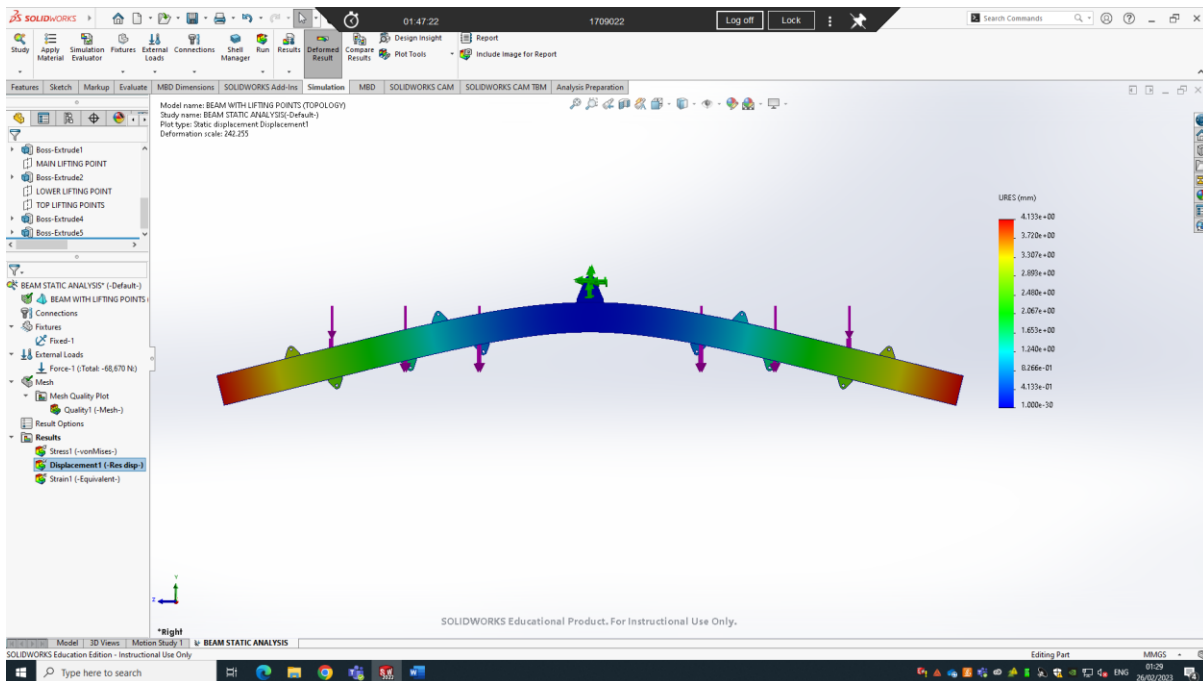


IMAGE - 30- SECONF RUN DEFLECTION

Below shows the displacement value.

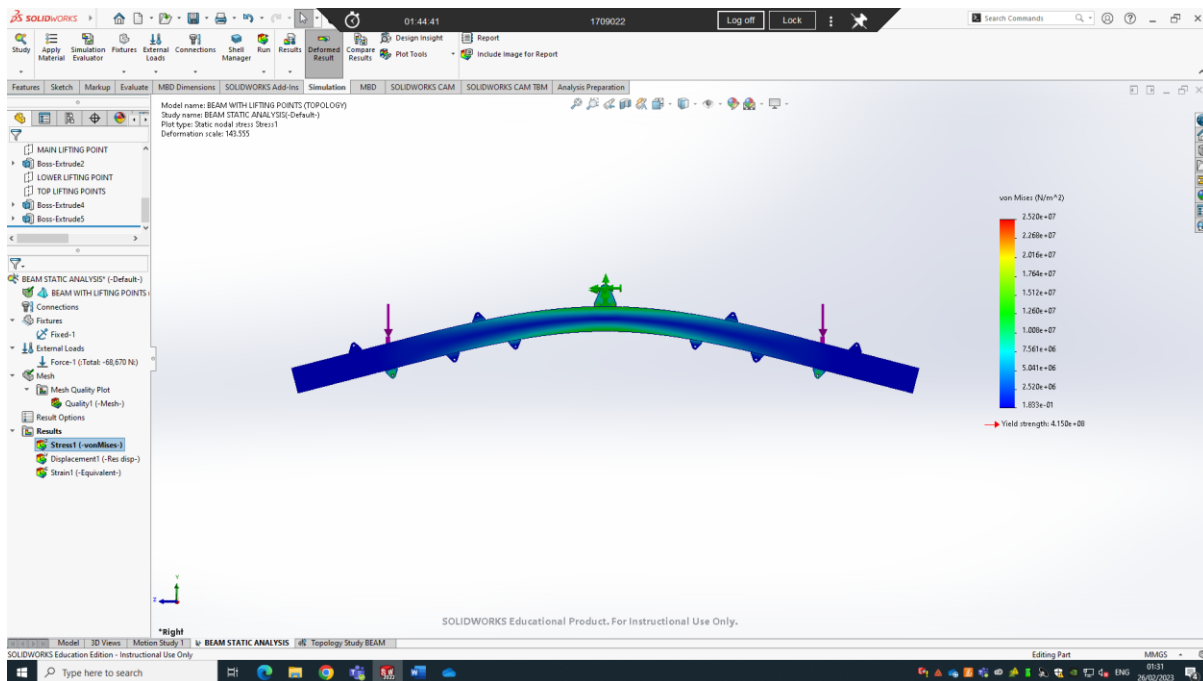


IMAGE - 31 SECOND STRESS VALUE

Strain value is shown in the below image.

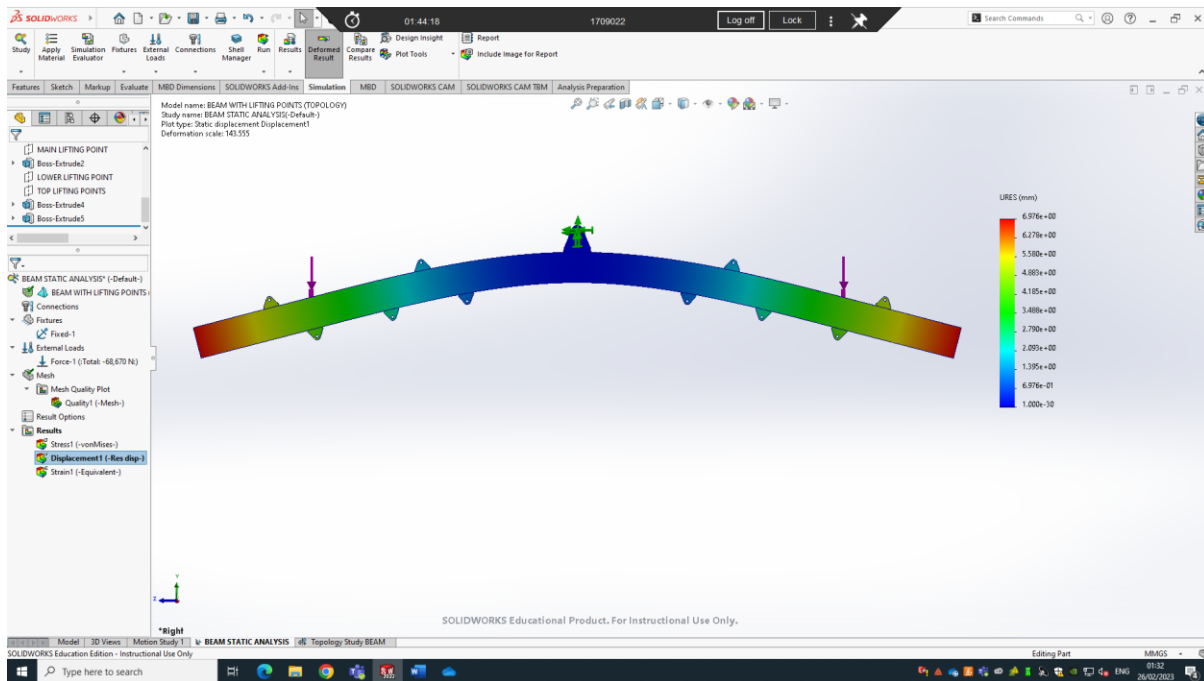


IMAGE - 32 SECOND RUN STRAIN VALUE

To run the topology and considering all the lifting points' fixtures and forces are applied on all points.

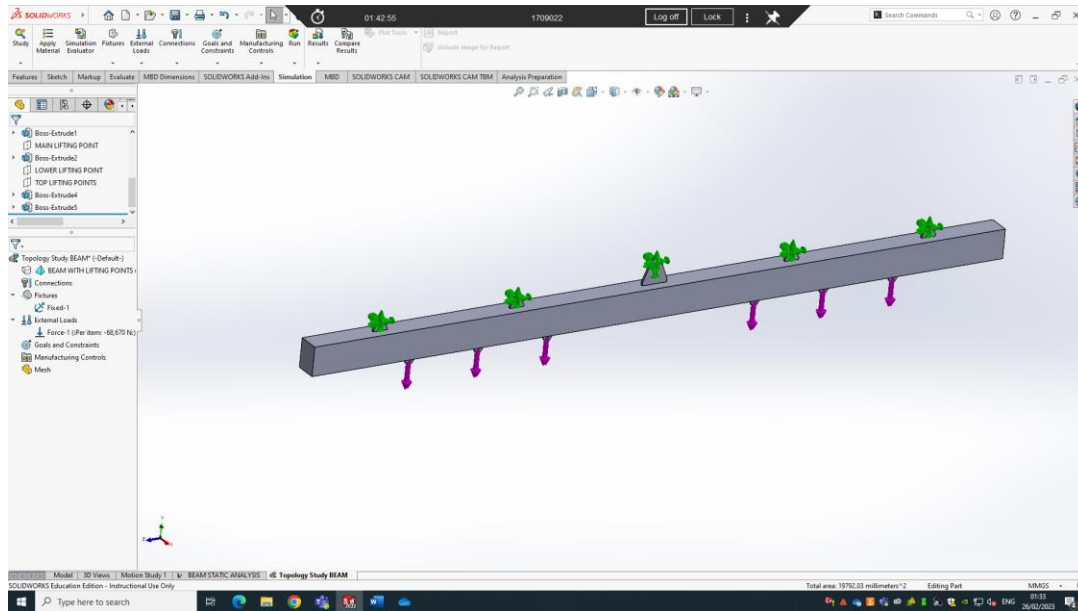


IMAGE - 33 TOPOLOGY FIXTURE (BOUNDARY CONDITIONS)

In the below image you can see the symmetric plane for the material to be removed to set constraints for the model.

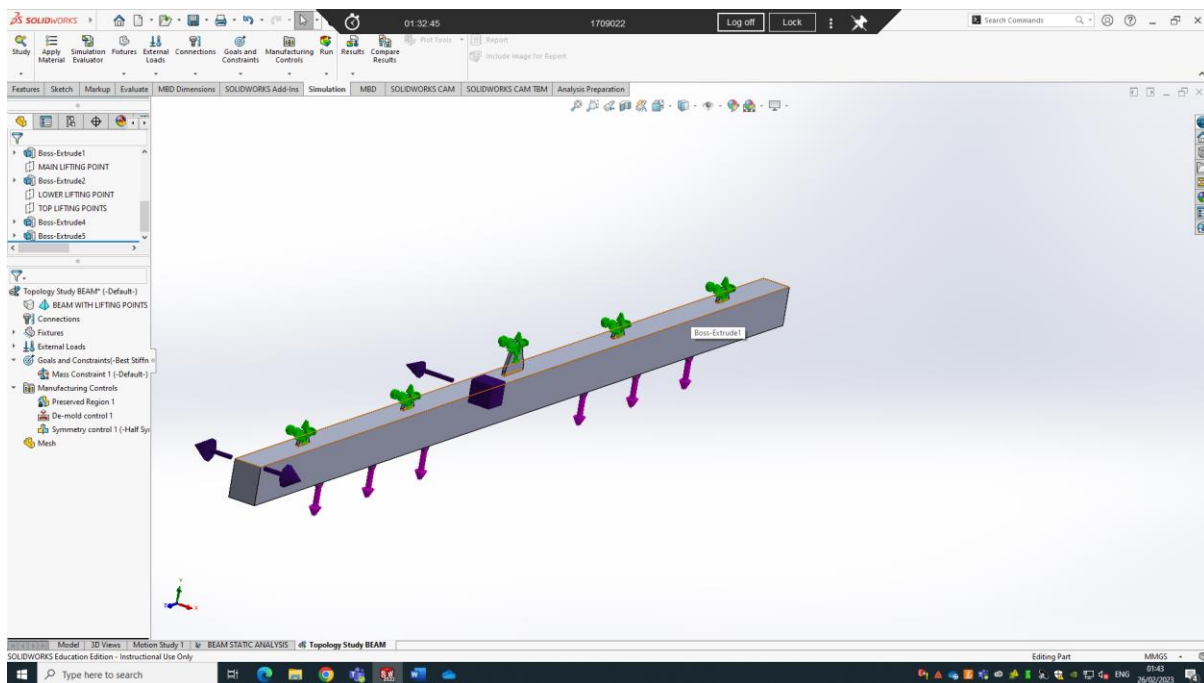


IMAGE - 34- TOPOLOGY MID PLANE SYMMETRY

Mesh applied on the model for topology.

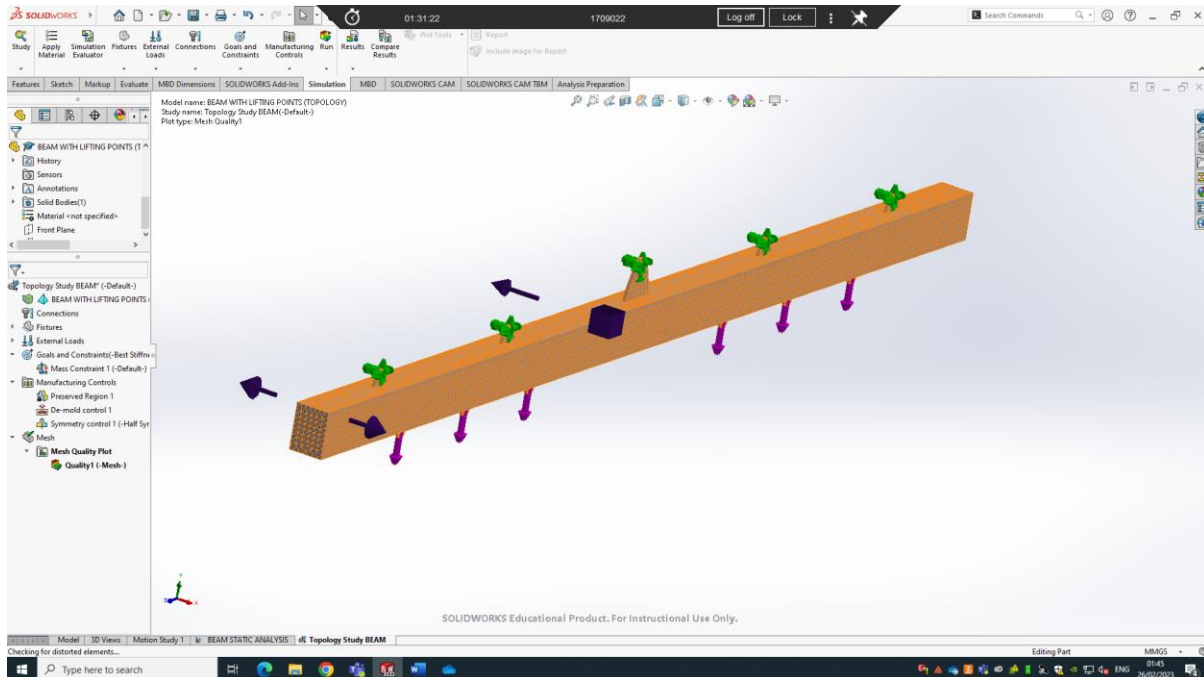


IMAGE - 35 TOPOLGY MESH

As all the lifting points and the fixtures were considered to run the topology, I ran the analysis while minimize the mass with stress ratio the analysis was running all night and at the end it said to abort the analysis and memory was giving a problem as well.

As too many cycles were going through the model because it was over constrained.

Further analysis on topology is below with the last outcome how the design can be improved and a lot less mass and stress on the material to take is just as same as the solid block of the beam.

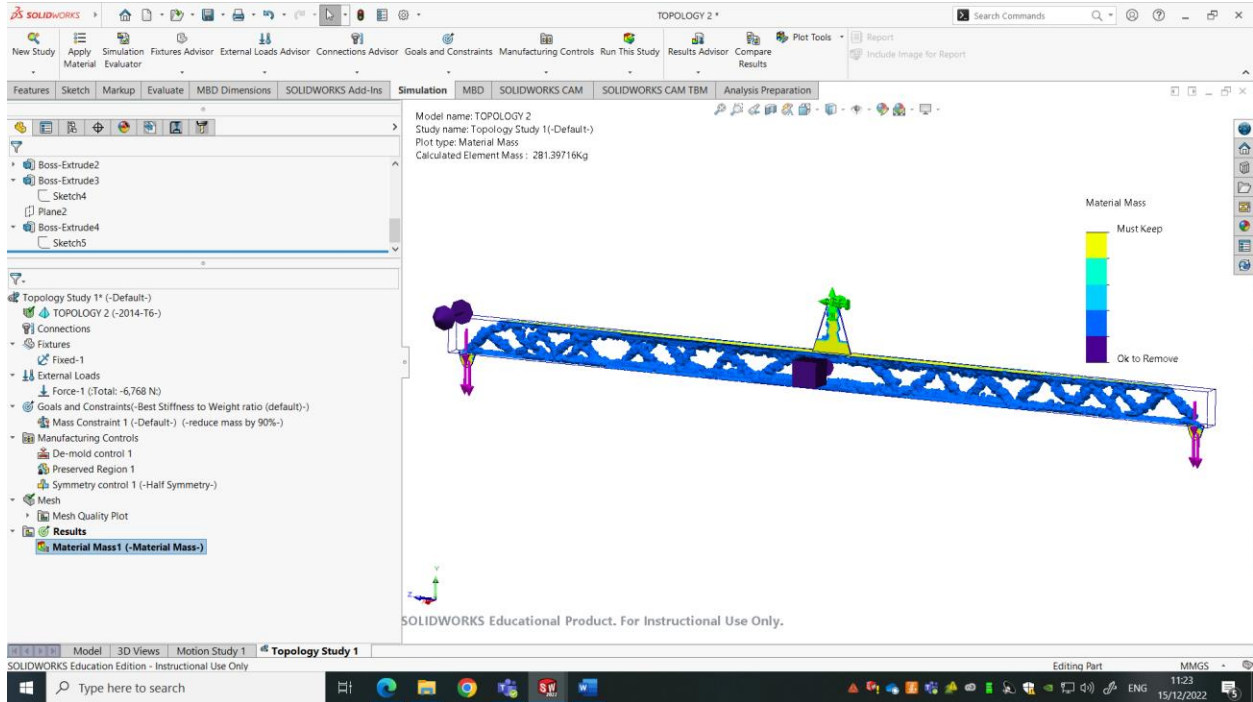


IMAGE - 36 TOPOLOGY 1ST RUN RESULTS

In the image below at the left it shows contact sets that have been used for the FEA analysis, the main solid pad eye plate where shackles will be attached for the lifting purposes.

A load of 2 tonne has been uniformly applied in the negative y direction on the pad eyes @ the maximum deflection point that is load applied on the outer most load points.

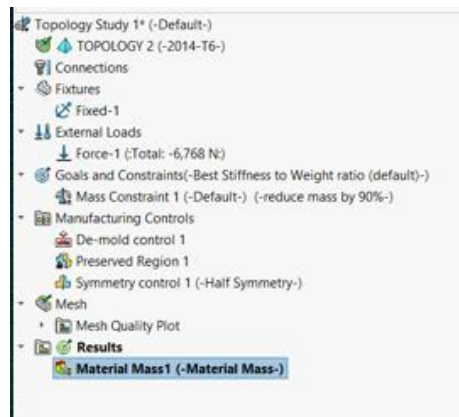


IMAGE - 37 SET CONSTRAINTS

Topology analysis has been run step by step going up in the percentage started from 50 % to see what difference and what results can be obtained.

Below the analysis is run @ 95%, see attached image below.

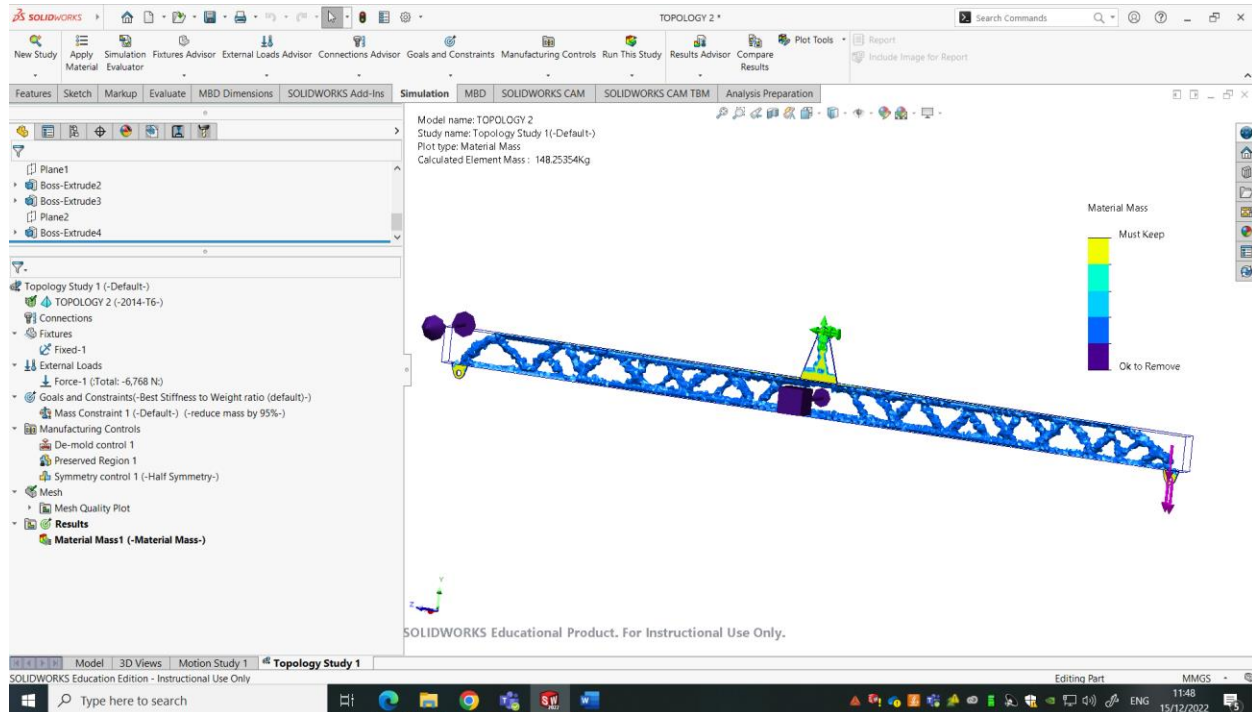


IMAGE - 38 TOPOLGY RESULTS @ 95% MASS REDUCTION

At the end of the topology analysis and keeping all the goals and constraints that is preserved region, mass constraint, de mold control, symmetry control & minimize the mass ratio (best stiffness to weight ratio).

Result shows which areas can be removed and what areas are necessary to keep.

For this counterbalance beam material which is used to create the model and run analysis is Steel S 355 below you can see the properties of the material.

	Prescribed by DIN EN 10025-2 [22]	Actual
Yield point R_{eh}	min. 355 MPa (transverse)	361 MPa (transverse), 381 MPa (longitudinal)
Tensile strength R_m	470-680 MPa	535 MPa (transverse), 550 MPa (longitudinal)
Elongation at fracture A	min. 22%	27,25%
Notch impact energy in Joule at -20 °C	40 Joule	58 Joule

IMAGE - 39 MATERIAL PROPERTIES (STRUCTURAL STEEL S 355)

First Run Result of Topology:

Model name: TOPOLOGY 2
Study name: Topology Study 1(-Default-)
Plot type: Material Mass
Calculated Element Mass : 148.25354Kg

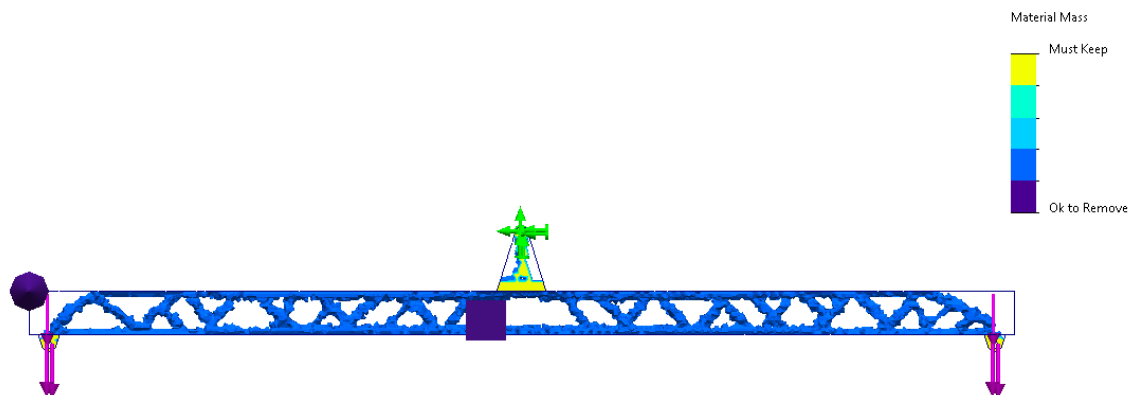


IMAGE - 40 TOPOLGY ANALYSIS RESULTS

Further Final Design:

Design analysis Topology & Finite Element Analysis:

In previous studies analysis while performing the topology the results obtained were not symmetrical whereas same load and fixtures have been applied with all the sketch and dimension been same.

To obtain the same results for the overall structure its best to cut the whole structure in half and apply advanced fixtures as a symmetry constraint which will then allow to gain the same results as the same study will be running just as a mirror feature.

The image below shows fully fixed geometry which stop the model from moving although in real life or in practical there will be movement there but to get results of the maximum deflection fully fixed geometry needs to be applied.

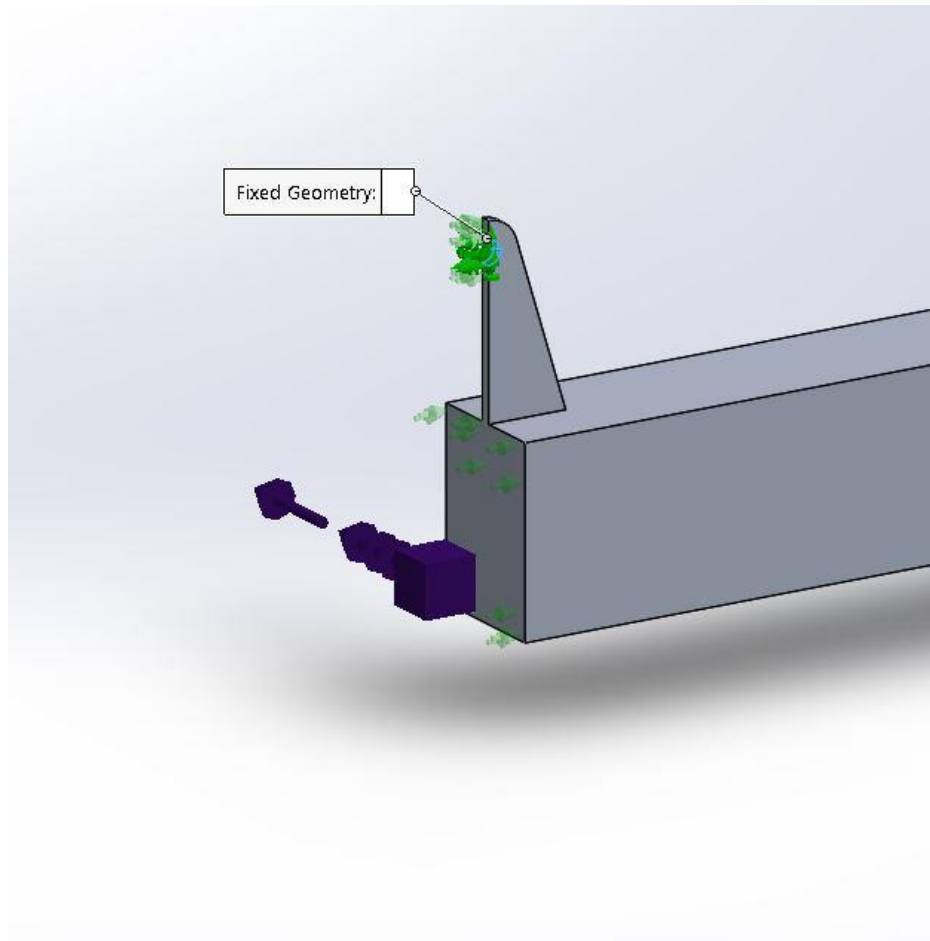


IMAGE - 41 TOPOLIGY 3RD RUN - SYMMETRY ADVANCED FIXTURE

In the image below you can see the fixed symmetry geometry is applied which will then allow the 3d model to act same in both half of the structure.

Due to the structure being symmetrically designed and loaded, each beam has been assigned a group number and identical discrete variables, this is due to stress results and displacement results not being symmetrical, so each group has now been forced to choose same discrete variables, this now causes the results to be symmetrically identical as expected.

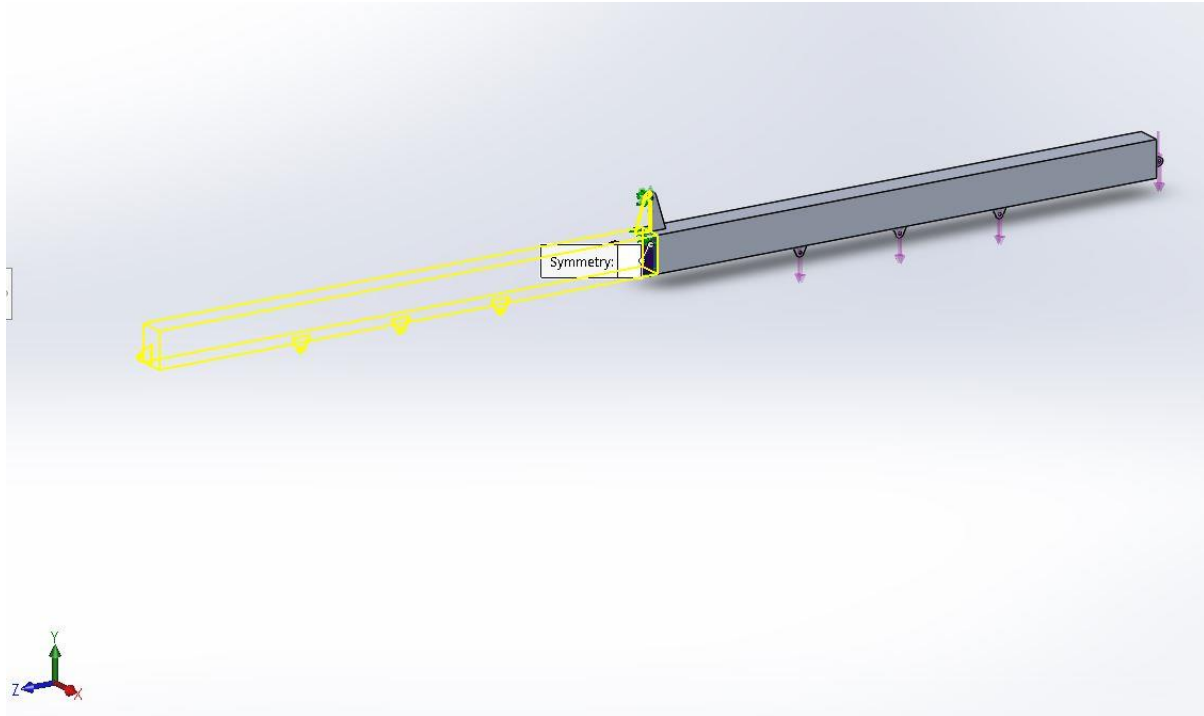


IMAGE - 42 TOPOLOGY- SYMMETRY FIXTURE PARTIAL PREVIEW

The structure consists of 1 No top lifting point & 6 NO bottom lifting points, while performing the topology analysis it is necessary to input all the information on what your model will be acting on.

As there are lifting points on top and bottom the program needs to know where the forces have been applied and on which area's it's possible to remove material and where it can be removed from.

Image below shows the preserved region of top lifting point.

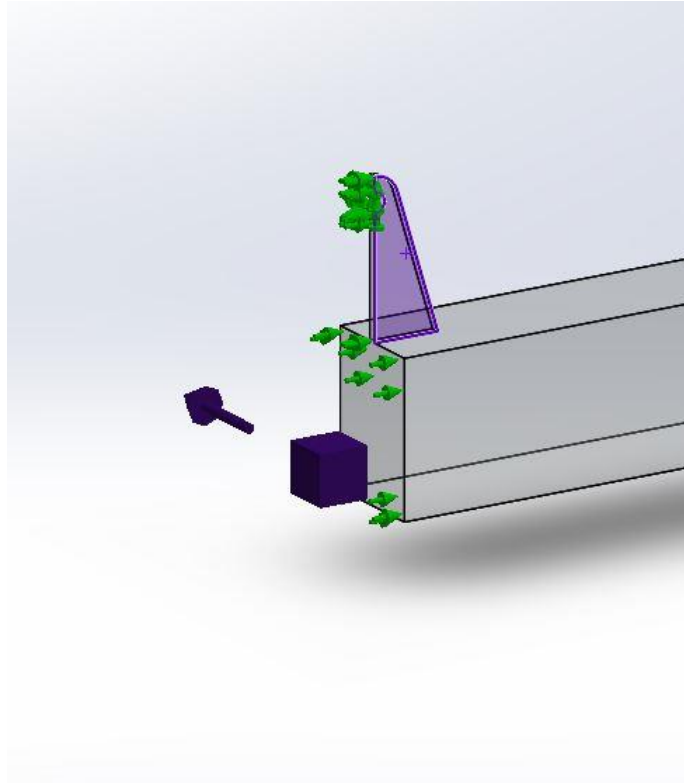


IMAGE - 43 TOPOLOGY PRESERVED REGION TOP LIFTING POINT

Image below also shows the preserved region for the bottom lifting points. From where not much material can be removed as they will be load applied on them.

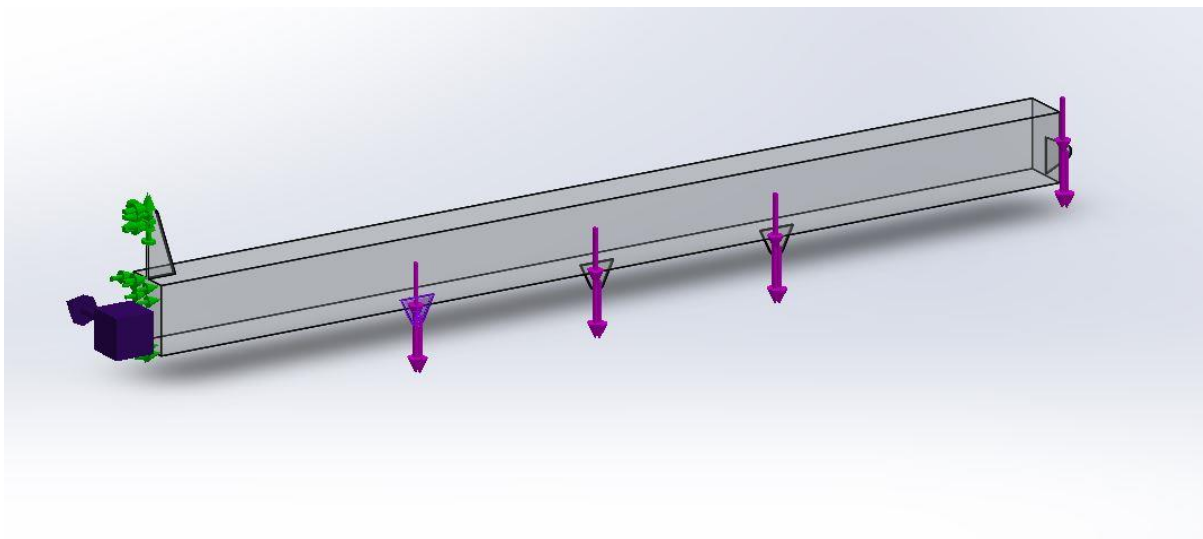


IMAGE - 44 TOPOLOGY PRESERVED REGION BOTTOM LIFTING POINTS

To run topology analysis the 3d model is designed in solid works as well as topology analysis is set up in solid works.

There are few requirements to run the analysis which includes the goals, fixture, force been applied, mesh etc. The process 3d model have gone through is explain below in step by step with images. Above you seen the fixtures and the preserved regions, in the below image you can see topology setup.

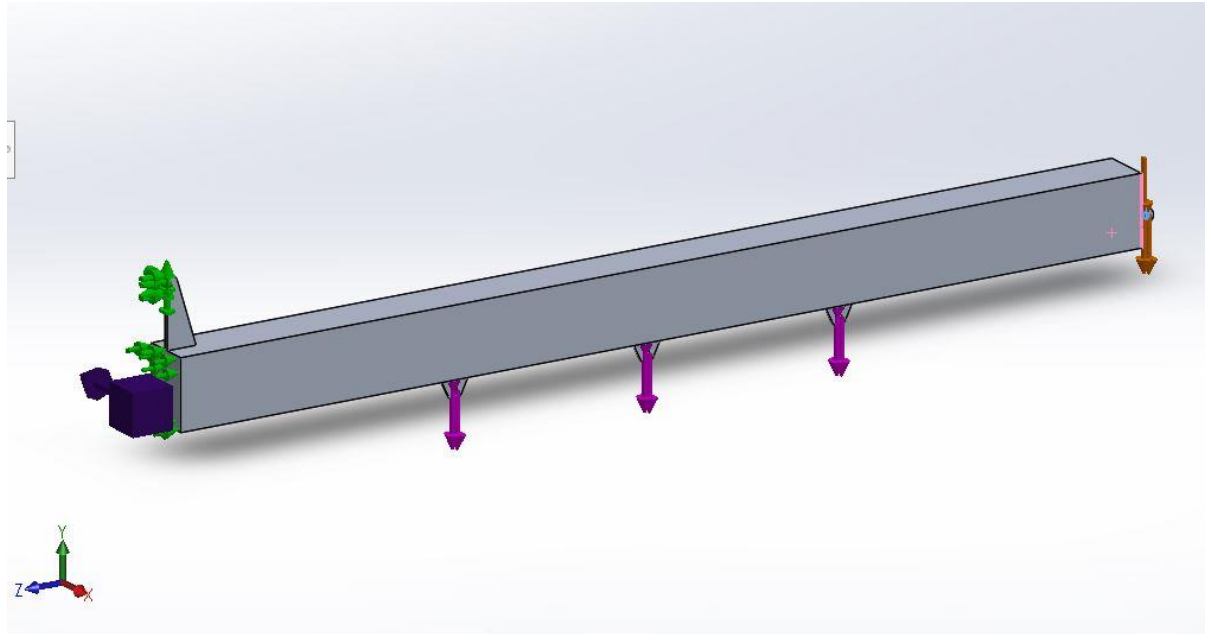


IMAGE - 45 TOPOLOGY FIXTURE, LOADINGS, SYMMETRY CONSTRAINTS & PRESERVED REGION ALL IN PLACE

Above shows the fixtures, half symmetry region to tell the solid works where its best to remove the material from or which direction. Force applied.

Two below images show the force applied on the model, also the force which is applied on the lifting points is multiplied by the gravity as the model will be lifting and the mass of the structure is attracted towards the globe.



IMAGE - 46 FORCE APPLIED

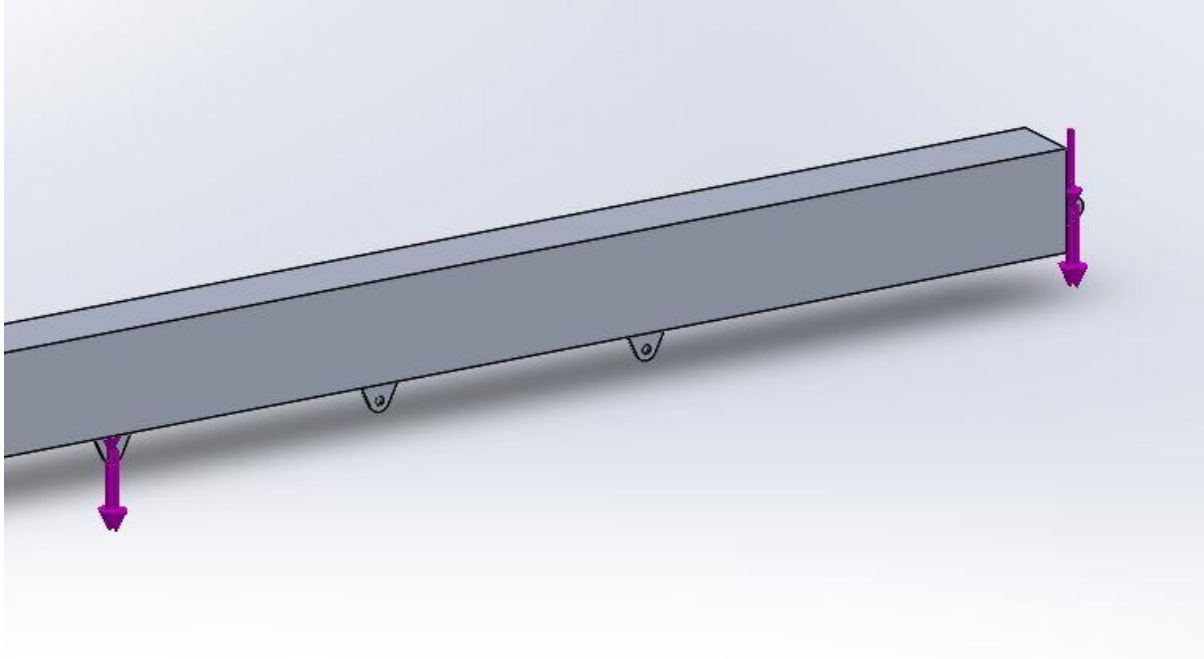


IMAGE - 47 TOPOLGY LOADINGS

Above is force applied and the direction of the force.

As reducing the weight of the model is an important factor, it is then set at 95% of mass reduction.

Select Goal

Best Stiffness to Weight ratio (default)

☐ Displacement Constraint

☒ Mass Constraint (Default)

Mass Constraint

Reduce mass by (percentage)

95

%

Current mass of part: 1228.5 kg

IMAGE - 48 STIFFNESS TO MASS RATIO

In the image above you can see the reduce mass percentage applied on the model, although the current mass of the block beam is approximately 1229.00 Kg by reducing it down to 95% percent of it, we will roughly end up with 60kg, which is not quite possible to make a lifting frame with the 60kg of weight as well as having a span of 10 meter.

95% is applied to get the best result with the shape and the stress values with most material removed and while performing the analysis with mass to stiffness ratio the topology will give you the minimum mass and with the higher stress value which the model can take which you have applied previously.

After setting this up mesh is applied on the model.

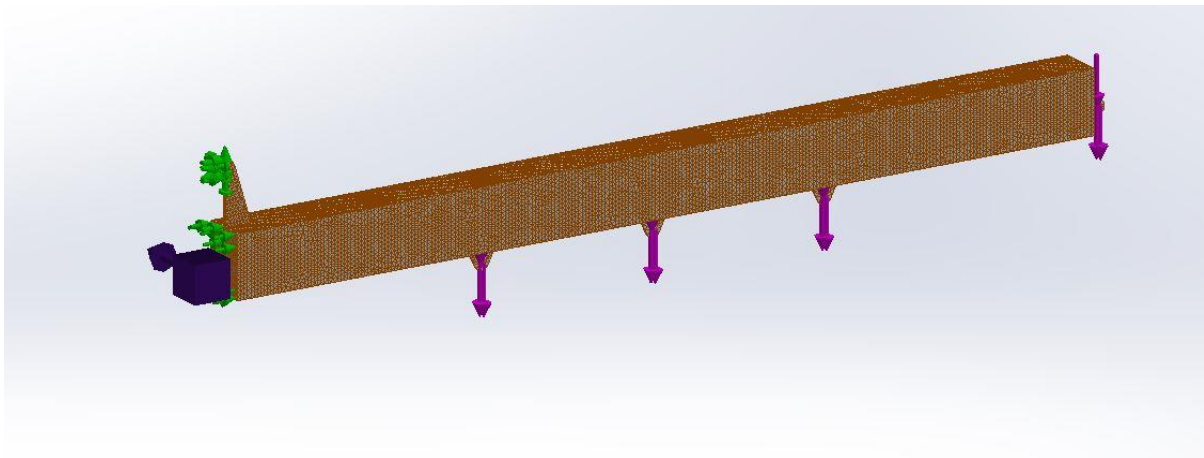


IMAGE - 49 TOPOLOGY MESH APPLIED

In the image above you can see curvature-based mesh applied on the structure, which have covered most of the surface.

The image below all the features used to run topology can be seen.

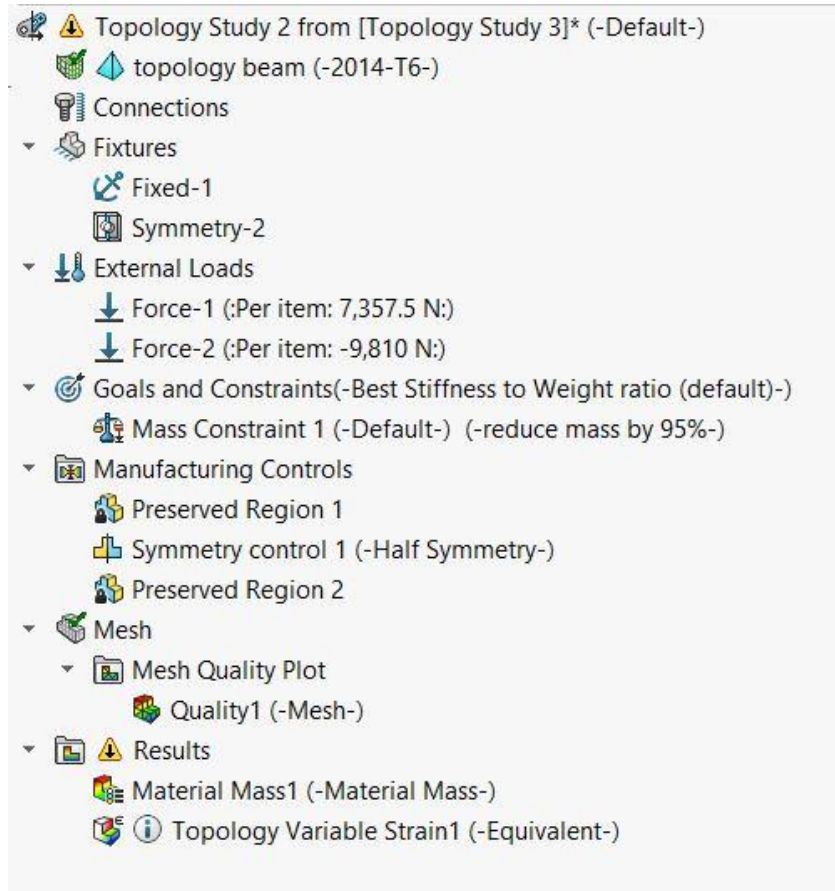


IMAGE - 50 TOPOLOGY CONSTRAINTS APPLIED

It takes many attempts for the topology analysis also take few hours to run each time, after running the topology it can be seen in the image below what results are obtained.

NOTE: topology and FEA should be run for several times and a person should read & observe every time when the results are obtained.

See image below.

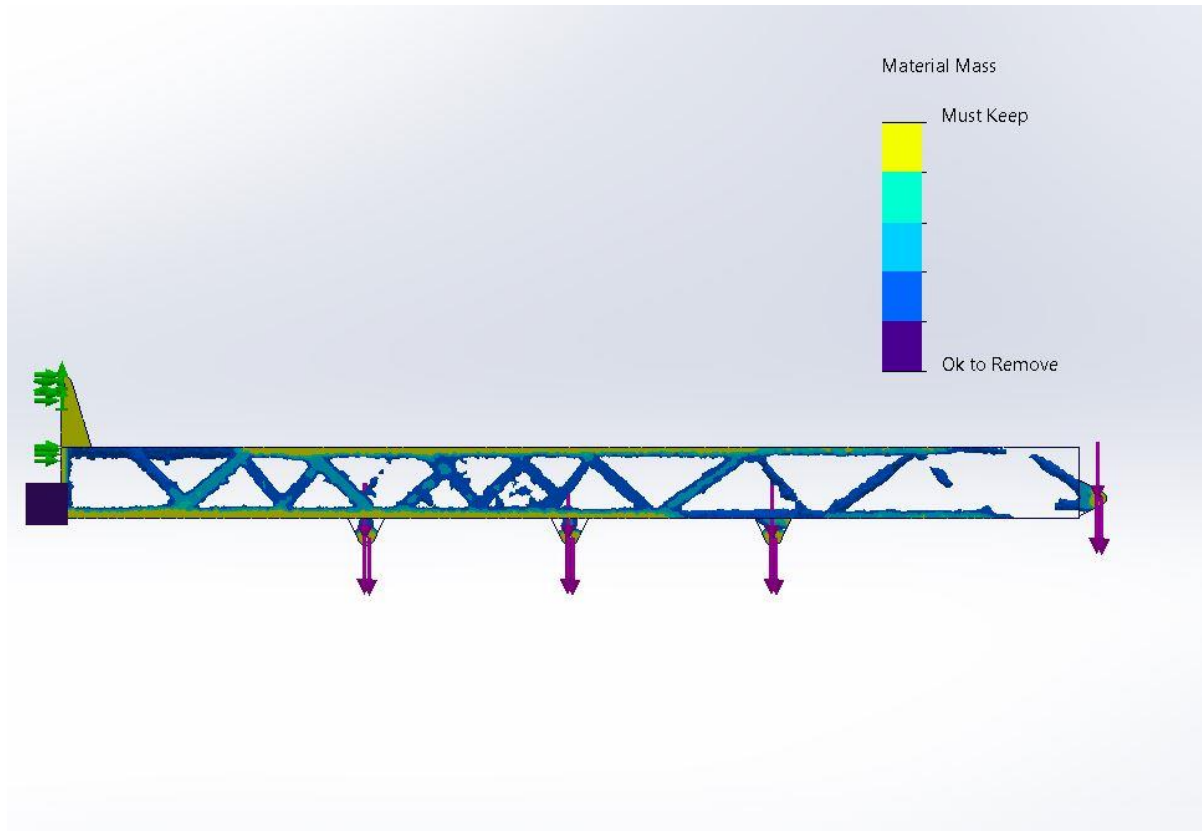


IMAGE - 51 TOPOLOGY RESULTS @ 95% MASS REDUCTION

In the image you can see how the preserved region and the material where it is ok to removed and where it must be kept. As the model is undergone with the symmetry feature it will be copied from the mid face and the results will be the same while having the same dimension and same stress & load to be taken.

Below topology variable strain value can be seen.

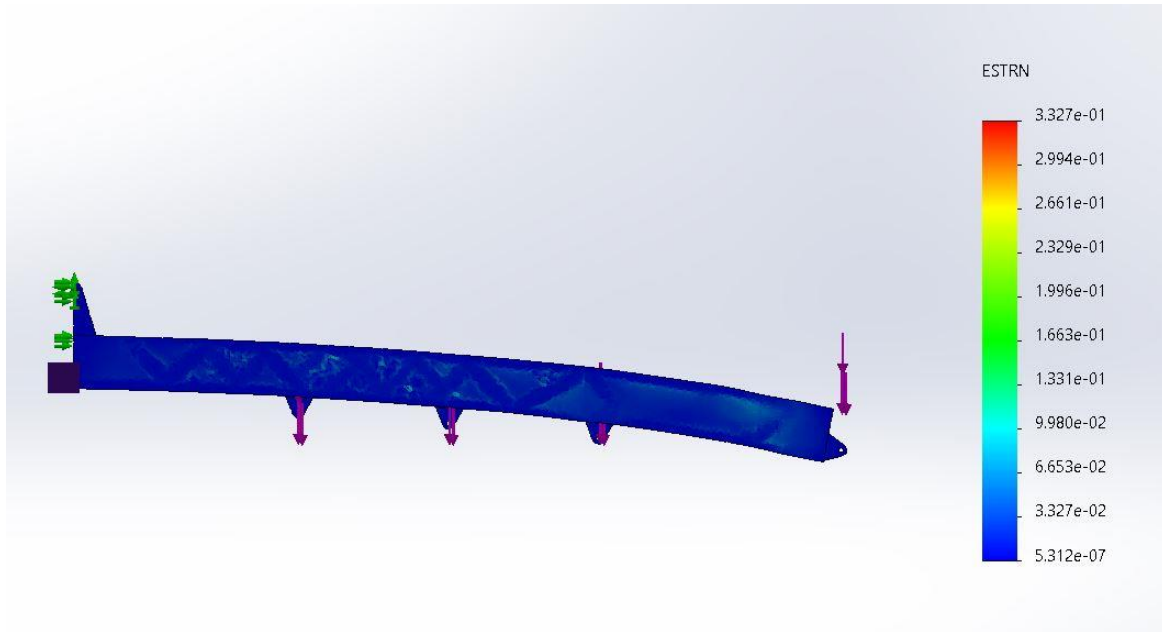


IMAGE - 52 TOPOLOGY STRAIN VALUE

Creating a 3d sketch and model:

After running the topology analysis on the model, it is now imported as a mesh surface and will be drawn in solid works sketch, see below to see the 3d check and then it will be converted into the structural members to gain the 3d model of the structural members as a solid body.

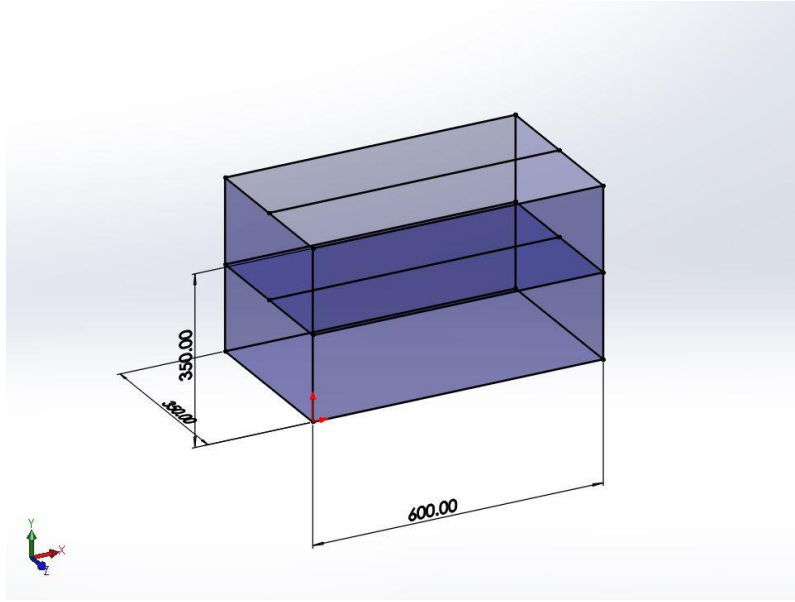


IMAGE - 53- 3D SKETCH MID LIFTING FRAME

3d Sketch of a mid-section lifting frame:

The image above shows the 3d sketch with the dimension and the axis.

After that the user can use the feature of structural member and make this 3d sketch into a 3d solid body model. You can see below in the image after its converted into a solid body where the square box sections are used to create it.

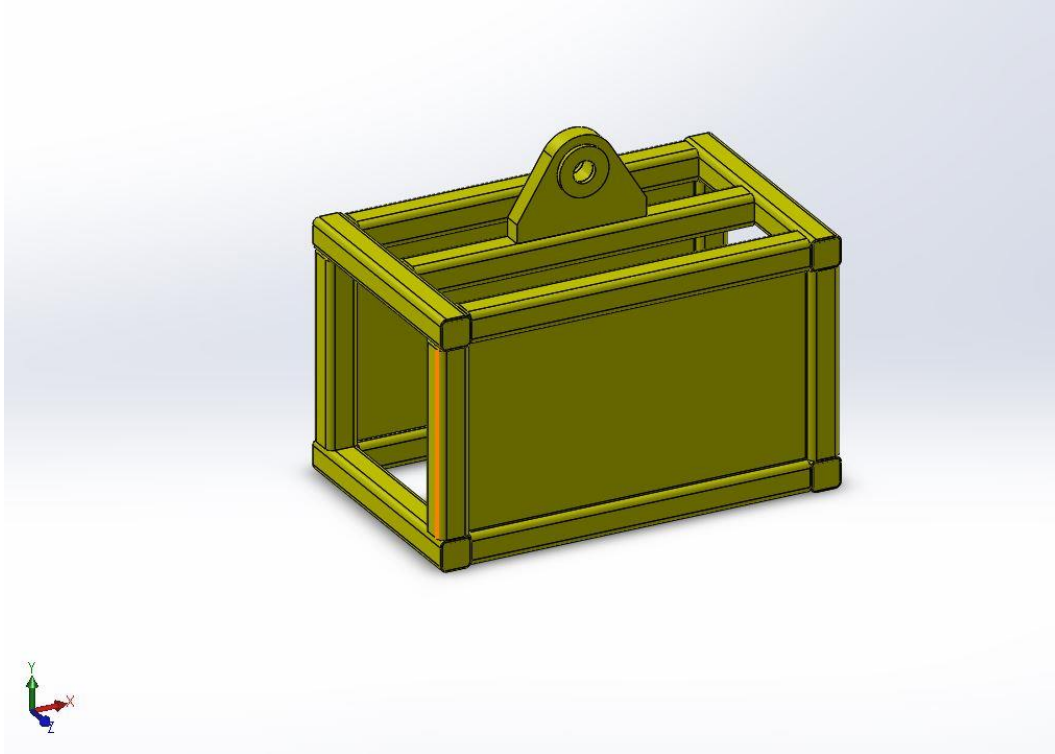


IMAGE - 54- LIFTING FRAME WITH STRUCTURAL MEMBERS

3d Solid body lifting frame.

Below you can see the 2d sketch on which the bottom lifting points will be welded on, once it's drawn then the 2d sketch will be converted into structural members where the square box section will be used. See below.

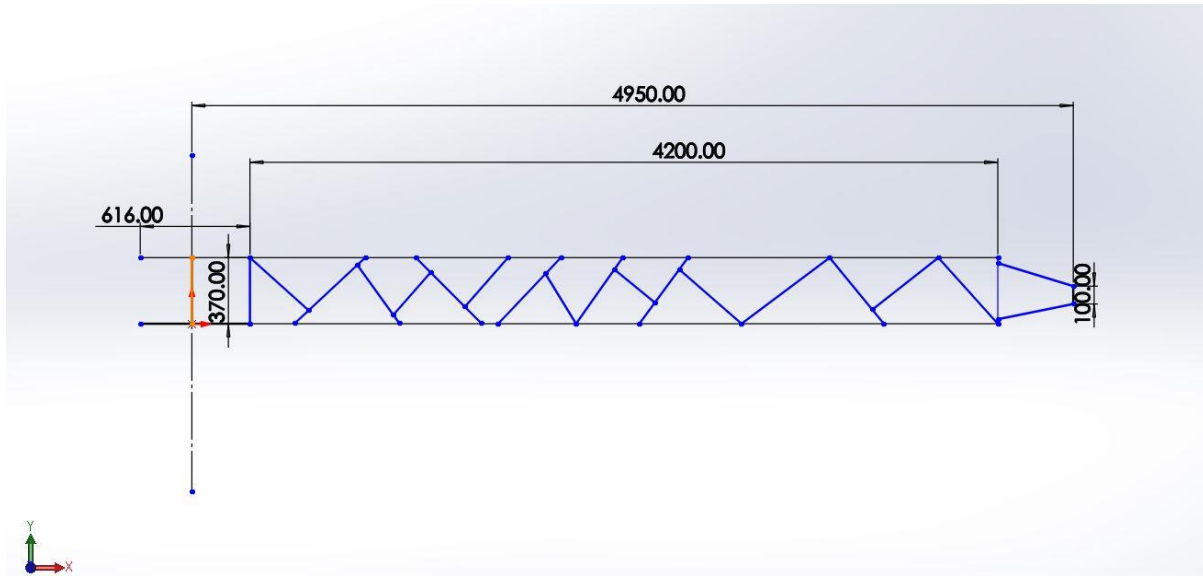


IMAGE - 55- BEAM SECTION 2D SKETCH

2d Sketch of lifting beam

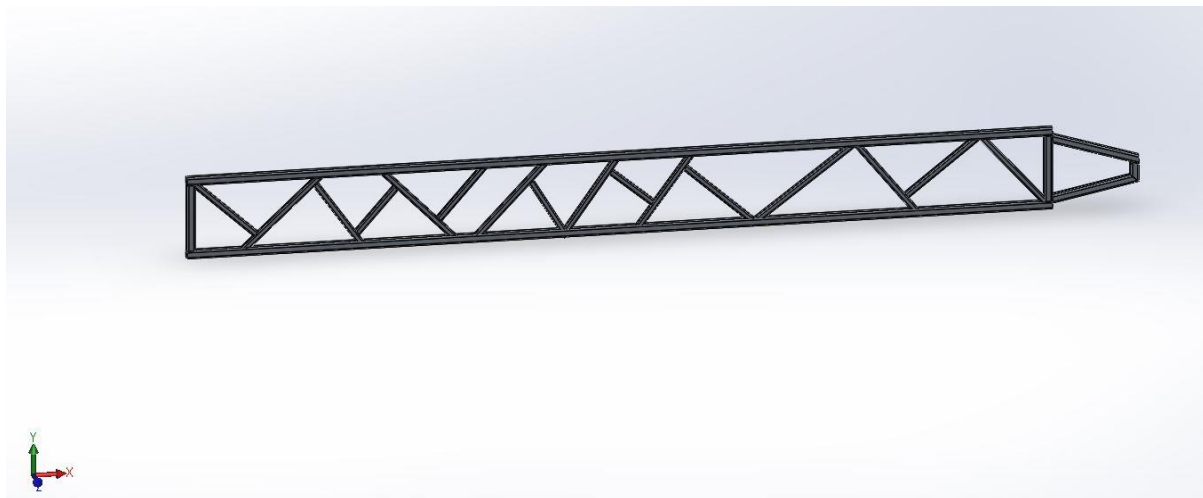


IMAGE - 56- BEAM LONG SECTION WITH STRUCTURAL MEMBERS

The image above shows the 2d sketch with the box sections, it's been designed like this as a one part of the lifting frame and the other parts will be used in the assembly file and will be assembled as a part it can be seen further down below.

In the image below the box section is created which will work as a strengthening gusset between the frames.



IMAGE - 57- MID GUSSET STRUCTURAL MEMBER

After all these parts are created, all these parts are assembled see below to see the image of assembled file.

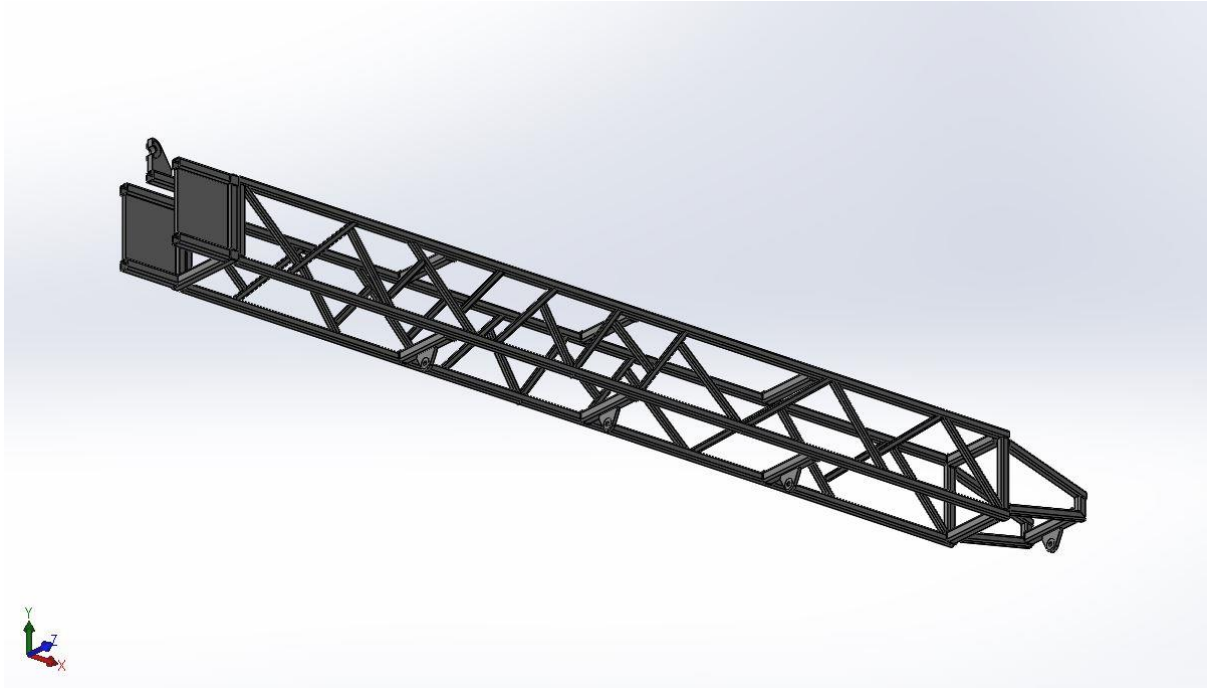


IMAGE - 58_ ASSEMBLED SYMMETRICAL 3D MODEL.

After the 3d model is created it is now to go through a Finite Element Analysis to see if the 3d model passes the stress, strain and the displacement values. Displacement which will be the deflection in the lifting beam or the lifting frame.

To run a FEA the 3d model will be set as a mid-section lifting frame to be treated as solid body and the long structural members to be treated as beam elements to get the best possible results.

In the image below you can see the list of parts.

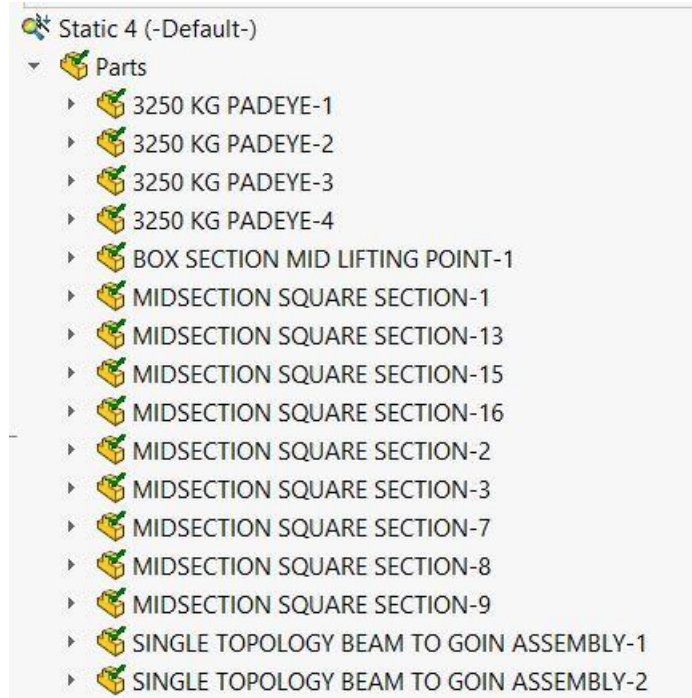


IMAGE - 59- PARTS LIST

In above 3.2 tonne pad eyes were created which are used a lifting point where the load will be applied, in FEA mesh the modelled lifting points conflicts with the engraving or any writing on the model. For the sake of FEA to run smoothly and get the results we require or by not taking too long the pad eyes were created which will work as a lifting point for the purpose of FEA.

Fixed geometry symmetry constrain is in place to get symmetrical results. Where beam elements can also be seen.

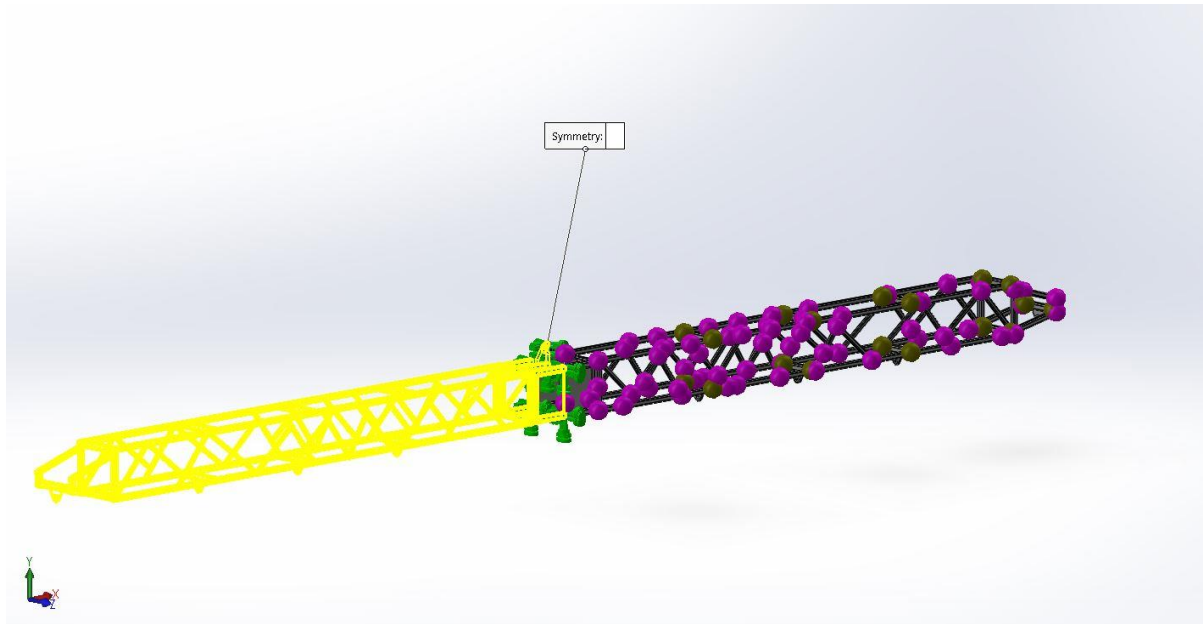


IMAGE - 60-SYMMETRICAL FIXTURE PREVIEW

As the pad eyes are solids and the box sections are structural members, they need to be bonded in local interactions in the image below you can see the box sections is bonded with the face of pad-eye lifting point.

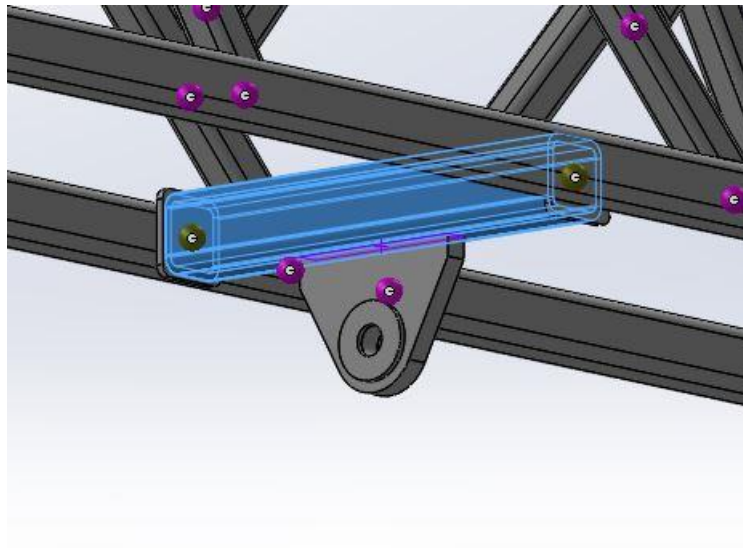


IMAGE - 61- LOCAL INTERACTION (BONDED) BEAM ELEMENT WITH SOLID BODY

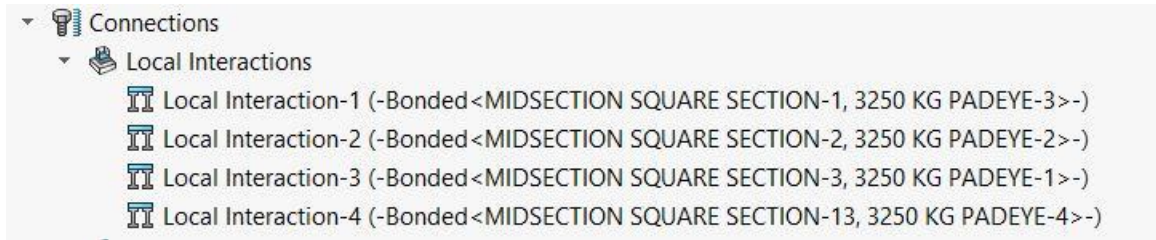


IMAGE - 62- LOCAL INTERACTIONS FEA

Above In the image **Local Interaction (FEA)** can be seen for all the local interaction where the lifting points are bonded with the box section beam elements.

Once all the boundary conditions, loading, local interaction, forces are in place it is then mesh parameter is applied to complete the process.

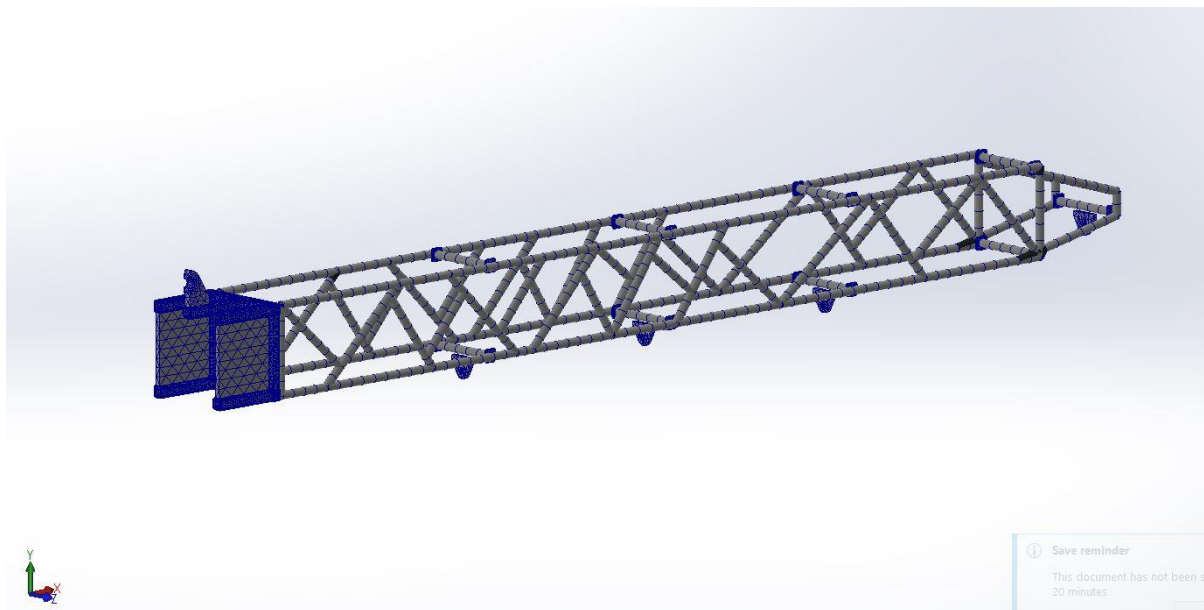


IMAGE - 63- MESH PARAMETERS

Mesh Parameter:

in the image above it can be seen the mesh is applied lifting frame is solid body and the frame is beam elements and they are bonded together where it allows the model to be bonded and knows where the attachment and welds are.

To get the best results all the constraints need to be the same as the model will be manufactured and act in real life.

Finite Element Analysis:

After running the topology & followed by design of the counterbalance lifting beam or frame, it is then run through a finite element analysis weather to see material and the box size sections are used can undergo the applied load.

Beam elements group box sections 50x50x5, 40x40x5 & 30x30x3 has been used to make the 3d model.

Below in the image you can see the full beam.

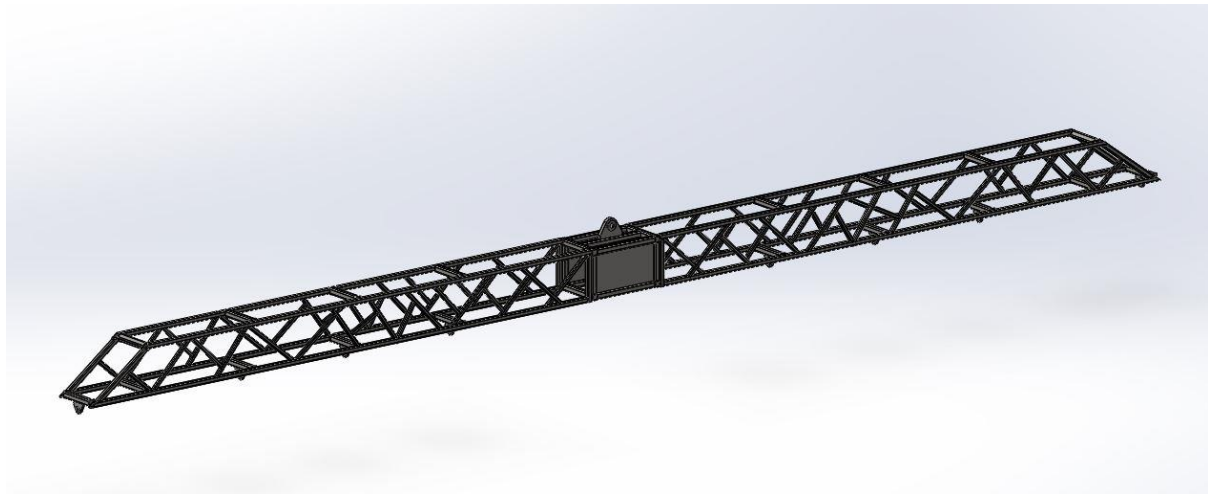


IMAGE - 64- COUNTER-BALANCE LIFTING BEAM

Counterbalance lifting beam in the image above all the mentioned box sections are in place as well as a shear plate and lifting points for FEA purposes late they will be replaced by suitable lifting points.

Finite Element Analysis Assumptions:

This simulation is a static linear elastic analysis, which means that the load applied is a snapshot in time and the material stiffness is linear.

All Material properties are as manufactured and do not account for any deterioration over time, nor any manufacturing defects.

All welds are treated as full penetration welds connecting sections together, welds are assumed to have better nor worst properties than the parent material, weld material properties are better than the parent material.

It is assumed that all material is homogenous and therefore assumed material properties are constant throughout.

FEA Loads & Fixture:

Image below shows the fixture on the model:

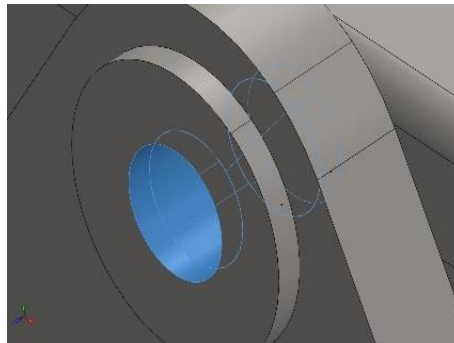


IMAGE - 65- FIXTURE ON MODEL

The resultant forces acting on it are below:

Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	0.00149536	39,240.1	-8.39233e-05	39,240.1
Reaction Moment(N.m)	0	0	0	1e-33

IMAGE - 66- RESULTANT FORCES

The fixture is fully fixed which enables the model to stabilize and to get the most accurate model, if the model is not stabilize the FEA analysis assume that model is just in the air and gives odd results.

Below in the image FEA local interactions all the local interactions can be seen, as the box sections are all beam elements and there are some lifting points, end caps and shear plates which are solid bodies, in order to run the FEA accurately these beam elements needs to be bonded with the solid bodies are in real model they will be welded together so for the FEA to know they are bonded and there is a local interaction between them.

Interaction Information

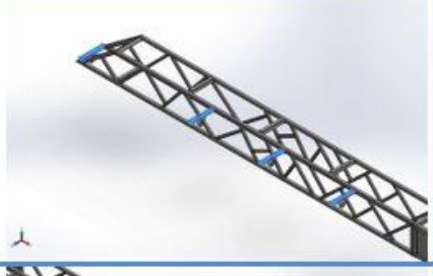
Interaction	Interaction Image	Interaction Properties
Local Interaction-1		Entities: 16 face(s), 4 Beam (s)
Local Interaction-2		Entities: 17 face(s), 4 Beam (s)
Local Interaction-3		Entities: 4 face(s), 4 Beam (s)
Local Interaction-4		Entities: 4 face(s), 4 Beam (s)

IMAGE - 67- LOCAL INTERACTIONS (1) FEA

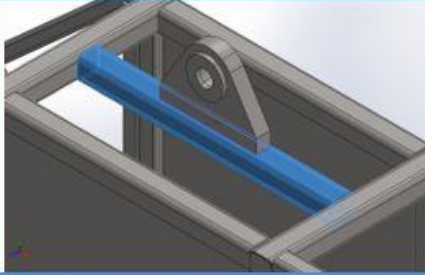
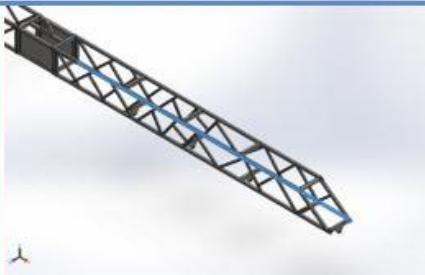
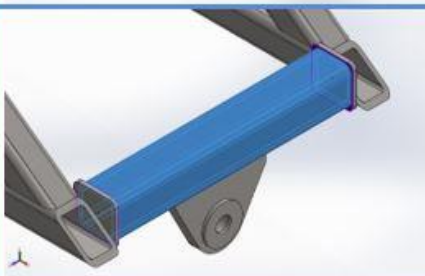
Local Interaction-5		Entities: 1 face(s), 1 Beam (s)
Local Interaction-77		Entities: 1 face(s), 1 Beam (s)
Local Interaction-78		Entities: 1 face(s), 1 Beam (s)
Local Interaction-79		Entities: 2 face(s), 1 Beam (s)

IMAGE - 68- LOCAL INTERACTIONS (2) FEA

Mesh:

3d model have gone through FEA with beam elements where mesh parameters have been set as curvature base.

See below mesh details and the 3d model while meshed and how they affect the result.

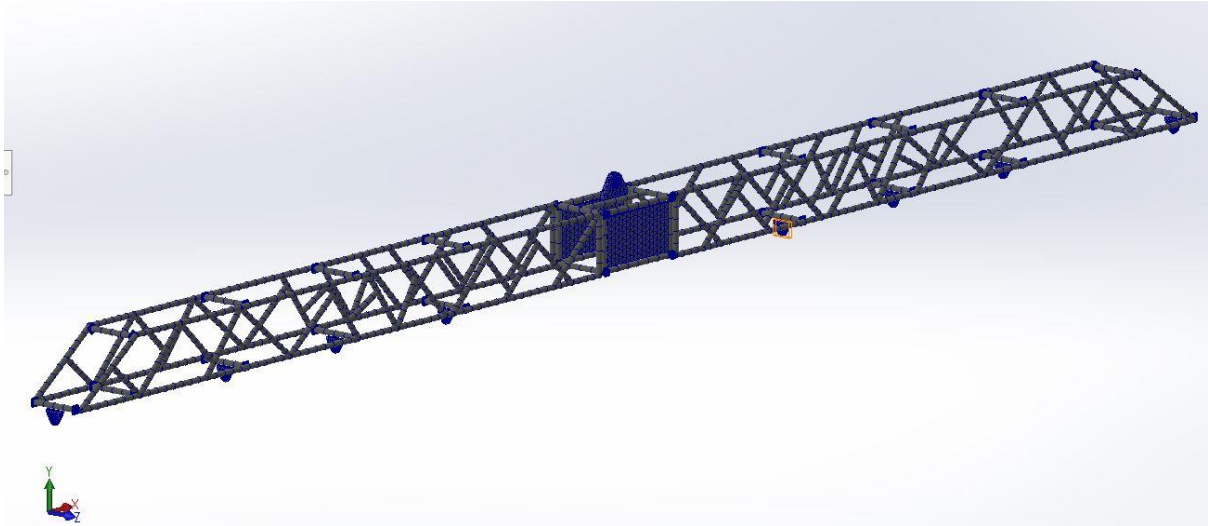


IMAGE - 69- APPLIED MESH ON 3D MODEL

Mesh information

Mesh type	Mixed Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Jacobian check for shell	On
Maximum element size	34.6854 mm
Minimum element size	5.35757 mm
Mesh Quality	High
Remesh failed parts independently	Off

Mesh information - Details

Total Nodes	60680
Total Elements	28487
Time to complete mesh(hh:mm:ss):	00:00:51
Computer name:	

IMAGE - 70- MESH TABLE

Sum of Resultant Forces:

See the table below for resultant forces:

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00149536	39,240.1	-8.39233e-05	39,240.1

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.187901	-0.240121	0.0638616	0.311517

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

IMAGE - 71- SUM OF RESULTANT FORCES

Applied Force:

Safe working load of the model is a maximum of 1 tonne per lifting point on outer lifting points.

A force of 4 tonne is applied on the outer lifting points which is 2 tonne per point for a proof load test. Note the lifting frame has 8 bottom lifting points, 4 on each side but while using the beam only 2 points will be getting used where one will be on each side to balance out the load.

Load name	Load Image	Load Details
Force-1		Entities: 2 face(s) Reference: Edge< 1 > Type: Apply force Values: ---, ---, 39,240 N Moments: ---, ---, --- N.m

IMAGE - 72- APPLIED FORCES

In the above image the force applied is 39,240 N is applied which is:

$$1000 \times 2 \times 2 \times 9.81 (\text{Gravitationnel Force}) = 39240 \text{ N.}$$

Where 1000 is 1 tonne, 2(Twice Proof Load) x 2 (Two Lifting Points) x 9.81 gravity = 39420 N.

FEA Results:

Once all the constraints were in place and all the fixtures, interactions, loading & mesh etc were set up, it is then the FEA analysis can take place and the model will go through the analysis.

FEA analysis was run several times to get the best results & also to correct if there are any unconstrained entities.

Stress results:

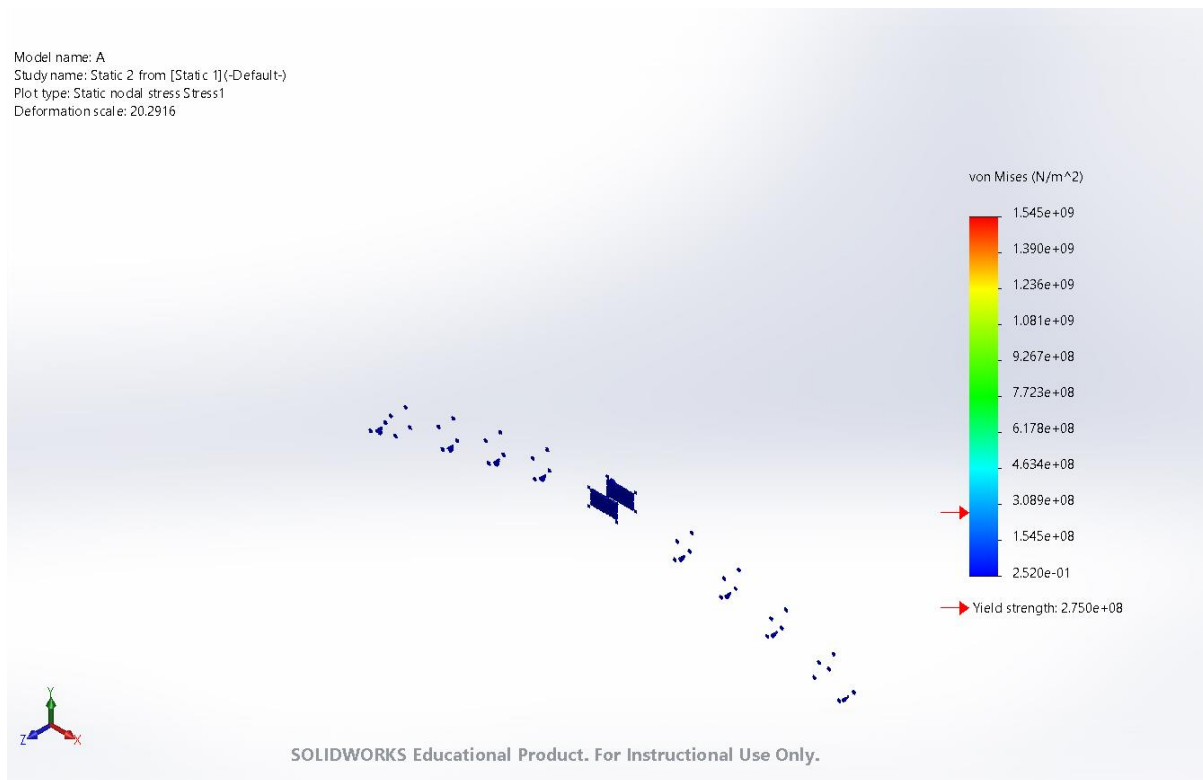


IMAGE - 73- FEA RESULT STRESS VALUE

In the Above image the stress results show a high value of stress although it is not exactly on the under-work areas, beam element stress value will be considered which is obtained from axial & moment results. To justify the higher stress value please see below 2 images which shows the higher stress value on end caps which are on end of box sections.

See below:

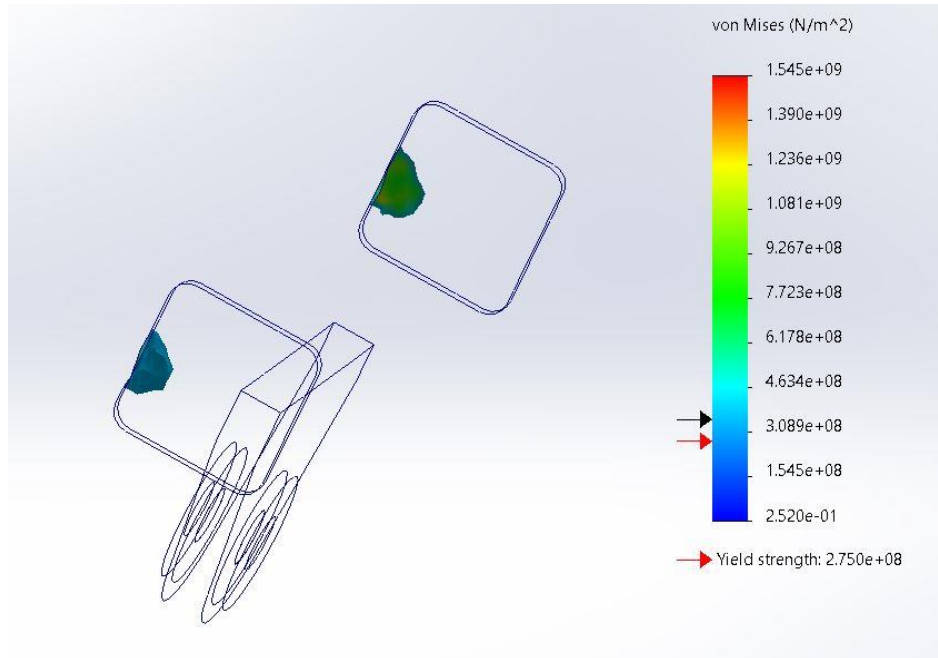


IMAGE - 74- STRESS ON END CAP (1)

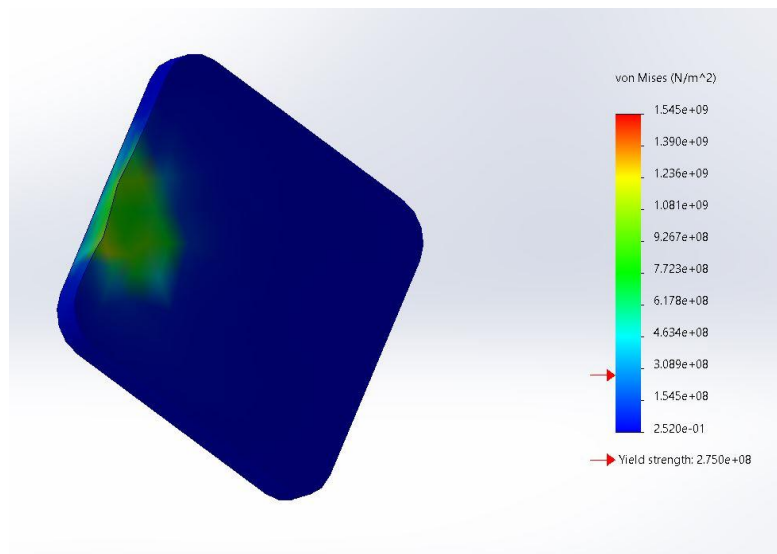


IMAGE - 75- STRESS ON END CAP (2)

Displacement:

Displacement shows the deflection on the model under the applied load, the results shows that the deflection on the model is just under 50mm, which is acceptable.

Note: the deflection observed @ 2 tonne applied (Safe Working Load) is 25mm.

Allowed deflection in the lifting beam is overall length/250.

Therefore, $10,000\text{mm}/250 = 40\text{mm}$. which is acceptable limit of deflection.

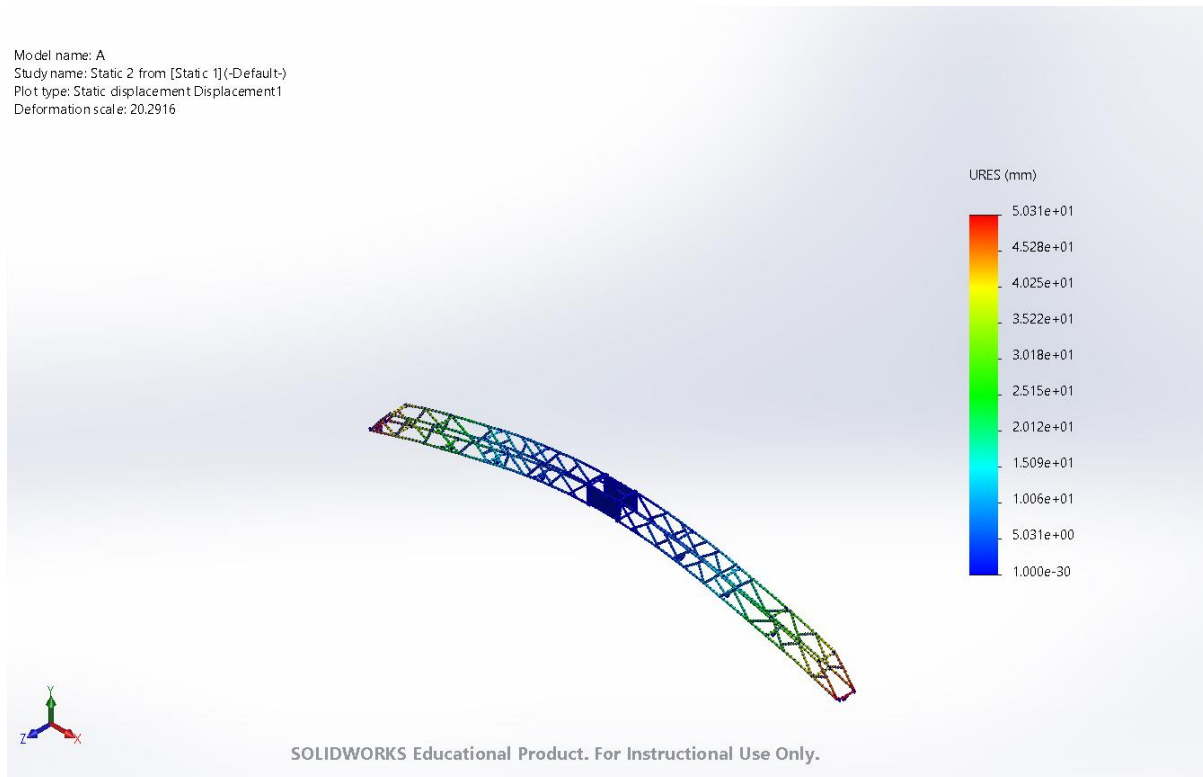


IMAGE - 76- FEA RESULTS DISPLACEMENT

Strain:

Below it shows the strain value obtained.

Model name: A
Study name: Static 2 from [Static 1] (-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 20.2916

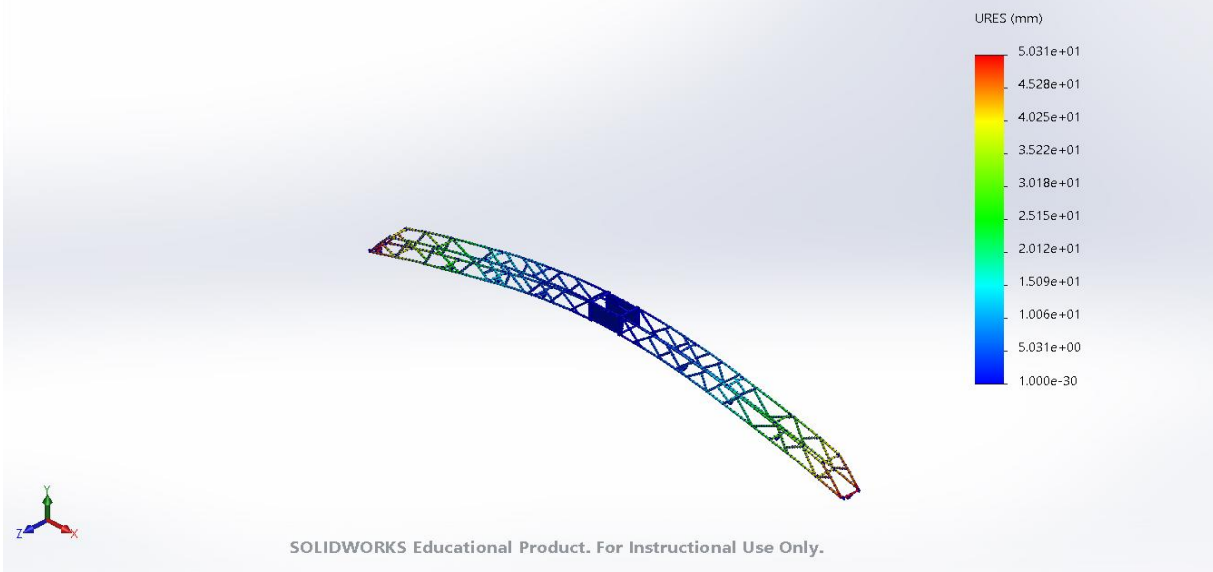


IMAGE - 77- FEA RESULTS STRAIN VALUE

Axial & Bending Stress:

As the analysis was run on beam elements, the results which matters the most are the stress value on the model.

Load applied was twice the safe working load which is 4 tonne times it by gravity as the lifting in the air & the results obtained are around 261 MPa which is below the yield strength of the material.

In general, the beam has a safe working load of 2 which means that the load it will be lifting is 2 tonne and under 2 tonne applied load the axial & bending stress is around 130 MPa which is well below the allowed yield strength of the material.

It is safe to say that the asset will perform well under the applied load which gives the asset a safe working load of 2 tonne.

Model name: A
Study name: Static 2 from [Static 1] (-Default-)
Plot type: Axial and bending Stress2
Deformation scale: 20.2916

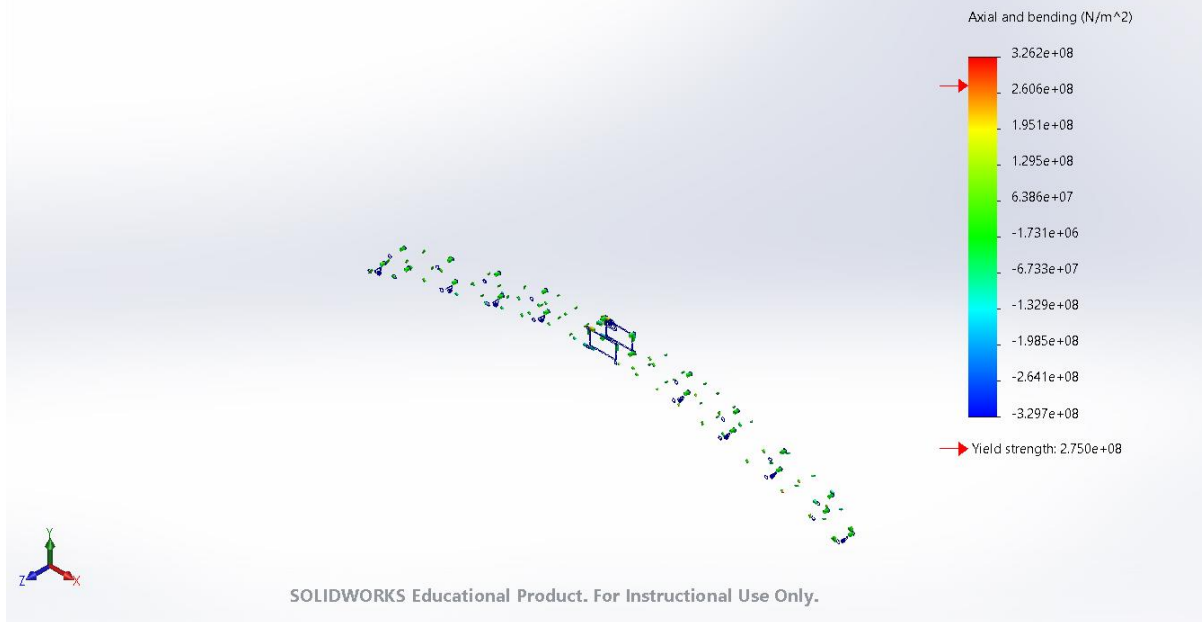


IMAGE - 78- FEA RESULTS AXIAL & BENDING MOMENT STRESS RESULTS

Counterweight Basket:

As the lifting beam will be used as a counterbalance beam a weight basket have to be designed to suit the requirement, a weight basket as a cage have been designed which will be designed to take calibrated weights to suit the need it is required below you will find the equation where it shows how to balance out the load.

Below you can see the cage with the calibrated weights designed in solid works.

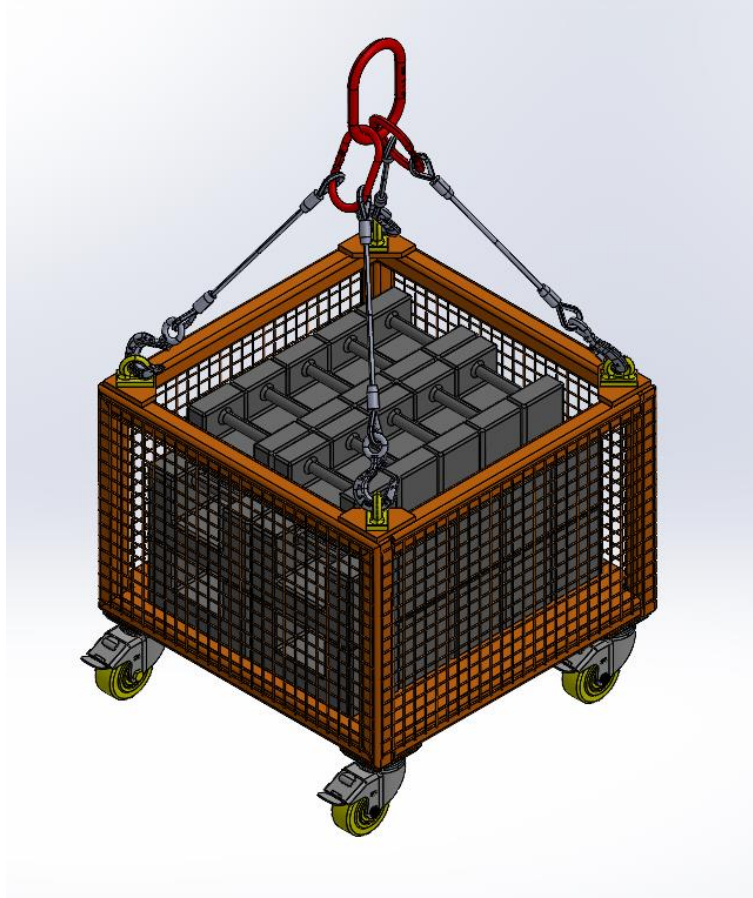


IMAGE - 79- COUNTER WEIGHT BASKET WITH CALIBRATED WEIGHTS

The above image is a complete assembly of full lifting gear is which is required for a secure lifting and balancing out the loads.

It contains:

4 x Wire rope slings 400mm effective working length = 1.4kg Approx.

1 x Master link = 2.8kg.

4 x 1T Hook = 0.290kg.

1 x Cage = 50kg.

Which gives a total mass of 54.53kg Approx.

Whereas there are 20 Calibrated weights = 20kg each

And 10 Calibrated weights = 10kg each.

Which gives us a total mass of 554.53kg which is below the SWL of the lifting beam.

Conclusion:

Topology is now complete, the initial mass of the beam was 1048kg, and the aluminium beam was 780kg, which is now been reduced to 413kg. The optimisation has been success in reducing the overall mass of the beam, this was made possible by identifying the critical load paths of the structure while under a load of 2 tonne. Therefore, the goal of reducing the mass of the structure has been reached. With having a mass of under 0.5 tonne, the counterweight basket with calibrated weights will adds up to a total of 967kg which is below 1 tonne.

See below image for current weight.

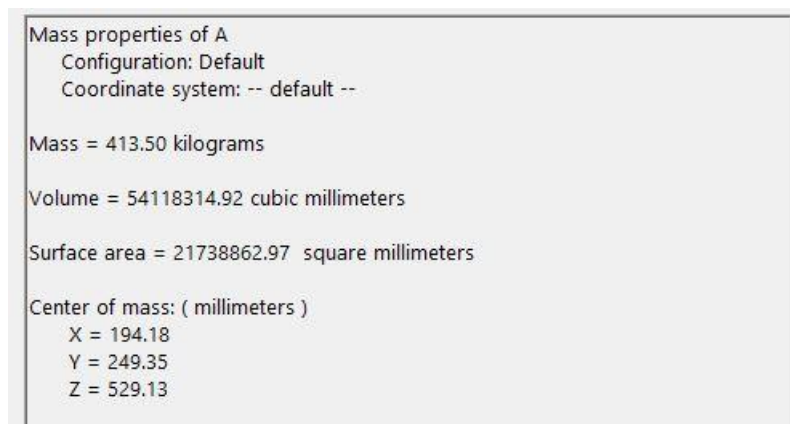


IMAGE - 80- WEIGHT OF LIFTING FRAME

However, even with the reduced mass the beam is still fit for purpose and meets the requirements for lifting standards. As well as allowing to take more load instead of 0.7 tonne it is now taking a load of 1 tonne on each lifting point with less deflection limit as well.

There are several benefits to optimization the structure ultimately the mass has been greatly reduced, the platform has been designed to work sufficiently under the loading conditions due to the critical load paths being identified, a light structure will be easier and lighter to transport around ultimately saving money due to reduce pay load. Lastly less material can often be cheaper to manufacture given that the design has not be over complexed resulting in higher fabrication costs. Thus, less material results in cheaper material costs.

Fully Assembled 3d model in Solid works:

See below images of the final lifting beam results fully assembled with lifting beam, shackles & Counterweight basket with calibrated weights.

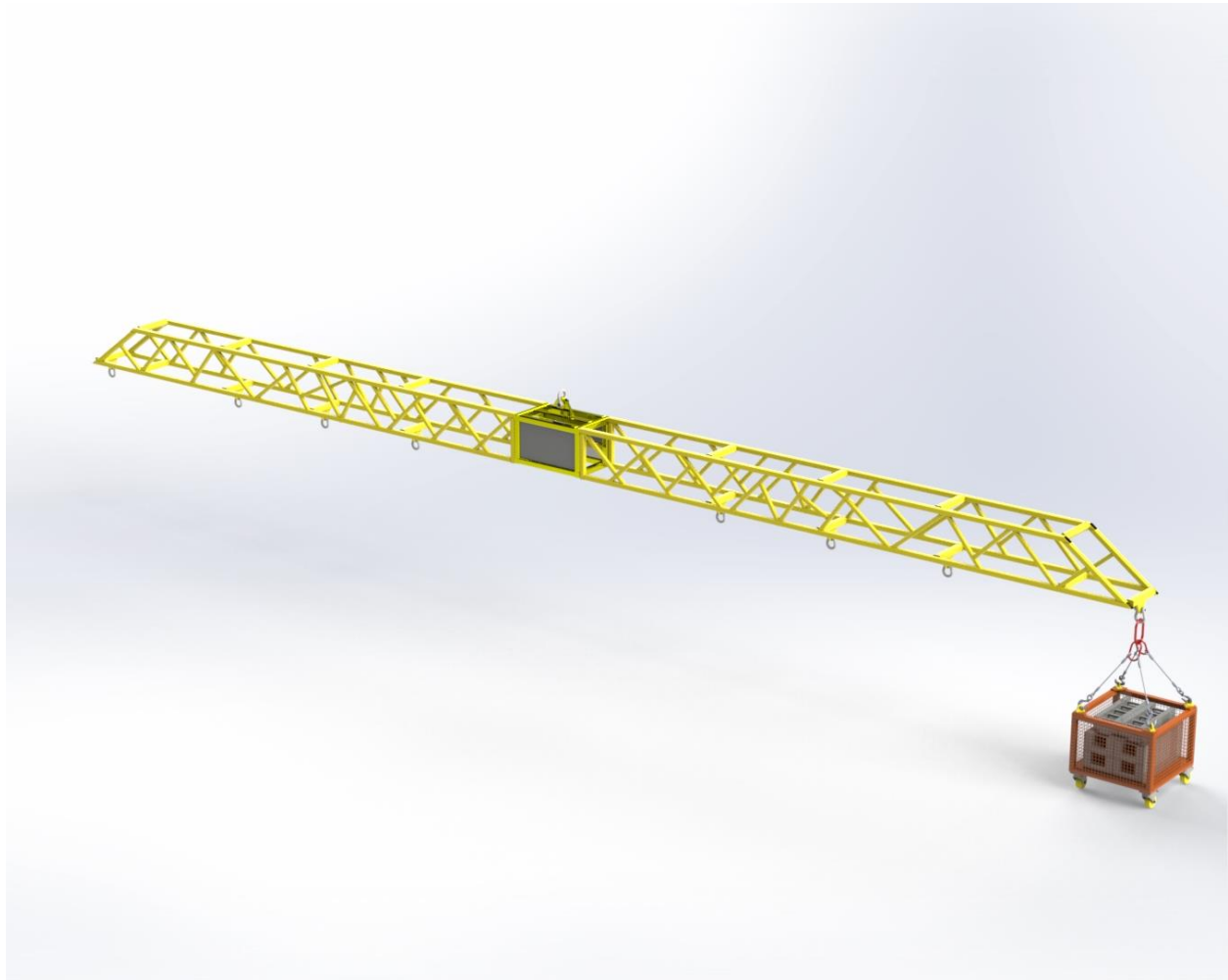


IMAGE - 81- RENDER IMAGE 1 LIFTING BEAM



IMAGE - 82- RENDER IMAGE 2 LIFTING FRAME



IMAGE - 83- RENDER IMAGE COUNTER-WEIGHT BASKET & CALIBRATED WEIGHTS

Costing:

See below for costing:

Material	Length Required	Units	Cost (£)	Total material cost (£)	Mark up Material @40%
RHS 50x50x5	5.55	Meters	44.4		
RHS 40x40x5	32	Meters	225		
RHS 30x30x3	7.457	Meters	40		
Lifting Eyes & Plates			200		
Cage Mesh			100		
Castors			80		
20Kg Callibrated weights			980		
10Kg Calibrated weights			300		
Slings,Hooks & Master link			50		
Shackels			60	2079.4	2911.16
Labour	1 Man 2 Weeks	8 hours/day @ £25/hour		£2,000	
Design Cost				£2,000	
Consumables				£300	
Powder coating				£1,000	
Management Paper work				£150	
Delivery				£500	
				Total Cost to manufacture	£8,861
				Martk up total cost to 100%	£17,722
				Profit	£8,861

Potential order for 10 lifting beams will generate a profit of £88610.00.

Comparison:

Table 1- COMPARISON TABLE

Comparison Table			
	Lifting Beam Previous Design	Lifting Beam Current Design	
Stress	120 MPa	130 MPa	
Displacement	32mm	25mm	
Tare Weight	1048kg (steel Beam) 780 Aluminium Bema	413 Approximately	
Safe Working Load	0.7 Tonne	2 Tonne	

Project Plan 1:

Table 2- PROJECT PLAN INTERM

[illegible]

Project Plan 2 Updated:

Table 3- FINAL PROJECT PLAN

Counter Balance Lifting Beam Final Project																																								
Project Timing (Weeks)	Oct-22				Nov-22				Dec-22				Jan-23				Feb-23				Mar-23				Apr-23				May-23				Jun-23				Jul-23			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Research																																								
Finite Element Analysis																																								
Optimization Techniques																																								
Optimization Utilized In Other Industries																																								
Potential Use of Lifting Beam																																								
Design																																								
Design Specification																																								
Modelling Of Design																																								
Final Design																																								
Material Spec																																								
Topology																																								
Finite Element Analysis																																								
Costing																																								
Research																																								
Components																																								
Design Cost																																								
Manufacturing																																								
Research																																								
Testing																																								
Delivery																																								

Further works:

There are several areas that can be developed further. These are listed below.

Now that the design and FEA analysis is complete, a concept drawing can now be sent to the customer and the quotation for the lifting beam for approval or acceptance.

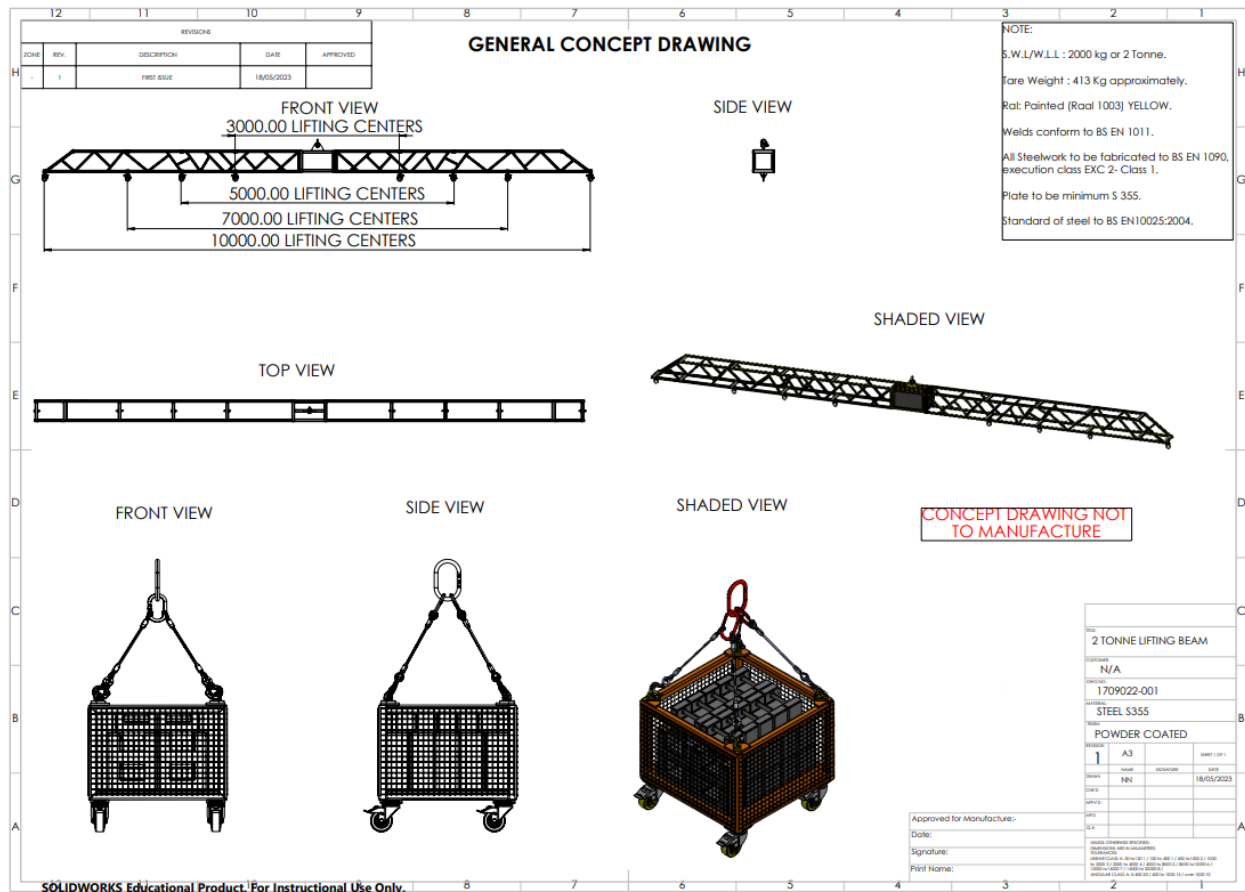
For further works engineering drawing can be complete with dimension, cut list, BOM (bills of Material), weld map & parts list this will then enable the lifting beam to be manufactured.

Further topology can be completed on the beam in smaller sections to reduce the weight further by dropping down the box section sizes, but that will increase the design cost as well as making it difficult to manufacture. As there will be few different box sections and with beam length being 10 meter it will be difficult for the fabrication and welder to keep the track. If we consider

dropping furthermore the weight it will allow to use even small crane can be used saving thousands.

Customer General Drawing:

A customer general drawing can be seen below which will be sent with the quotation.



Above drawing shows a concept drawing where all the lifting centres can be seen, SWL, tare weight as per customer requirement.

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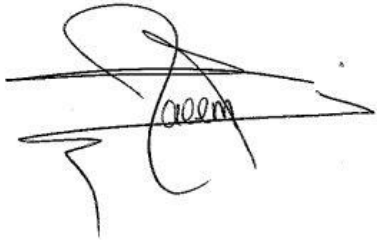
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Declaration:

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.'

Signature:A handwritten signature in black ink, featuring a large, stylized 'S' or 'R' shape with a horizontal line through it, and the word 'Orelm' written below it.**Date:**

19/05/2023