MECH2400
ASSIGNMENT B

Group Name: Briozzo Industries (Group 30)

NAME	SID	DATE	SIGNATURE
Abby Shen	480379218	13/09/2019	
Harry Hawthorne	480380959	13/09/2019	
Ingrid Bonney	470406610	13/09/2019	
Rebecca Johnson	460293839	13/09/2019	RJohnson
Nguyen Tien Duc	480125280	13/09/2019	Duc
Vishant Prasad	470416309	13/09/2019	

Component Design - Spine

Crane & Pulley System

Solution Report

Briozzo Industries

(Briozzo, 2019)

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Written By:

- Abby Shen
- Harry Hawthorne
- Ingrid Bonney
- Rebecca Johnson
- Nguyen Tien Duc
- Vishant Prasad

Edited By:

- Vishant Prasad
- Rebecca Johnson

Table of Contents

Conceptualisation & Design Creativity

Completed By:

- All Members

Introduction

Project Outline

The project at hand involves designing a machine that is able to move either sandstone block to any position (and be swapped in order) along a concrete ramp on a sculptural art piece. The sculptural composition sits on a grass and dirt terrain surrounded further by concrete walkways on all four sides.

Requirements

- Components that are powered by electricity, magnetism, chemical reactions or compressed air is strictly prohibited.
- Framework must be constructed from either mild steel or aluminium sections.
- Adjoining grass environment is to be avoided. No components or individuals can be on the grass section around the sculpture.
- The design must be able to connect and disconnect with reasonable ease and be transportable by truck.
- The design must be able to 'pull and push' either sandstone block independently or together.
- The design must have a safety mechanism that ensures that if the load is suddenly removed, there is no danger to the artwork or participants.
- The speed of the movement of the blocks during the machine's operation is not a critical factor and may be small (i.e. $0.1 m/s$).
- Two feasible mechanical solutions to the design of the machine must be provided.
- All components that require adjoining elements must use fasteners such as bolts.
    - Welding is prohibited in the construction of the system.
    - Drilling or scratching of the artwork is prohibited.

Mechanical Design Solutions

Completed By:

- All Members

Option 1

Stationary Gantry Crane & Pulley System

The gantry crane is a mobile, four beam support crane. The four wheels will be attached to a track on either side of the artwork. The crane will attach to a harness system that is removable and will be placed around five visible faces of the concrete block. The harness is then attached to the hook component of the crane. Cables run through the beams of the crane connecting to the hook component. Cables also run through the axial component of the crane that allows for wheel rotation. The students operate pulleys that have gears pulling the cable for both the movement of the hook and the turning of the axial.

Option 2:

Mobile Gantry Crane & Turn-Table System

Similar to option two, however instead of pulleys controlling the movement of the various components, turnstiles are used that have the cable wound at its centre (at the base of the turn-table). Protruding from this table are various handles that allow the students to push on to allow for rotation of the cable. This turnstile is utilized on both the crane lift mechanism and the rotation of the axial of the gantry crane.

Creative Methods

Completed By:

- All Members

Brainstorming (Individual)

The initial creative method utilized to gain the final selected solution includes individual brainstorming. The following section includes a variety of initial system ideas that were suggested for the project by a variety of members individually:

- *Suction Cup System*
    - Employed two pulleys for the horizontal movement of the concrete block.
    - The ends of the pulley have a large suction cup to be attached to the blocks.
    - A secondary crane sub-system has a suction cup that can move the blocks into alternate arrangements.
    - Employs the energy of the 300+ students to operate the crane cup and pulleys.
- *Harness & Pulley System*
    - A buckled harness is attached to the blocks with the ends attached to a cable and pulley system.
    - The 300+ student's energy is employed for the operation of the two pulleys.
    - A crane is also in place with a similar harness system for the lifting of the blocks and movement to arrange them in different orders.
- *Water Wheel System*
    - Utilizes two wheels that can collect water to rotate a cable connected to the blocks via a harness.
    - The water allows for the wheel to rotate and therefore, creates tension in the cable to pull the blocks individually.
    - This requires no energy from the students apart from filling that required water and moving of the basins to allow for the wheel to rotate in an opposite direction.
    - The basin can be transported by the energy of 300+ students, or two different basins may be employed but will require a lifting system to re-rotate the wheel in a clockwise or counterclockwise direction. The falling of the water (left or right side) will determine the direction of rotation of the wheel.

Brainstorming (Collectively)

The next stage of the creative design process involved the discussion of the solutions individually proposed. The discussion would determine the most efficient and effective method of achieving the outcomes of the project while also satisfying the requirements proposed. This process involved the selection of a system as well as a combination of other systems that were determined to be of benefit to the project as a whole. The final selection of the system would therefore, be a hybrid of multiple solutions and would be agreed upon by all members.

To assist in the selection process a design trade-off table method was utilized to weight quantitatively the systems and their effectiveness.

While discussion of the various ideas that individuals had brainstormed, it was found that most push-pull system in the horizontal axis of movement was not a viable solution as scratching would occur to the ramp. Furthermore, the lifting of the blocks would be challenging due to the large weight of the blocks and the inability to wrap a harness through the base of the block that makes contact with the ramp. It was concluded that the harness would cover five of the six faces of the blocks. Finally, it is a goal to reduce the effort and energy exerted by the students in the operation of the system, allowing for efficient movement of the systems mechanical components as well as saving time and money in the design.

More specifically, it was found that a *suction system* would require an unrealistic sized cup and would have a large chance of potentially failing in any lifting process and damage the artwork.

The *crane and pulley system* would result in scratching of the blocks, therefore, the crane lifting component of that design was kept but the pushing and pulling action of the block was removed.

After consideration of the *water wheel system,* it was found that the water would require a pump system to allow it to move back to the top of the wheel to allow for constant circular movement. Furthermore, the large amount of weight collectively in the system would require a large amount of water constantly moving through the wheels and large water wheels themselves. This would exponentially increase cost but save energy required from the students.

Finally, it was agreed that the most viable solution would be a heavily supported crane that has one dimension of movement (vertical *z* axis of movement) for the lifting of the blocks via a hook and harness system. The movement of the block along the ramp would be achieved by placing the crane on a mobile support making a gantry crane.

Trade-Off Table

Table 1 shows the criteria that was analysed to select an appropriate design. The criteria include cost, reusability, safety, function, speed, size and energy. Each design was given a value out of 10 for each criterion, then a weighted score based on the importance of the criteria for the design.

Table 1 – Trade Off Table

Design Criteria	Weighting Factor	Design1 Gantry Crane		Design 2 Water Wheel		Design 3 Crane & Pulley	
	Value (/10)	*Score (/10)*	*V*S*	*Score (/10)*	*V*S*	*Score (/10)*	*V*S*
Cost	4	5	20	3	12	4	16
Reusability	7	7	49	4	28	6	42
Safety	9	5	45	5	45	7	63
Function	8	7	56	6	48	6	48
Speed	6	6	36	4	24	4	24
Size	4	5	20	5	20	5	20
Energy	5	8	40	7	35	4	20
Total:			*266*		*212*		*233*

Trade-Off Table Discussion

The cost design criteria within this system analysis was rated a lower integer if the cost is high (and the inverse is also true). The cost of the gantry can singular system would be an average value since most of the components are straight beams with no overly technical elements. In contrast the crane and pulley system would have a slightly higher cost (lower cost score/value) since the system incorporates an increased number of elements to reduce energy. The water wheel has the highest cost due to the large amount of water required that will most probably not be reusable unless manually recycled. The overall value of cost is average-low since cost is not specified by the requirements.

The reusability of the system is valued high as the requirements of this project involve the moving of the blocks in multiple different orders efficiently. The gantry crane has high reusability as the crane and cables will all be steel with most of the structure being high strength. The water wheel system however will not be able to be used as long as the other two options due to the requirement of large amounts of water. The crane and pulley system although is reasonably reusable, overtime its effects on the artwork and itself will cause it to be replaced.

Safety is a high priority in the project due to the specified factor as well as the requirement of the students to function the components of the system. The water wheel and the gantry crane systems have an equivalent safety value as the water increases the risk of physical injury (although energy required close to the heavy blocks is decreased, therefore in the event of failure, students are not close to the damage or danger). The crane pulley design has a slightly lower safety value since the pulleys, block and harness can fail causing the cables to destroy the susan close to students operation and the blocks can slide off the artwork.

The function of the system is high in value rating as the design must be fully operational and satisfy all the requirements of the project. The pulley system would result in damage to the artwork justifying its low rating. Similarly the water wheel would result in a less efficient system with a very slow speed of movement. The gantry crane however, is resonably fast at movement with low damage to the artwork. This relates to the next criteria of speed. The pulley would have frictional forces slowing down its movement. The speed is of average value due to its mention in the specification.

The energy of the system is low for the water wheel requires low energy from the individuals operating the system however, would stil require more energy in comparison to the gantry crane system due to refilling of the water components.

The size is not of high prority as the system does not require any limits on the sizing therefore, sizing is based souley on the most efficient and effective design that covers the least space and requires less disturbance to the surrounding area. The water wheel therefore, would have the introduction of the water element while the gantry and pulley systems would be an overall large overhanging system. Both are equally as distrubing to the area and large in size.

Discussion of Final Design

The **Mobile Gantry Crane & Turn-Table System** operates with a one dimensional crane at the centre of the system. The crane will always lie above the ramp and move only perpendicularly (vertical) to the ramp that holds the blocks. The crane hooks onto a harness system that will lift the blocks individually. The crane has one dimension of movement in the *z-axis* direction (denoted in figures below). Once the block is lifted, the block will be locked in place with one-way threaded gears working with the cable and therefore, the block will remain suspended a safe distance above the artwork. The horizontal movement of the block is now achieved by using the mobility of the crane which includes four wheels attached to tracks. Once the system is moved over the desired position on the ramp, the wheel lock on the current track position and the crane slowly lowers the block onto the ramp. All movement involved in the design will be accomplished using turn-tables that require students to push horizontally onto them (demonstrated in sketches below). The turn-tables will be attached to the crane using a cable winding around the table's base (acting like a pulley). There will also be two more turn-tables control the forward and backwards movement of the crane respectively.

Safety Consideration

There are various safety considerations in this system such as the suspension and lifting action of the block without failure, the movement on wheels and ability to stop-go, the lowering of the block onto the ramp without damaging the ramp and/or any individuals close by and the safe use of the turn-tables with the cables kept safely away from the students (avoid pinching on any components). Safety mechanism within our system includes:

- Gears with one-way complementing threads that result in a steady lifting of the blocks without the possibility of the sudden slipping or release of the block.
- The cables would have to be grooved complementing the threads of the gears as well as being high density to support the weight of the blocks ($\approx 7000kg$).
- The turnstile that controls the lift of the block or the movement of the hook/crane component will only have the ability to move in one direction at a certain time with a locking mechanism.

Design Requirements

Table 2 below outlines how the Mobile Gantry Crane & Turn-Table System addresses the design requirements.

Table 2 – Design Requirements

	Requirement	**How the requirement is addressed in the design**
1	Move either sandstone block to any position (and be swapped in order)	Crane will be able to move a single block in the x and y plane.
2	Energy comes from 303 students only.	Simple, human powered machines will be used.
3	Framework must be constructed from either mild steel or aluminium sections.	Material selections are either mild steel or aluminium.
4	Must not touch adjoining grass	The crane will have a width of 13m to avoid contact with the grass.
5	Safety mechanism	A locking mechanism is implemented for the capstan to secure the load.
6	No welding.	Bolts used to join sections.
7	The artwork or adjoining grass cannot be damaged in any way	The machine will not contact the concrete block nor adjoining grass. Appropriate material selection will ensure no damage to the sandstone block.

Basic Stress Analysis & Calculations

Completed By:

- Rebecca Johnson
- Ingrid Bonney

Introduction

A basic stress analysis is conducted to ensure that the design will meet the necessary load and safety requirements. The stress calculations have been divided into 4 sections to provide a comprehensive analysis of the design. These calculations include;

1. Force to lift block using pulley and wheel & axle system
2. Stress and deflection of beam due to lifting of block
3. Force required to move the structure
4. Force on bolted connections

Parameters

Table 3 below details the parameters of the system to be used in the following calculations.

Table 3 – Parameters

Parameter	Symbol	Value	Units
Density of sandstone block	ρ	2323 [1]	kg/m^3
Length of block	L_B	1.5	m
Width of block	W_B	1.5	m
Depth of block	D_B	1.5	m
Width of grassed area	W_G	12	m
Factor of safety	FS	1.25	$-$
Length of cross-beam on structure	L_1	13	m
Length of vertical beams	L_2, L_3	4	m

Calculation 1 – Force to Lift Block

For this design, the block will be lifted by a combination of a pulley and wheel and axle system. Students will turn the capstan (wheel and axle system), which will pull the rope through the 3-pulley system. This will lift the block in the vertical direction. The objective of this calculation is to determine the number of students that will be required to lift the block using this system.

Assumptions;

- Mass of ropes is negligible, i.e. $m_{rope} = 0$.
- Mass of pulleys is zero, i.e. $m_{pulley} = 0$.
- Rope slips along pulley and wheel and axle system, i.e. no friction.

FBD – Pulley System

Figure 1 shows the free body diagram for the pulley system. The 3 pulleys are connected to the beam structure and the force, F_P, is the force that the students are required to pull in order to lift the block of mass m_B.

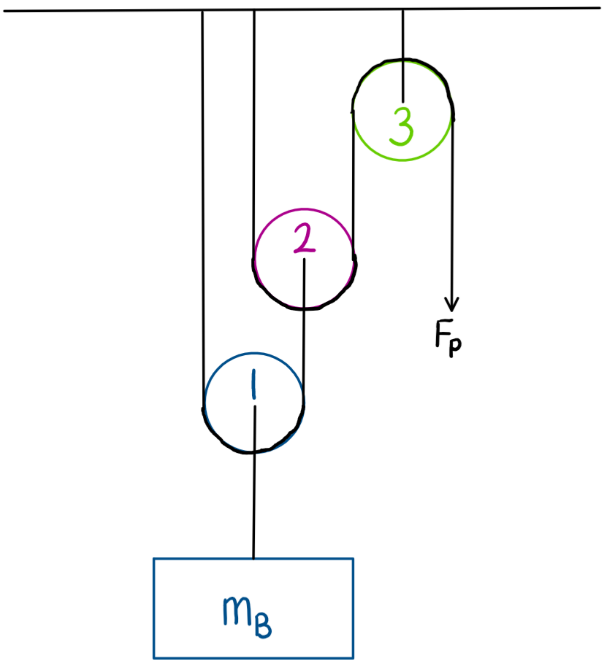

Figure 1 – FDB Pulley System

Force due to mass of block

The length, width and depth of the block are given as parameters of the system. Therefore, the volume of the block is;

$$V_B = L \times D \times W = 1.5 \times 1.5 \times 1.5$$

$$V_B = 4.5\, m^3$$

The mass of the block and the resulting force can then be calculated;

$$m_B = V_B \rho = 4.5\ (m^3) \times 2323 \left(\frac{kg}{m^3}\right)$$

$$\therefore m_B = 10{,}453.5\ kg \cong 10{,}500\ kg$$

$$F_B = m_B g = 10{,}500 \times 10$$

$$\therefore F_B = 105\ kN$$

A factor of safety must be applied to the system to ensure that it will not fail under maximum loading. This factor of safety is given as 1.25.

$$FS = \frac{F_{allowable}}{F_{actual}}$$

$$F_{allowable} = FS \times F_{actual}$$

$$\therefore F_B = 1.25 \times 105 = 131.25\ kN$$

Force on pulleys;

Pulley 1:

$$\sum F_y = m_1 a_1 = -F_B + 2T_1$$

$$m_1 = 0$$

$$\therefore T_1 = \frac{1}{2} F_B$$

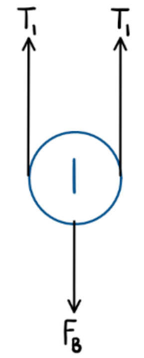

Figure 2 – FBD Pulley 1

Pulley 2:

$$\sum F_y = m_2 a_2 = -T_1 + 2T_2$$

$$m_2 = 0$$

$$\therefore T_2 = \frac{1}{2} T_1 = \frac{1}{4} F_B$$

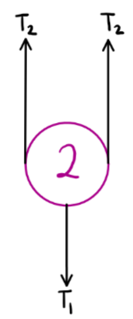

Figure 3 – FBD Pulley 2

Pulley 3:

$$F_P = T_2$$

$$\sum F_y = m_3 a_3 = -2T_2 + T_3$$

$$m_3 = 0$$

$$\therefore T_3 = 2T_2 = \frac{1}{2} F_B$$

$$\therefore F_P = \frac{1}{4} F_B$$

$$\therefore F_P = \frac{1}{4} \times 131.25\ kN = 32.8125\ kN$$

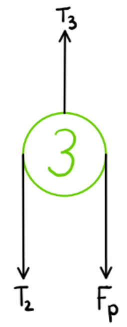

Figure 4 – FBD Pulley 3

Therefore, the force required to pull the block up is 32.8125 kN. The rope from the pulleys connects to the wheel and axle system which is controlled by the students.

FBD of the wheel and axle system

Figure 5 shows the free body diagram for the capstan (wheel and axle system). The inner circle is the supporting post for the system and the rope will coil around this post. The outer circle is where the students will push the system to coil the rope. Due to the difference in radii of the two circles, a mechanical advantage is achieved.

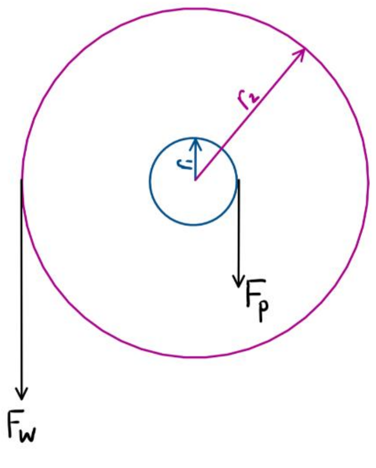

Figure 5 – FBD Wheel and Axle System

Where; r_2 is the radius of the wheel, r_1 is the radius of the axle, F_P is the force required to pull the block and F_w is the force acting on the wheel (force students push).

Mechanical Advantage

$$MA = \frac{r_{wheel}}{r_{axle}} = \frac{r_2}{r_1}$$

$$MA = \frac{output\ force}{input\ force}$$

$$MA = \frac{F_{Pull}}{F_{wheel}} = \frac{r_2}{r_1}$$

$$F_{wheel} = \frac{r_1}{r_2} \times F_{Pull}$$

Where;

$$r_1 = 0.5m, r_2 = 2.5m$$

$$F_{wheel} = \frac{0.5}{2.5} \times 35.81$$

$$F_{wheel} = 7.163kN$$

The number of students required to rotate the wheel is;

$$Number\ of\ students = \frac{F_{wheel}}{Force\ that\ students\ can\ push}$$

Calculations for the force that students can push is based on the fact that the average human can push 20% of their body weight [2], and the average weight of 61kg for males and females of 18 years of age.[3]

$$F_{student} = 61 \times 0.2 \times 9.81$$

$$F_{student} = 119.682N$$

$$Number\ of\ students = \frac{7.162kN}{119.682N}$$

$$\therefore Number\ of\ students = 60$$

Therefore, 60 students will be required to turn the capstan to lift the block.

Calculation 2 – Force on beam due to lifting

The pulley system is connected to the supporting structure of the machine. As the block is lifted, significant stress will be induced on the supporting cross-beam and vertical beams. A basic stress analysis can be undertaken to select an appropriate material for the structure and ensure it will not fail during operation.

FBD of lifting structure

Figure 6 shows the free body diagram for the structure. The force acting on the cross-beam is due to the force from the pulley system lifting the block and the weight of the beam itself. The force from the 3 pulleys is approximated as a single force acting in the centre of the beam. The weight of the beam is also resolved as a single point force acting in the centre of the beam.

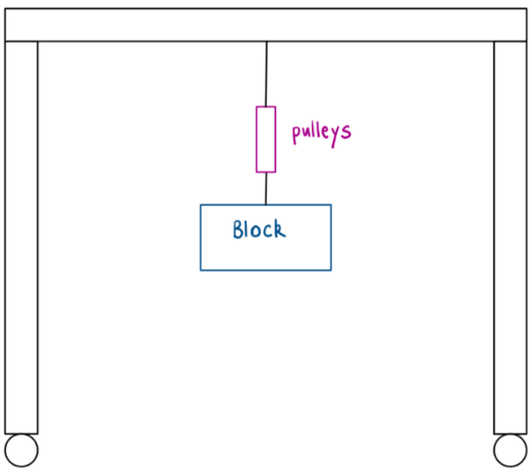

Figure 6 – FBD of Supporting Structure

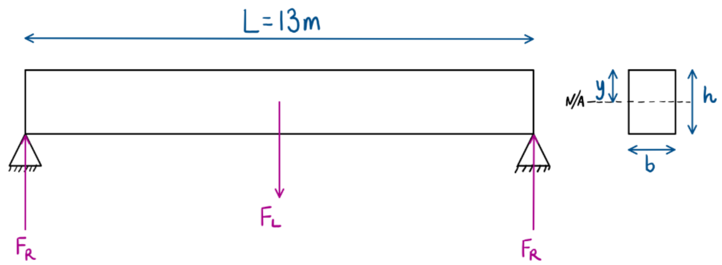

Figure 7 – FBD of Cross-Beam

Forces acting on the beam from the pulley and weight of beam;

$$F_{pulleys} = T_1 + T_2 + T_3 = \frac{1}{2}F_B + \frac{1}{4}F_B + \frac{1}{2}F_B$$

$$\therefore F_{pulleys} = 1.25F_B$$

$$F_{mass} = m_{beam}g = 10m_{beam}$$

Where $g = 10\ m/s^2$.

The mass of the beam is dependent on the material selected and remains a variable through the calculations. Therefore, the force acting on the centre of the beam, F_L, is the sum of the force due to pulleys and force due to mass;

$$F_{Lift} = F_{pulleys} + F_{mass}$$

$$F_L = 1.25F_B + 10m_{beam}$$

$$F_L = 1.25(131250) + 10m_{beam}$$

$$\therefore F_L = (164063 + 10m_{beam})N$$

From the FDB, the forces can be resolved from the following equilibrium equation;

$$\sum F_y = 0 = 2F_R + F_L$$

$$\therefore F_R = \frac{F_L}{2}$$

Shear Force Diagram

The shear force diagram is shown in Figure 8. However, the value of F_L cannot be determined until the material is selected and the corresponding mass of the beam is known.

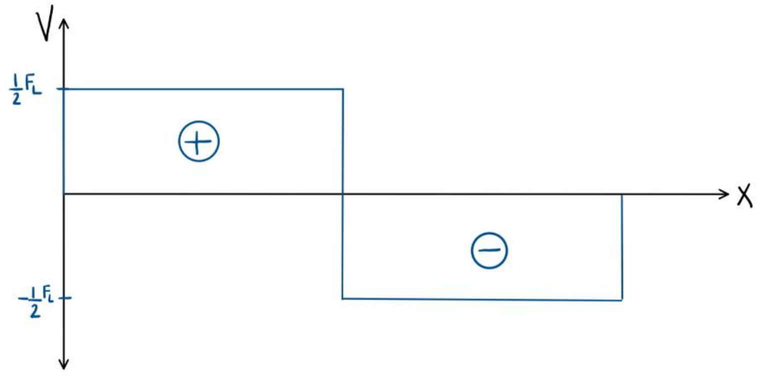

Figure 8 – Shear Force Diagram

Bending Moment Diagram

The bending moment diagram is shown in Figure 9. However, the value of M_{max} cannot be determined until the material is selected.

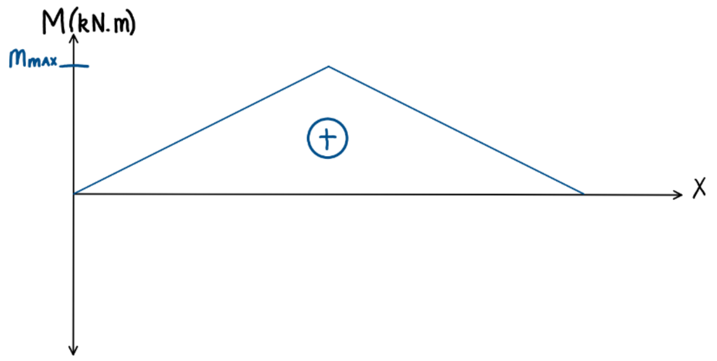

Figure 9 – Bending Moment Diagram

The maximum moment occurs at $x = \frac{L}{2}$, as shown in the BMD.

The maximum moment is;

$$M_{max} = \left(\frac{1}{2}F_L\right)\frac{L}{2}$$

$$M_{max} = \frac{1}{2} \times (164063 + 10m_{beam}) \times \frac{13}{2}$$

$$\therefore M_{max} = (533205 + 65m_{beam})\frac{N}{m}$$

Material Selection

To select the beam material, the calculated stress, σ_{calc}, must be lower than the maximum yield stress of the material. The maximum yield stress, σ_{yield}, is given in the reference documentation for each material and is typically 360 MPa or 450 MPa. The calculated stress is found using the following formula;

$$\sigma_{calculated} = \frac{M_{max}\, y}{I}$$

Where;

- M_{max} is the maximum bending moment (N/m); $M_{max} = (533205 + 65m_{beam})\frac{N}{m}$
- y is half the height of the beam (m); $y = \frac{1}{2}d$
- I is the second moment of area (m^4); $I = \frac{bh^3}{12}$.

In addition, the deflection of the beam should be minimised to reduce the likelihood of failure. The deflection of the beam is found using the following formula;

$$\delta_{max} = \frac{F_L L^3}{48EI}$$

Where;

- F_L is the force at $x = \frac{L}{2}\,(N)$; $F_L = (164063 + 10m_{beam})N$
- L is the length of the beam; $L = 13m$
- E is the Youngs modulus of the material; $E = 200\ GPa$
- I is the second moment of area (m^4); $I = \frac{bh^3}{12}$.

The material options explored for the structure sections were steel I-beams from OneSteel or rectangular hollow steel sections and square hollow steel sections from AusTube Mills. Figure 100 and Figure 11 show examples of an I-beam and hollow section, respectively.

Table 4 shows the calculated values for various beam dimensions. The difference between the yield stress and calculated stress should be minimised to ensure that the beam is not oversized, as the factor of safety has already been applied. The deflection of the beam should also be minimised to reduce likelihood of failure.

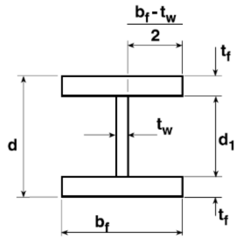

Figure 10 – I-Beam

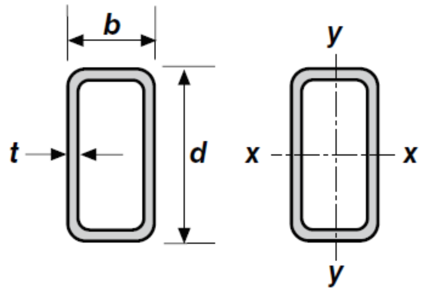

Figure 11 – Rectangular Hollow Section

Table 4 – Material Selection

Selection Number	Reference Document	Material Name	Maximum Yield Stress (MPa)	Second Moment of Area, Ix (mm^4)	Height, d (mm)	Mass (kg)	Moment (N.m)	Calculated Stress (Pa)	Difference b/w Yield & Calc Stress (Pa)	Force on beam (N)	Deflection of beam (m)
1	AusTube Mills	RHS - 400x300x16	450	453	400	2093	669250	295,474,614	154,525,386	184993	0.093457878
2	AusTube Mills	RHS - 400x300x12.5	450	370	400	1664	641365	346,683,784	103,316,216	180703	0.111769282
3	AusTube Mills	RHS - 400x200x16	450	335	400	1768	648125	386,940,299	63,059,701	181743	0.124157143
4	OneSteel	1200 WB 455	360	15300	1200	5915	917680	35,987,451	324,012,549	223213	0.003338773
5	OneSteel	350 WC 280	360	747	355	3640	769805	182,918,859	177,081,141	200463	0.061414716
6	OneSteel	700 WB 173	360	2060	716	2249	679390	118,068,748	241,931,252	186553	0.020724967
7	AusTube Mills	RHS - 350x250x12.5	450	233	350	1417	625310	469,653,433	-19,653,433	178233	0.175061651
8	AusTube Mills	RHS - 75x50x6	450	0.8	75	125.71	541376.15	25,377,007,031	-24,927,007,031	165320.1	47.29274215
9	AusTube Mills	RHS - 400x300x8	450	251	400	1094.6	604354	481,556,972	-31,556,972	175009	0.159567884
10	OneSteel	1200 WB 455	360	15300	1200	5915	917680	35,987,451	324,012,549	223213	0.003338773
11	OneSteel	700 WB 173	360	2060	716	2249	679390	118,068,748	241,931,252	186553	0.020724967
12	AusTube Mills	SHS - 400x400x16	450	571	400	2418	690375	241,812,609	208,187,391	188243	0.075446926
13	AusTube Mills	SHS - 400x400x10	450	382	400	1560	634605	332,253,927	117,746,073	179663	0.107635147
14	AusTube Mills	SHS - 350x350x16	450	372	350	2093	669250	314,835,349	135,164,651	184993	0.113807578
15	AusTube Mills	RHS - 400x200x10	450	306	400	1352	621085	405,937,908	44,062,092	177583	0.132812449
16	AusTube Mills	RHS - 300x300x16	450	161	300	1443	627000	584,161,491	-134,161,491	178493	0.253719669
17	OneSteel	500 WC 440	360	2150	400	5720	905005	84,186,512	275,813,488	221263	0.023552074
18	OneSteel	400 WC 361	360	1360	430	4693	838250	132,517,463	227,482,537	210993	0.035504873
19	OneSteel	350 WC 197	360	486	331	2561	699670	238,262,109	121,737,891	189673	0.089315754

The OneSteel 350 WC 280 I-beam [5] [6] and AusTube Mills Rectangular Hollow Section (400x200x10) [7] were determined to be the most appropriate selections and are highlighted in Table 4 above. However, the rectangular hollow section will be used in this design as it has a lower mass and smaller difference in calculated versus yield strength compared to the I-beam. Table 5 below contains a summary of parameters and calculated values for the selected material.

Table 5 – Parameters for AusTube Mills RHS 400x200x10

Parameter	**Symbol/Units**	**Rectangular Hollow Section (400x200x10)**
Yield Stress	$\sigma_{yield}\ (MPa)$	450
Calculated Stress on Beam	$\sigma_{calculated}\ (MPa)$	405.94
Height	$d\ (m)$	0.4
Width	$b\ (m)$	0.2
Thickness	$t\ (m)$	0.01
Mass/metre	(kg/m)	104
Second Moment of Area	$I\ (m^4)$	0.000306
Moment	$M\ (kN.m)$	621.1
Force	$F\ (kN)$	177.6
Maximum Deflection	$\delta\ (m)$	0.133

The Shear Force Diagram and Bending Moment Diagram can be updated because the force and maximum moment have been determined. The shear force diagram is shown in Figure 12 and the bending moment diagram is shown in Figure 13.

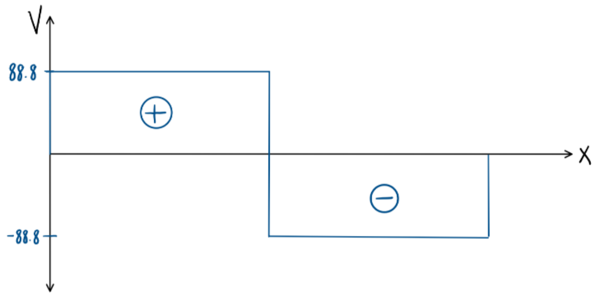

Figure 12 – Shear Force Diagram

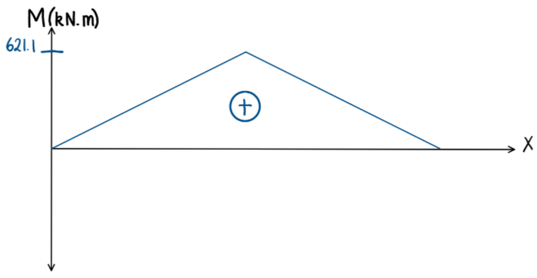

Figure 13 – Bending Moment Diagram

Calculation 3 – Force to pull structure

Once the block has been lifted by the pulley and wheel and axle system, the machine will then be moved so that the block can be placed in different location along the length of the structure. The machine will be pulled by students using ropes to position the block where required. The students will pull both ropes with the same force and at the same speed to ensure that the structure remains perpendicular to the artwork. The structure will be modelled as a simple block moving along a flat surface. As the structure is in motion, the dynamics of the system must be analysed.

Assumptions;

- Students pull at the same time, speed and force on both sides of the structure.
- The students will push from the centre height of the structure, ensuring that it will remain upright.
- That the columns are the same material as the cross beam.
- Surface surrounding the artwork is perfectly flat

Free Body Diagram

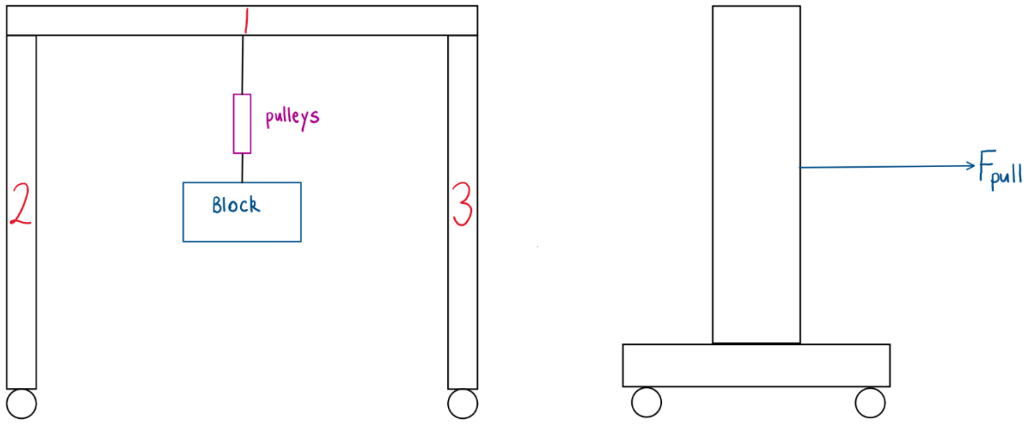

Figure 14 - Simple Representation of the Structure

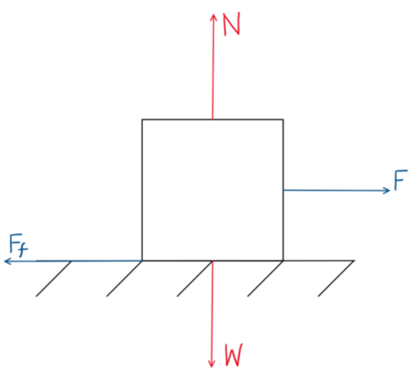

Figure 15 – Free Body Diagram of Simplified Model

Force Due to Mass;

The force due to the mass of the beams is the summation of the weight of each section;

$$W_{beams} = W_1 + W_2 + W_3 = g(m_1 + m_2 + m_3)$$

$$W = 10(m_1 + m_2 + m_3)$$

The mass of each beam is determined from the material properties, where $Mass/metre = 104\ kg/m$. It is assumed that the material of the vertical sections (section 2 and 3) are the same as the cross-section (section 1).

$$L_1 = 13m, L_2 = L_3 = 4m$$

$$m_1 = 104\frac{kg}{m} \times 13m = 1{,}352\ kg$$

$$m_2 = m_3 = 104\frac{kg}{m} \times 4m = 416\ kg$$

$$W_{beams} = 10(m_1 + m_2 + m_3) = 10(1352 + 416 + 416)$$

$$\therefore W_{beams} = 21{,}840\ N$$

Force required to pull structure;

Assume a kinetic coefficient of friction of $\mu_k = 0.65$ for concrete and acceleration of $a = 0.5\ m/s^2$. As per Figure 14 and Figure 15 , the force required to pull the structure is;

$$\sum F_x = ma = F - F_{friction}$$

$$F = ma + F_f$$

$$F_f = \mu_k N = \mu_k W_{beams} = 0.65 \times 21{,}840$$

$$\therefore F_f = 14{,}196\ N$$

$$F = (2184 \times 0.5) + 14196$$

$$\therefore F = 15{,}288\ N$$

The force will be pulled via 2 ropes, thus;

$$F_{pull} = \frac{1}{2}F$$

$$\therefore F_{Pull} = 7940\ N$$

The number of students required to pull each rope is;

$$Number\ of\ students = \frac{F_p}{Force\ that\ students\ can\ pull}$$

Assuming students can pull 30% of their body weight [2];

$$F_{student} = 61 \times 0.3 \times 9.81$$

$$F_{student} = 179.523N$$

$$Number\ of\ students = \frac{F_{Pull}}{F_{student}} = \frac{7940}{179}$$

$$Number\ of\ students = 45\ per\ rope$$

Therefore, 90 students will be required to move the structure once the block has been lifted. 60 students were required to operate the pulley system to lift the block. Therefore;

$$Students_{total} = Students_{lift} + Student_{structure} = 60 + 2(45)$$

$$\therefore Students_{total} = 150$$

Calculation 4 – Bolted connections

The various steel sections will be connected via bolts. A stress analysis must be connected on these bolts to ensure they do not fail under loading.

The force due to the summation of the mass of each of the beams is;

$$F_w = F_{block} + W_{beams}$$

$$F_w = 105\ 000N + 21\ 840$$

$$\therefore F_w = 126.84kN$$

Considering the factor of safety;

$$F_{w,allowable} = FS \times F_{w,actual} = 1.25\ \times 126.84$$

$$\therefore F_w = 158.550kN$$

The force will be distributed across two sides of the structure, therefore the applied load on each joint will be;

$$V_f^* = \frac{1}{2}F_w = 79.275\ kN$$

Free Body Diagram;

Figure 16 shows that the bolts are located at the four joints of the structure. Joints 1 connect one cross-beam to one vertical beam. Joints 2 connects one vertical beam to two horizontal beams. Figure 17 shows a detailed view of joint 1, with 4 bolts all in tension. Figure 18 shows a detailed view of joint 2, with bolts 4&5 in compression and 3&6 in tension.

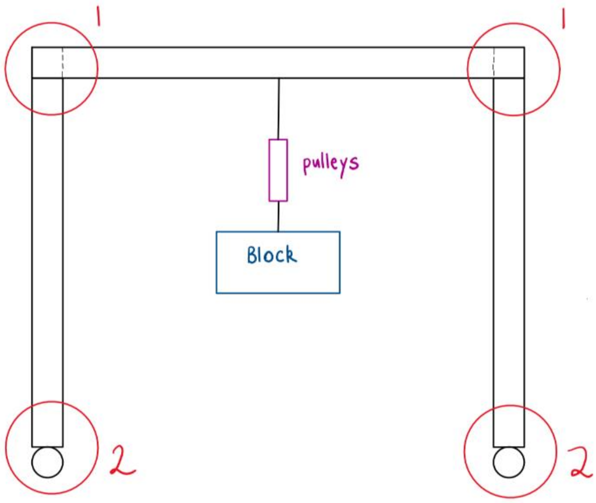

Figure 16 – FBD Bolts

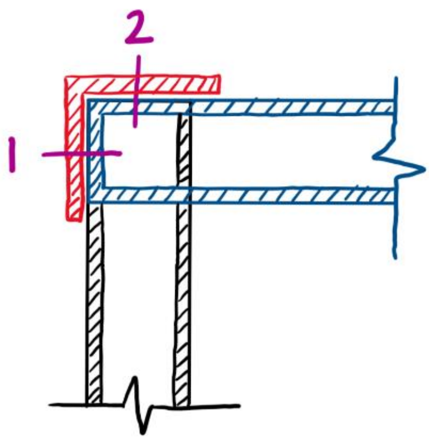

Figure 17 – FBD Joint 1

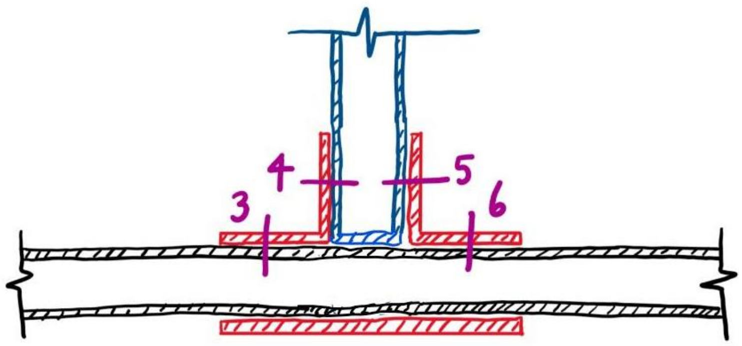

Figure 18 – FDB Joint 2

Compression bolts at top and bottom;

Using 2 off M8 Grade 10.9 bolts aligned in single shear at this joint;

Table 6 – Parameters for M8 Grade 10.9 bolts loaded in shear

Parameter	Symbol/Units	2 off M8 Grade 10.9 bolts
Load capacity (including safety factor)	$V_f^*(N)$	$79.275kN$
Nominal Shear Capacity	$V_f = 0.62f_{uf}k_r(n_nA_c + n_xA_o)$	$82.1376\ kN$
Capacity Factor (bolt in shear)	ϕ	0.8
Minimum tensile strength of bolt	$f_{uf}\ (MPa)$	$1000\ MPa$
Joint Length Factor	k_r	1.0
Number of shear planes with threads intercepting the shear plane	n_n	2
Bolt core area	$A_c\ (mm^2)$	$32.8mm^2$
Number of shear planes without threads intercepting the shear plane	n_x	2
Bolt shank area	$A_o\ (mm^2)$	$50mm^2$

Clause 9.3.2.1, AS4100 [4]

Such that;

$$V_f = 0.8 \times 0.62 \times f_{uf} k_r (n_n A_c + \ n_x A_o)$$

$$V_f = 0.8 \times 0.62 \times 1000 \times 1.0(2 \times 32.8 + \ 2 \times 50)$$

$$V_f = 82.1376 \ kN$$

$$V_f^* < V_f$$

The width of the bolt cannot be increased due to the limited width of the beam.

Therefore, the bolt design is adequate.

Calculating the load at the top two connections (bolts 1&2 from Figure 17);

Using the same 2 off Grade 10.9 bolts in single shear, the imposed load at each connection would be;

$$F_B = 118\ 520N$$

Force at each joint is half of the overall force due to the block;

$$F_{joint} = \frac{1}{2} F_B = 59\ 260N$$

These bolts are loaded in tension, and hence we are analysing the ultimate tensile stress required S_{ut}, where A represents bolt core area, Ac, and bolt stress area, As, respectively.

This is such that;

$$S_{ut} = \frac{F_{joint}}{n_n A} \ MPa$$

Using the bolt core area:

$$S_{ut} = \frac{59260}{2 \times 32.8} MPa$$

$$S_{ut} = 903.35 \ MPa$$

$$1040 > 903.35 \ MPa$$

Using the bolt stress area:

$$S_{ut} = \frac{59260}{2 \times 36.6} \ MPa$$

$$S_{ut} = 809.56 \ MPa$$

$$1040 > \ 809.56 \ MPa$$

Therefore, the bolt design is sufficient in tension using both bolt core and bolt stress area.

Calculating the bolt load at the base connections between the side beams and the wheel connections (bolts 3 & 6 from Figure 18)

The imposed load will be the force that is pulled by the students, loading the bolts in tension, hence;

$$F_P = 7940N$$

Considering the factor of safety:

$$F_P = 9925N$$

Using two off M8 Grade 4.8, with a minimum tensile strength of 420MPa;

Analysing ultimate tensile stress required, as completed in the previous calculations through the formula for S_{ut}, using bolt core area, Ac, and the bolt stress area, As, respectively.

Using the bolt core area:

$$S_{ut} = \frac{9925}{2 \times 32.8} MPa$$

$$S_{ut} = 151.30MPa$$

$$420 > 151.30\ MPa$$

Using the bolt stress area:

$$S_{ut} = \frac{9925}{2 \times 36.6}\ MPa$$

$$S_{ut} = 135.59\ MPa$$

$$420 > 135.59\ MPa$$

Therefore, the bolt design is sufficient in tension using both bolt core and bolt stress area.

Materials

Completed By:

- Ingrid Bonney

Beams:

As seen through the previous calculations, it was determined that Rectangular Hollow Section beams would be used throughout the structure due to the minimisation of their calculated stress and their relative lightweightedness compared to an I-Beam. More specifically, the beam selected was an AusTube Mills Rectangular Hollow Section (400x200x10), which, in accordance with Australian Tube Mills [5] would compose of a Structural Steel Grade C450L0 (AS1163) [10].

Bolts:

There are two types of bolts that are used in this design. The first is a M8 Grade 10.9 bolt that is used to secure the shear force connections at sections 1 and 2, the bolts located at positions 1, 2, 4 and 5 in the figures FBD Joint 1 and FBD Joint 2. Since there is a limited width size of the beam that must accommodate two bolts, the principal bolt area can be no wider than 50mm, hence resulting in the need for a higher bolt property class. These bolts will be made with low-carbon martensite.

The bolts at positions 3 and 6 in Figure 18 - FBD Joint 2 do not require a high grade as they will be required to hold a smaller load. As a result, M8 Grade 4.8 bolts will be used and will be composed of low-carbon steel.

Wheel and Axle system:

The force applied to each of the individual bars of the system is reduced by the moment and the mechanical advantage of the previous pulley system, therefore a lower grade steel will be required in comparison to the structural steel used for the beams. As a result, mild steel was used.

Hook and Pulleys:

The hook and pulleys will need to be produced using heat treated steel, to allow it to have a high tensile characteristic. This will make it suitable for heavy lifting applications. [10]

Wires:

Under a direct load, the material of the wires will need to be made of stainless steel, with a diameter of 36mm, to provide a safe working load of 15.8 tonnes [10], which is larger than the 13.125 tonnes of the weight of the block that is required to be lifted, including the factor of safety.

The fasterns to be utilized in the system includes that which is used to connect the block to the crane hook and the corresponding harness.

Material Finish:

The material finish will be Hot Dipped Galvanised, which will extend across all materials, including hooks, pulleys, beams and bolts.[9]

Engineering Drawings

Section Completed By:

- Harry Hawthorne
- Vishant Prasad
- Abby Shen

Engineering drawings are necessary to visualise the final design of the assembled structure and main components. The assembly drawing of the mobile gantry crane and turn-table system is shown in Figure 19. Figure 20 to 24 show sub-assembly drawings of the design.

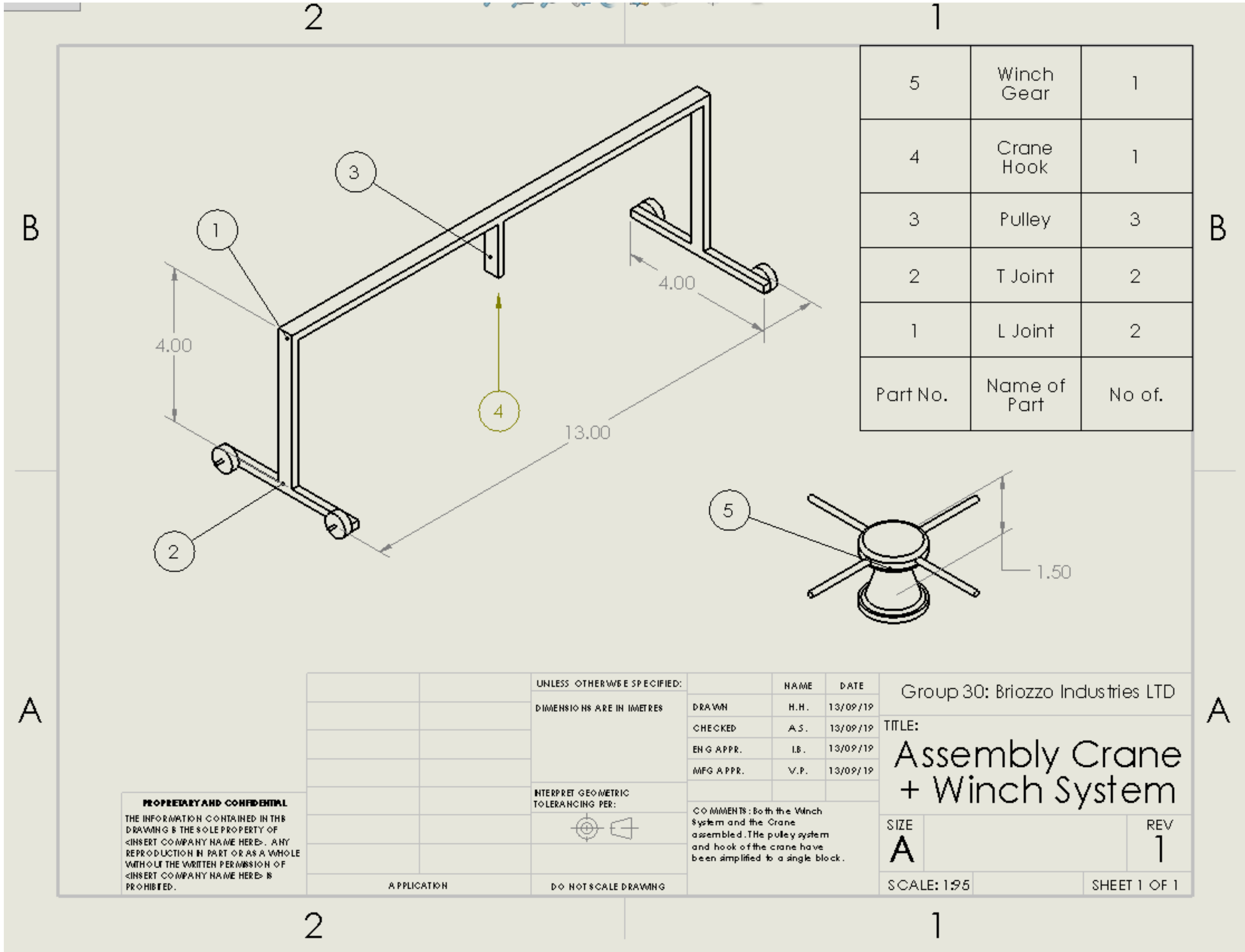

Figure 19 - Final Assembly of System

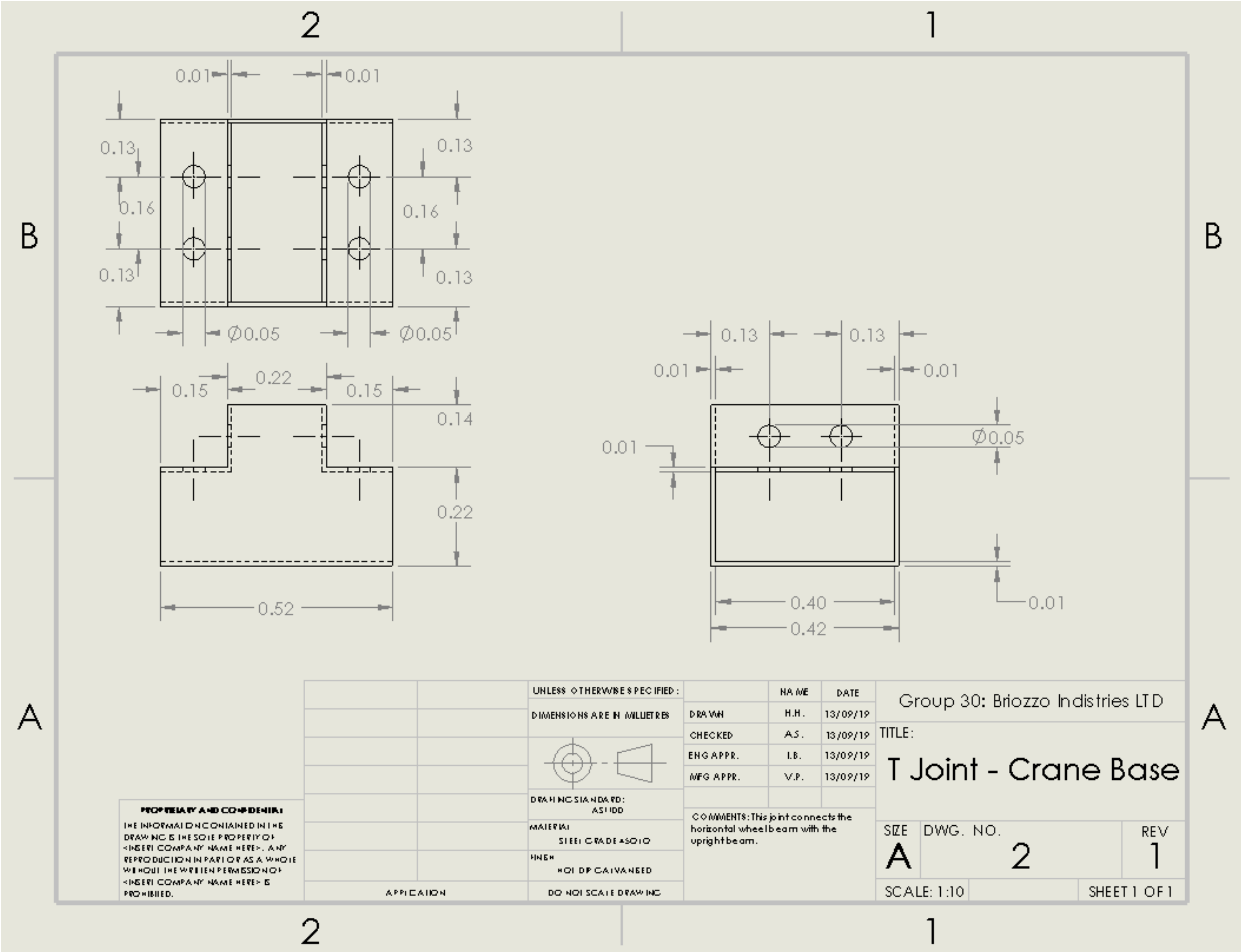

Figure 20 – T-Joint Crane Base Drawing

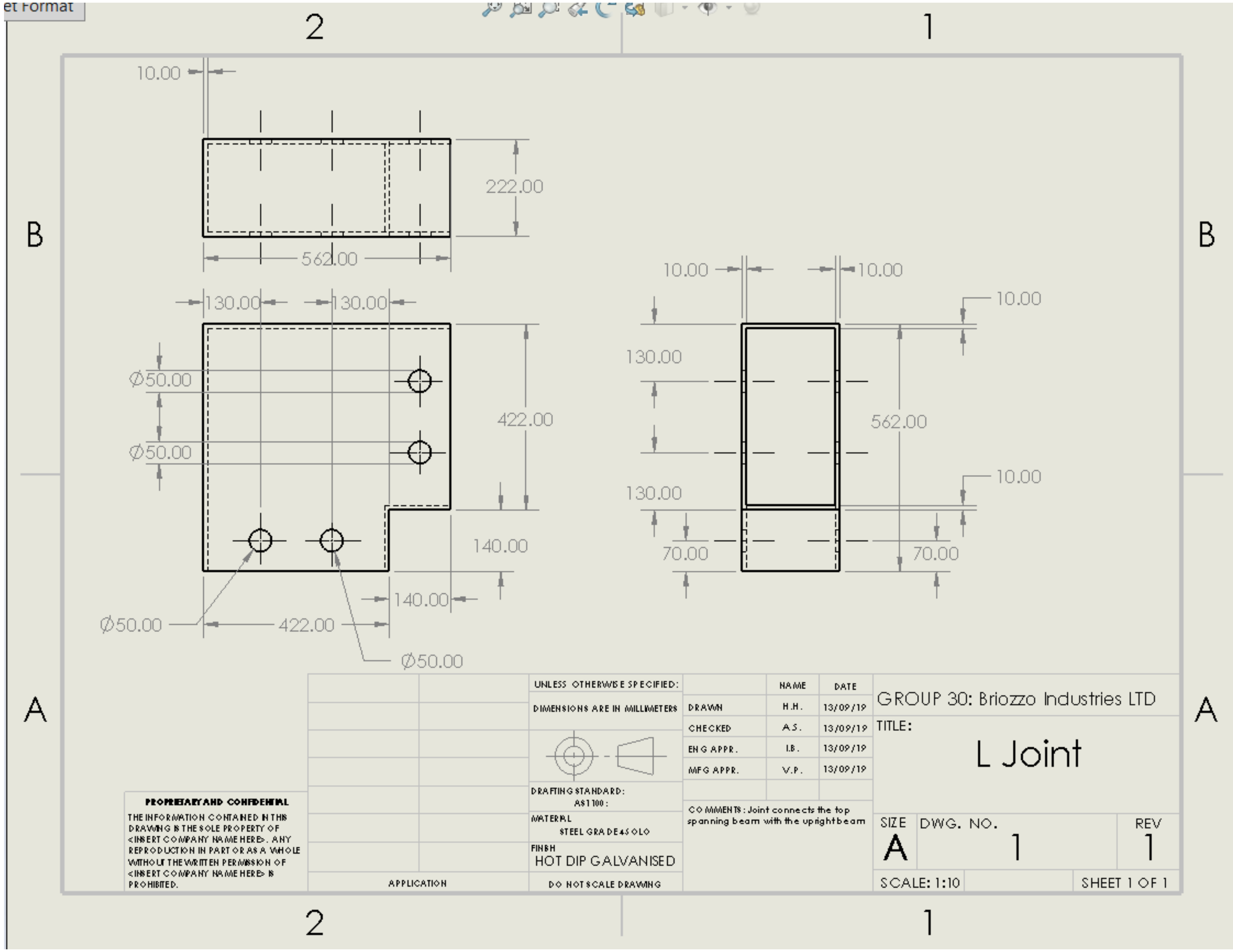

Figure 21 – L-Joint Drawing

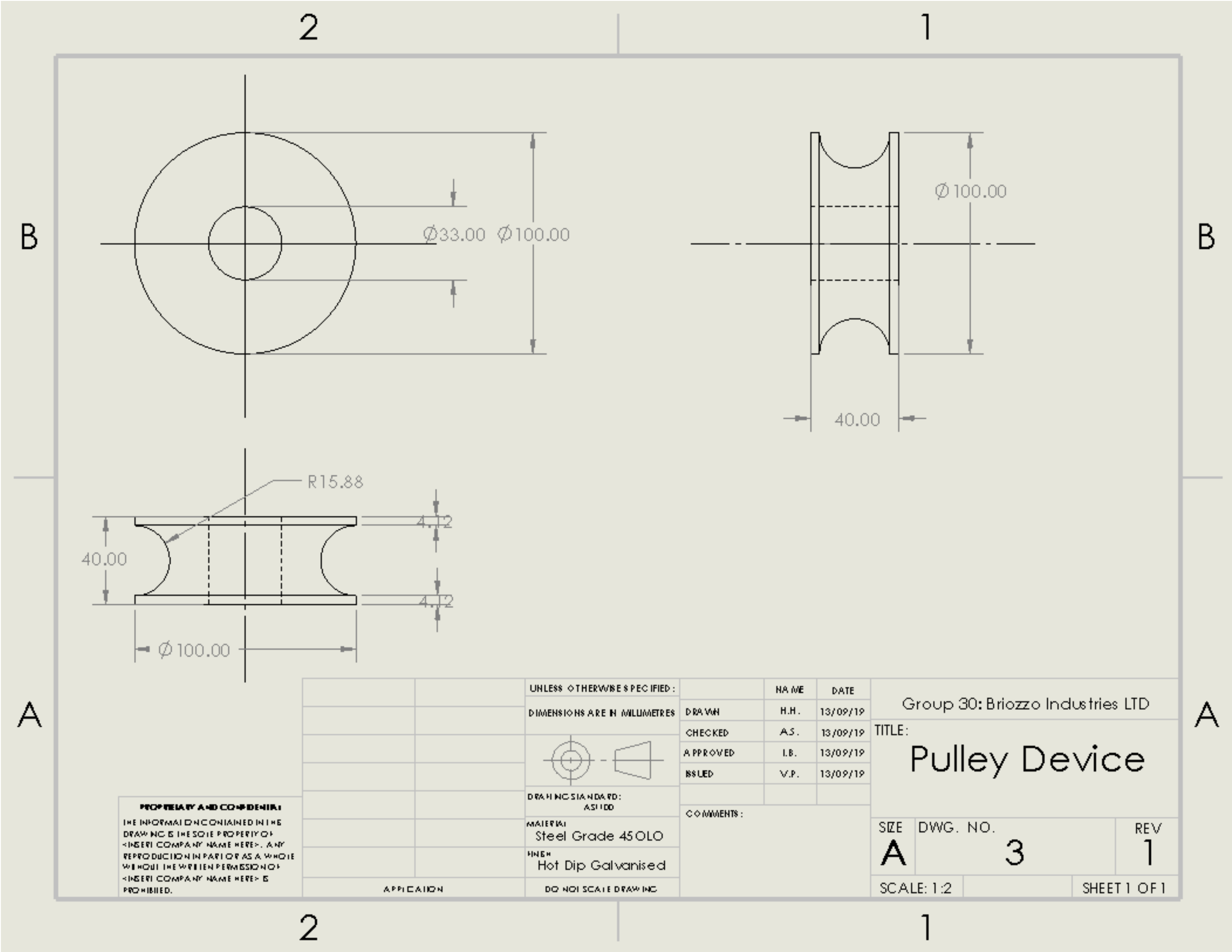

Figure 22 – Pulley Device Drawing

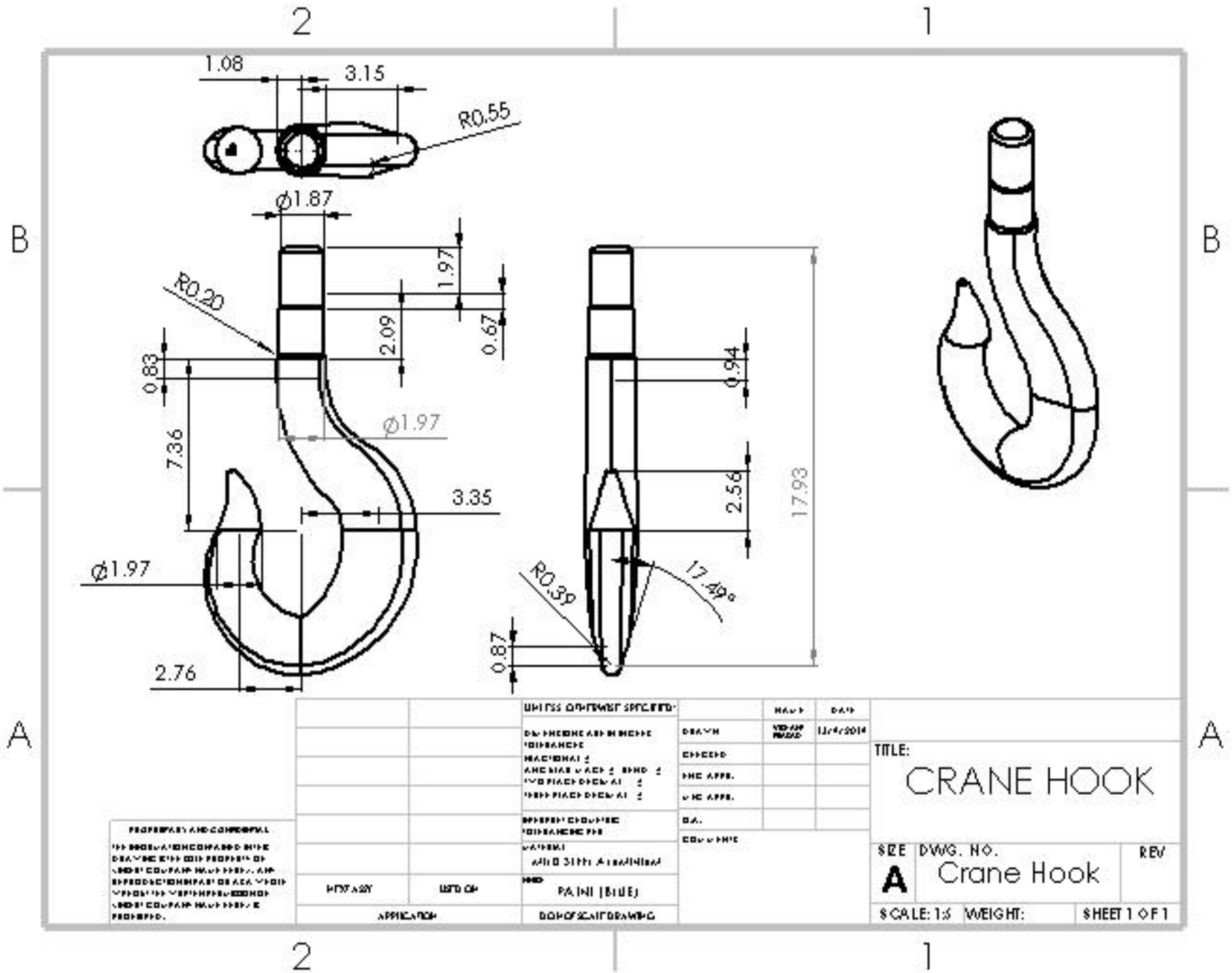

Figure 23 – Crane Hook Drawing

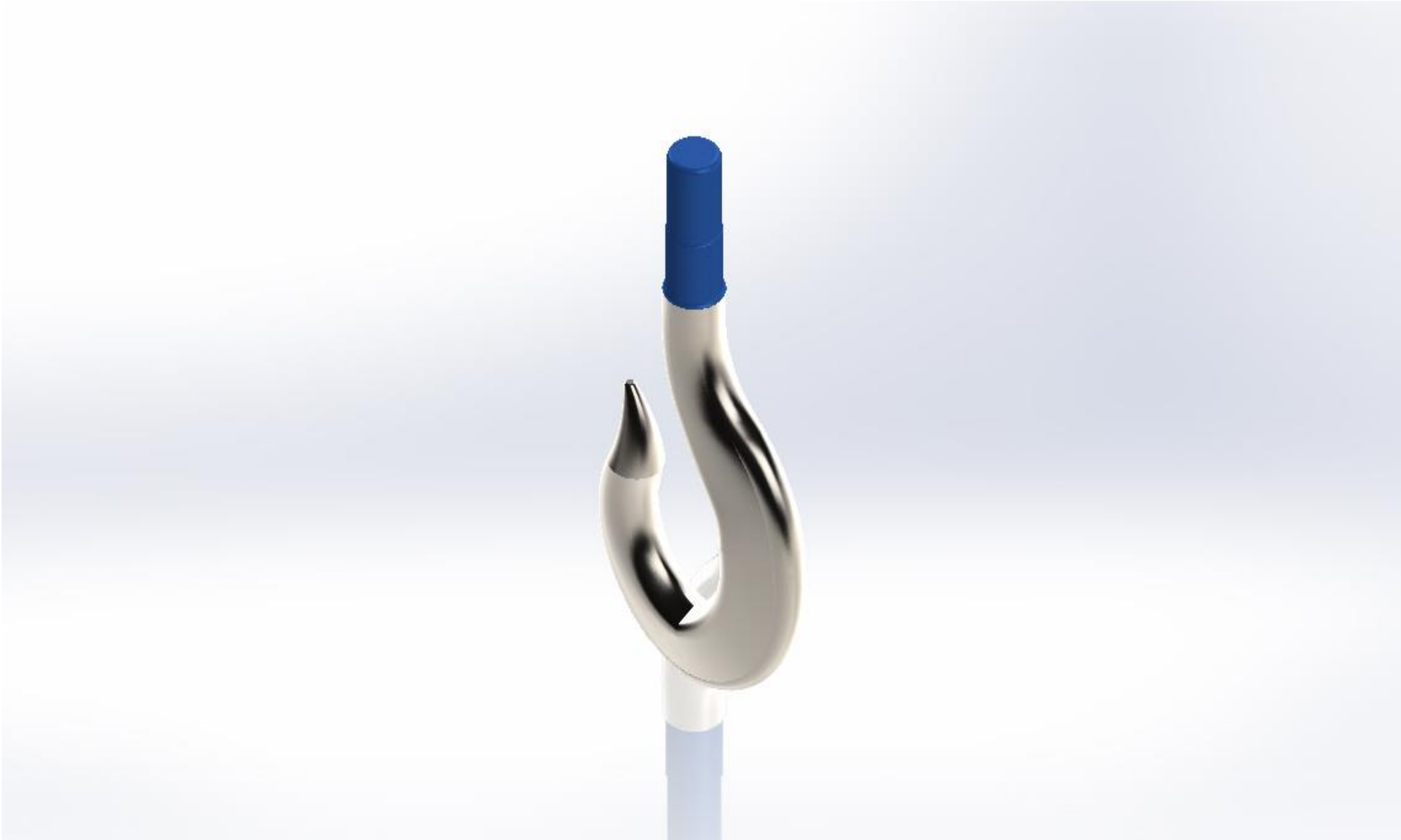

Figure 24 – Isometric View of Crane Hook

Appendices

Appendix 1

Completed By:

- Abby Shen

Meeting Minutes

Meeting 1

Date: 30/08/2019

Time: 10-11am

Attendees:

- Abby Shen
- Harry Hawthorne
- Ingrid Bonney
- Rebecca Johnson
- Nguyen Tien Duc

Absences:

- Vishant Prasad

Ideas:

- Turn - table system with twist rather than pulling movement. Placed onto Lazy Susan inspired object.
- Pulley system for the movement of the crane or vertical lift of the blocks.
- Battering ram for the horizontal movement of the blocks.
- Crane with three dimensional movement rather than vertical suspension only.
- Scissor crane for extension over the artwork and surrounding prohibited areas.

Final Solution:

- Crane with pulley system (displayed in trade-off table).

Secondary Design:

- Scissor crane with following accessories or components:
    - Lifting slings.
    - Rigging slings.

- Crane slings.
- Cargo slings.
- Chain slings.
- Wire rope slings.

Tasks & Roles:

1. **Conceptualisation & Design Creativity and Basic Stress Analysis using Calculations (10%)**

Assigned to:

a. Ingrid Bonney (Conceptualisation)
b. Rebecca Johnson (Calculations)
c. Vishant Prasad (Calculations)

2. **Engineering Drawings (10%)**

Assigned to:

a. Abby Shen
b. Harry Hawthorne
c. Nguyen Tien Duc

Final Notes:

- $weight\ =\ 2323kg/m^3 \times 1.5^3 = 7840.125kg$
    - Note: $dimensions\ = hbl = 1.5 \times 1.5 \times 1.5 = 1.5^3$

Meeting 2

Date: 03/09/2019

Time: 4-5pm

Attendees:

- Abby Shen
- Harry Hawthorne
- Ingrid Bonney
- Rebecca Johnson
- Nguyen Tien Duc
- Vishant Prasad

Ideas:

- Require both vertical and horizontal movement.

- Pushing the block onto a platform (connected to the crane) to move it vertically, then pushing the other block along the concrete platform.
- Crane movement is not required to move horizontally, only vertically.
    - Not feasible to have a system that has two components that is capable of moving horizontally.
    - Safety of people operating must be considered.

Changes to Design:

- Scratching of the block results in the elimination of the method that involves the block dragging across the concrete material.
- Crane moves up and down not horizontally.
- Two turnstiles (lazy susan with sections protruding for the students to grip increasing distance from the pivot point and hence, reducing the work required: $W = F \times d$.
- Suspension of the block and horizontal movement is accomplished by the wheels and tracks.

Secondary Design:

- Similar idea as above however, there is movement of the crane (no tracks and wheels).

Final Design:

- Gantry Crane
- One Way Gears
- Lazy Susans
- Two Beams (more stable with lifting) with a beam at the top with the crane hooking mechanism.
- Axial for cable to pull and operate the wheels on the tracks.

Meeting 3

Date: 06/09/2019

Time: 10-11am

Attendees:

- Abby Shen
- Harry Hawthorne
- Ingrid Bonney
- Rebecca Johnson
- Vishant Prasad

Absences:

- Nguyen Tien Duc

Design Considerations:

- Surrounding area of the artwork is on a slope.
- Minimum speed is $0.1m/s$.
- Factor of Safety no larger than 1.25 on all members.
- 10,500kg (as many students) - one student can pull x (calculate the force that is in the cable).

Consolidation of Design:

- Using a pulley system for the cable to move through for the lifting component of the crane.
- Turnstile used for the lifting action (capstan) with 2-3 students on the capstan for the mechanical advantage. Turnstile has locking mechanism that stops it from falling.
- Two pulleys in front of each other.
- Remove the two turnstiles for horizontal movement and use the students to pull the gantry crane.
- Increase the width of the crane for students pulling and allowing for it to cover the grass and artwork section (noted that the artwork is also on an angle).

Initial Sketches:

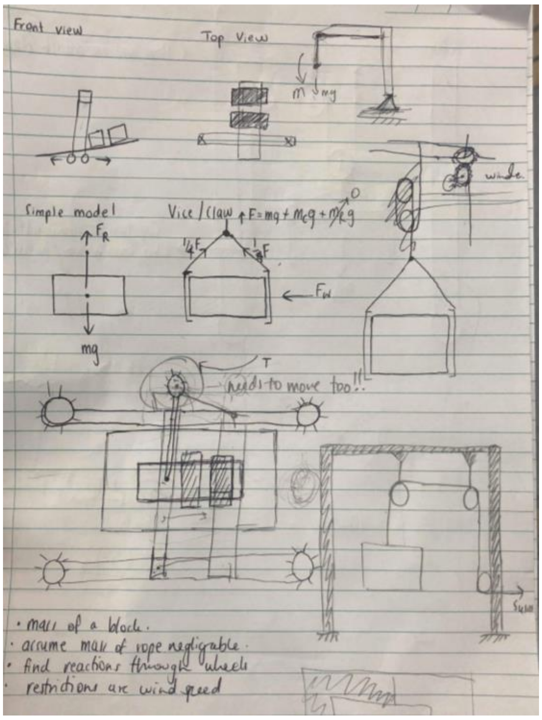

Figure 1: initial plan

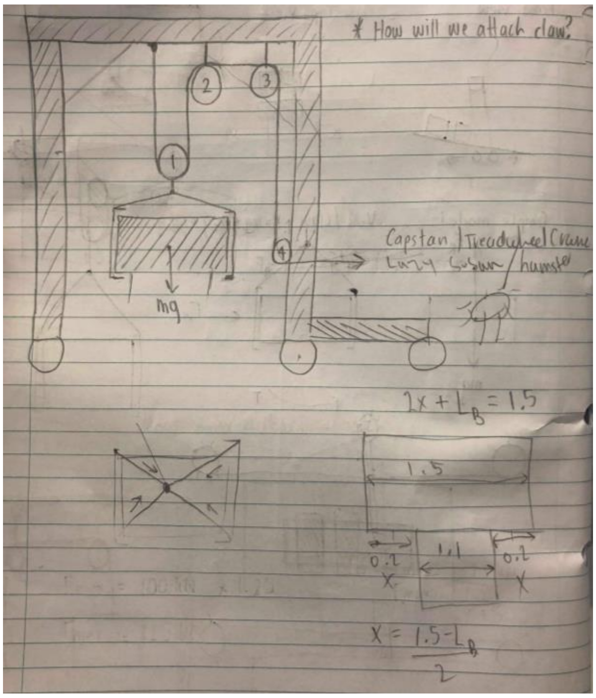

Figure 2: initial pulley plan

Meeting 4

Date: 10/09/2019

Time: 4-5pm

Attendees:

- Abby Shen
- Harry Hawthorne
- Ingrid Bonney
- Rebecca Johnson
- Nguyen Tien Duc
- Vishant Prasad

Design Considerations:

- Consider improvement on strength to reduce defection of horizontal beam.
    - Add diagonal reinforcement.
    - Addition of trusses in the hollow beam.
- Discussion of the beams form: hollow or solid.
- Breaking up of the five parts for drawing.
- Creating a single assembly of the system.
    - Figured out how to break the part into sub-parts/creating a new part.

Remaining Components:

- Create the cables.
    - Use thin cylinders within the solidworks modelling.
    - Check for pre made parts online/in libraries.
- Use pre made/ template components such as bolts and connections, etc.
- Create gears, pulley and crane.
    - Render all final parts and assembly.
- Complete final sizing.

Consolidation:

- Using the lazy susan for a part that will be broken down (as part of the five drawings required).

Major Changes at this Stage:

- Using one lazy susan turnstile.
- No longer using tracks.
- Students will pull the crane from an axle using rope and windings.
- The lazy susan has the rope and windings attached to the top face of the turnstile.
    - Attached to the centre rod.

References

[1]"Density of Sandstone", *Aqua-calc.com*, 2019. [Online]. Available: https://www.aqua-calc.com/page/density-table/substance/sandstone-coma-and-blank-solid. [Accessed: 13- Sep- 2019].

[2] G. Knapik and W. Marras, "Spine loading at different lumbar levels during pushing and pulling", *Ergonomics*, vol. 52, no. 1, pp. 60-70, 2009. Available: https://www.tandfonline.com/doi/full/10.1080/00140130802480828. [Accessed 9 September 2019].

[3] "Average Height to Weight Chart - Babies to Teenagers", *Disabled World*, 2019. [Online]. Available: https://www.disabled-world.com/calculators-charts/height-weight-teens.php. [Accessed: 09- Sep- 2019].

[4] *Steel Structures,* AS 4100:1998, 2016.

[5] OneSteel Manufacturing, "Hot Rolled and Structural Steel Products", OneSteel, 2014.

[6] OneSteel Metalcentre, "Know Your Steel: Steel Mass Reference and Product Catalogue", OneSteel, 2014.

[7] Australian Tube Mills, "Design Capacity Tables for Structural Steel Hollow Sections", AUSTRALIAN TUBE MILLS, Sunnybank, Queensland, 2013.

[8] *Cold-formed Structural Steel Hollow Sections,* AS/NZS 1163:2016, 2016

[9] *Hot-dip galvanized (zinc) coatings on ferrous hollow sections, applied by a continuous or a specialized process,* AS/NZS 4792:2006, 2006

[10] HES, "Wire Rope and Fittings", Hoisting Equipment Specialists, Loganholme, 2016.

[11] Briozzo, P. (2019). *MECH2400 9400 Assignment B Component Design - Spine 2*. 2nd ed. [ebook] Sydney: Paul, B, pp.1-4. Available at: https://canvas.sydney.edu.au/courses/18252/assignments [Accessed 13 Sep. 2019].