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Profile Project

Conceptual Design of Monopile Clamps for Use in Decommissioning of Offshore Windmills

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I confirm that the work is self-prepared and that references/source references to all sources used in the work are provided, cf. Regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 12-1.

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Abstract

As the energy industry is shifting focus towards greener alternatives, offshore wind farms have become an alternative to the oil and gas industry. These wind farms consist of multiple wind turbines. The majority of the wind turbines currently installed offshore are monopile wind turbines. Monopile wind turbines consist of the blades, the generator and one single support structure, installed in modules. The monopile support is installed in 30 meters water depth and further 20 meters into the seabed.

The generators within the wind turbines have a life expectancy of 20-25 years. Seeing that offshore wind turbine farms are rather new technology there is no industry standards in regard to efficient decommissioning equipment. There have been multiple suggestions in regard to solving this problem. Many of these suggestions involve modifying equipment and solutions already in use in the oil and gas industry in the decommissioning of oil wells. Examples of such tools are wireline tools using a water jet to cut the monopile from the inside of the structure and ROVs with specialized cutting tools. These methods do not remove all of the monopile and parts are left below the seabed and large amounts of material is lost.

Another possible solution to the decommissioning problem is modifying the monopile clamps currently used in installing the wind turbines. The monopiles are fixed only by the friction force between the monopile and the seabed. Research is therefore currently being conducted on the possibility of using the same installation claps to remove the monopiles.

In this paper the objective will be to conceptual design for decommissioning clamps. The design will be based on the master thesis “Presenting an Ecco-Sustainable Approach to Decommission Offshore Wind Parks by Designing a new Ship, New Tools and Efficient and Reliable Procedure” by Hamed Askari and Ahmad Halimah from the Decom Tools project. The conceptual design will include 3D model of the proposed solution and a general estimate of the power unit design. Gathering info on the availability of these claps will be of later use in concluding whether or not the solution is viable.

Introduction

In this paper there will be an introduction to the current installation process of monopile wind turbines. The concept design for a decommissioning clamp will be based on the tools currently used in monopile installation operations. Concept design will include a design for the clamp and force calculations will be completed to determine a sufficient hydraulic system.

Monopile Offshore Wind Turbines

All wind turbines consist of some base components, windmill blades, generator, and the support structure. Some of the offshore structures consist of a floating element, but by far the most common structure to date is the monopile support structure. These monopile wind turbines are placed close to the shore in relatively shallow water. The support structure consists of three main units. The bottom levels is called the driven monopile, the mid-level is the transition layer, and the last component is called the top level or the turbine hall.

The Driven monopile consists of a foundation pile placed approximately 20 meters into the seabed. The base is, in the simplest description, a pipe with a diameter between 7.5 and 10 meters. The main force keeping the monopile stationary is the friction force between the monopile base and the seabed, there are no additional anchors or supports.

Typical sea depth is approximately 30 meters. The structure from the seabed to the water surface is the transition level. There is placed a platform around the structure just above sea level. The platform is used to offload technicians and equipment for maintenance operations. The transition area is usually painted bright yellow or orange to avoid collisions with seafaring vessels.

The monopile tapers slightly from the base and up to the generator and blades.

Offshore Installation Process

During the installation of monopile offshore wind turbines there are multiple ways to complete the installation process. There are three main tools found in most installation operations in addition to the construction vessel. These being Monopile Upending Tool, Installation clamp and Driving Hammer.

Monopile Upending Tool

The main components will be produced onshore in separate units and transported to the chosen location onboard a construction vessel. The vessel will have equipment specialized for the operation for the installation.

The components are transported horizontally and must be oriented into the vertical position for the first step in the installation process. This operation can be completed by using a hydraulic monopile upending tool connected to the onboard crane. The tool is placed within the monopile, and prongs are expanded to fit the inside of the monopile module.

The upending tool is equipped with hydraulic accumulators. By using these accumulators, the equipment does not need to be connected to an external power source while in use, making the equipment easier to use in an offshore environment.

There are multiple different versions of upending tools. Another solution will grip the monopile from the outside with three gripper arms. (Huisman, 2022)

Installation Clamps

Monopile gripper arms are currently widely used in the installation of monopile wind generators. All installation clamps consist of these base components: gripper arms, hydraulic power system and rollers.

There is in addition a major difference between the two main types of gripper arms currently on the market. The complete module may include an automatic motion compensating system. This system will in addition to the ships Dynamic Positioning System keep the monopile stationary during the installation process. Other versions of the installation clamps do not include the additional stabilization system and fully depend on the Dynamic Positioning System of the construction vessel to keep the monopile steady.

Figure 1: Houlder Limited Monopile Gripper Arms. (Houlder Limited, 2022, p.1)

One of these producers is the British based marine design company Houlder ltd. The company produces a product called the Monopile Gripper Arms, MGA for short, for the installation of monopile windmills. The Gripper Arms provide a vertical tolerance of $\pm 0.25°$ and a tolerance for radially positioning from consented location of $\pm 1.5\ m$. (Houlder Limited, 2022, p.3)

Houlder produces different variations of the MGA. The first gripper arms that were produced by the company is the HOULDER MGA-01 in 2013. These gripper arms were installed on the turbine installation vessel “The MIP Discovery” and were able to handle a maximum monopile diameter of 6.5 m. The next system produced is the HOULDER MGA-02. The MGA-02 differs from the original design by the incorporation of a modular grillage. This grillage will not be connected to the transom. This means that the total unit will be able to be mobilized and demobilized from vessel to vessel. (Houlder Limited, 2022, p.3)

The last system is the 7.5M JAW. This is a system that may be added to the previous systems. The 7.5M JAW is a gripper arm configuration enabling the arms to handle piles with a maximum diameter of 7.5 meters. (Houlder Limited, 2022, p.3-7)

The Houlder brochure for the Monopile Gripper Arms states that the total unit consists of the following components.

Component	**Quantity**
Jaw assembly	2
Inner arm assembly	2
Outer arm assembly	2
Hinge assembly	2
Outer cylinder	2
Inner cylinder	2
Lifting cylinder	2
Lifting link assembly	2
Lifting frame assembly	2
Deck frame assembly	2
Grillage	
Hydraulic power unit	1

Table 1:Components for Holulder Limited MGA, (Houlder Limited, 2022, p.4)

The total unit is powered by a twin 110 kw Hydraulic power unit that is electrically driven. The hydraulic system is supplied by an oil tank containing 2000 l of hydraulic oil. The Hydraulic power unit may be positioned differently in relation to the rest of the unit depending on the job and vessel specifications. (Houlder Limited, 2022, p.4)

The performance specification of the 7.7M Jaw is listed below

Specification	**Unit**
Maximum water depth	40 m
Total Pile weight	650 t
Maximum length of pile	65 m
Maximum pile diameter	7.5 m
Maximum Current	3 knots
Maximum side load	150 t
Significant wave height	2 m

Table 2: Houlder Limited MGA preformance spesifications, (Houlder Limited, 2022, p.2-3)

Another producer of similar monopile gripper arms is the Scottish based company MacGregor. The company has in cooperation with the Norwegian company Kongsberg Maritime produced a Motion-compensated pile gripper. The Motion-Compensated pile gripper will be more accurate in keeping the monopile stationary during the installation process. When the active Motion-Compensation system is being used in addition to the ships' Dynamic Position System the installation time will be reduced.

The MacGregor/Kongsberg solution is installed on the side of the vessel as opposed to the Houlder solution which is installed at the aft of the vessel. (MacGregor, 2022)

As the Clamps are usually made to the customers' specifications, they come in many different varieties depending on customer needs. One of these differences involves the clamping arms themselves. Some of the gripper arms, clamp around the monopiles completely while some have an open grip solution.

Driving Hammer

The last major tool in use in the installation of the monopile is a hydraulic driving hammer. These hammers are placed upon the monopile by the onboard crane, while the monopile is kept in place by installation clamps, the hammer uses a hydraulic system to slowly drive the monopile step by step into the seabed. These hammers drive monopiles of varying diameter. (Huisman Equipment B.V. 2022)

Decommissioning clamp concept design

Proposed initial solutions

The following is some of the base design concept proposed by the DecomTools team.

The clamps are installed at the back of the vessel. These clamps are positioned vertically after each other with appropriate gapping. They are placed quite far within the vessel as the crane must be positioned directly above the monopile. While the clamps hold the monopile firmly the ships ballast tanks are emptied and raise the monopile up in five-meter increments. The pile will then be connected to the onboard crane and an onboard cutting tool cuts the monopile section. The piece is removed and placed elsewhere onboard the vessel. The jaws will release, and the vessel will take in ballast water and lower again. The process is repeated until the monopile is completely removed from the seabed.

For this proposed design concept there is a need for a specialized vessel.

Decommissioning vessel

These base design concepts for a decommissioning vessel are provided by DecomTools. This are discussed and designed in the master thesis "*Decom Tools Vessel Design: Presenting an Eco-Sustainable Approach to Decommission Offshore Wind Parks by Designing a New Ship, New Tools and Efficient and Reliable Procedure*" written by Askari, H. & Halimah, A in 2021.

This thesis will supply some additional base design concepts of the decommissioning clamp concept design. Preferably the completed clamp design will be installed within the proposed vessel design without major changes.

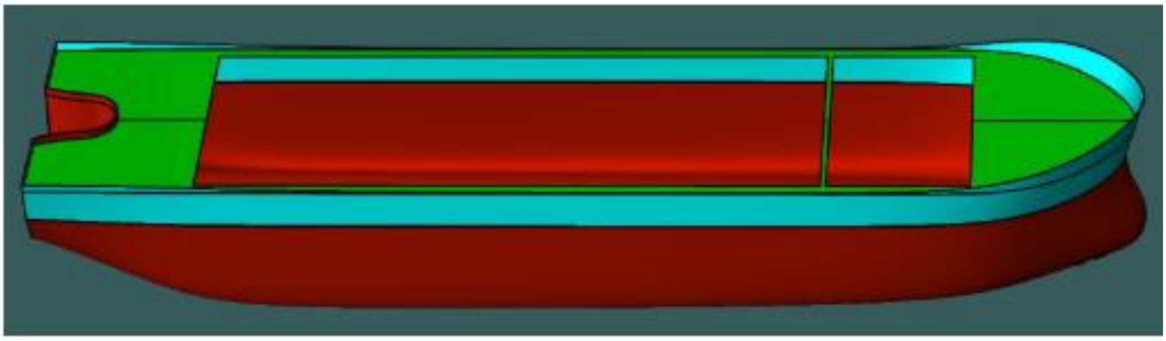

Figure 2:Decommissioning vessel hull design, (Askari & Halimah, 2021, p.121 figure.5-2)

Above is a concept drawing of the decommissioning vessels hull design. The design includes a rather standard hull shape, except that the aft of the ship includes a circular cutout for the clamp module.

The base hull dimensions for the proposed Decom Tools Vessel Design are stated below:

Module	**Value**
Vessel width	48 m
Length over-all	194 m
Max crane hook height	53 m above keel/ 24.4 m above deck
Crane with	47 m
Inner diameter of hydraulic gripper opening	10 m
Outer with of hydraulic gripper opening	28 m

Table 3: Base hull dimensions DecomTools vessel design, (Askari & Halimah, 2021, p.124, figure. 5-8)

It is stated in the thesis that the structure for monopile wind turbines can have a diameter of 10 m. The monopile installation clamps currently in use and production can assist in the installation of monopiles up to 7.5 m. The proposed design for the DecomTools Vessel has an inner diameter for the placeholder clamps of 10 m. The vessel design itself is not clear when it comes to how big the space meant to hold the future decommissioning clamps is. Calculations and design decisions must be completed to determine if this proposed vessel design is viable.

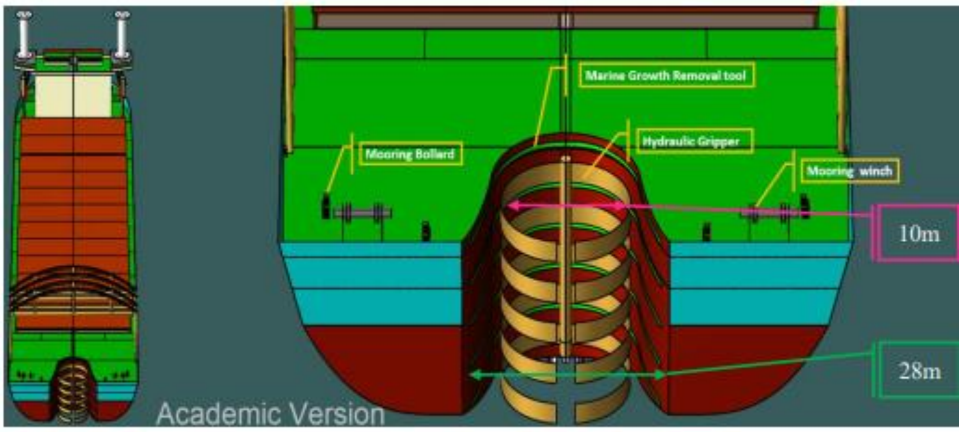

Figure 3:Proposed design vessel aft. (Askari & Halimah, 2021, p.207, figure.5-87)

Within the design of the proposed “Decom Tools Vessel” the outer opening of the aft of the ship is 28 m wide, as the inner diameter of the vessel is not listed it is uncertain if the clamps will be able to open sufficiently to be able to grab around the monopile. There is no clear statement as to how deep the clamp opening will be or maximum possible height of the decommissioning clamp. The height is therefore assumed to be 23 m. These measurements are assumptions based on other vessel dimensions and the conceptual drawings. It is probable that the proposed vessel design will be in need of modifications to house the final clamp design.

It is stated that an “automatic marine growth removal system” will be fitted within the decommissioning clamp opening. There is no further information stated regarding the dimensions or specifications of this removal system. As there are no dimensions or further information, this system will not be considered during the clamp design process.

Design Challenges

While using the installation clamps in the decommissioning process might prove to be a satisfactory solution there are some challenges that are presented. It will be expected that some modifications will have to be made to these clamps to make them suitable for use in the decommissioning process.

The first of the possible major problems when it comes to using installation clamps in the decommissioning of monopile windmills is that while the clamps have a strong hydraulics system it is focused on simply closing the clamps and not necessary clamping around the monopile. As the clamps are not intended to produce a large continues clamping force the hydraulics system will have to be redesigned.

The clamps are equipped with rollers placed on the inside of the clamps. These rollers are useful in the installation process. As the hammer drives the monopile into the seabed the installation clamps keep the monopile in the right position while the monopile slides freely through the clamp. These rollers will be a hindrance in the decommissioning process.

The rollers are on some installation claps positioned on arms where they can be moved to be in contact of monopiles of different circumference. To be able to accommodate monopiles of varying circumference a similar adjustable solution should be implemented for the decommissioning clamp.

Another possible challenge regarding the decommissioning process will be the force of friction one single clamp is able to produce. There is unfortunately no information regarding how much closing power one of the installation claps can produce. Calculations must be completed to determine how many clamp modules are necessary to perform the monopile decommissioning operation.

Initial Discussion and Decision for Conceptual Design of Decommissioning Clamps

There is a proposed solution from the DecomTools Project where the monopile decommissioning clamp module consists of multiple stacked clamps. The clamps will be attached to the decommissioning vessel and move in unison under the lifting operation. Further design will be based on three clamps stacked vertically in the finale module.

Due to the limited space for movement a solution where there are joints in the clamp can prove preferable. The initial concept does prove difficult in regard to the hydraulics, as there is limited space to fit the hydraulics system.

The clamps should be able to adjust to monopiles with varying dimeter. Installation clamps currently on the market can handle monopiles with a diameter of 7.5 m. Monopiles can vary in diameter, the most common being between 6 and 10 m. The decommissioning clamps should preferably be able to enclose monopiles between 7.5 to 10 m.

The installation clamps have contact points with rolling elements to avoid friction and insuring free vertical movement during installation. During decommissioning the goal is to achieve sufficient friction between the clamps and the monopile so that most movement is upwards due to the buoyancy of the vessel. The contact points will be fitted with hard, wickered slip pads. The pads will dig into the monopile and ensure a good grip during the operation.

For easy access there should be sufficient space for installation of rail and walking path over the decommissioning clamps.

The clamps will be designed around the following requirements

Unit	**Value**
Minimum Clamp diameter capability	7.5 m
Maximum Clamp diameter capability	10 m
With	2 m
Maximum clamp height	< 23 m

Forces and Calculations

Calculations for Friction Force

It is stated that the main force keeping the monopile stationery is the friction force between the pile and the seabed. In a possible solution involving monopile installation clamps the clamps themselves will need to be able to deliver a clamping force that is able to maintain a friction force great enough to assist in pulling the monopile out from the seabed.

In this paper the force calculated in the bachelor "*Technology to Extract Monopiles from Seabed*" by Hohl, L.K. will be the basis on further calculations preformed. The conceptual design for the decommissioning clamp is based on the ability to be able to assist in decommissioning of monopiles with varying diameter and weight. Force calculations are therefore general and can deviate from a real-life case.

Hohl states that there are three main forces acting on the monopile during a removal process. The force of gravity (F_g), the lifting force (F_q) and the friction force between the clamp and the monopile (F_N). The friction coefficient is assumed to be 0.5. The calculations are based on a monopile with a diameter of 10 meters. (Hohl, 2020, p.25)

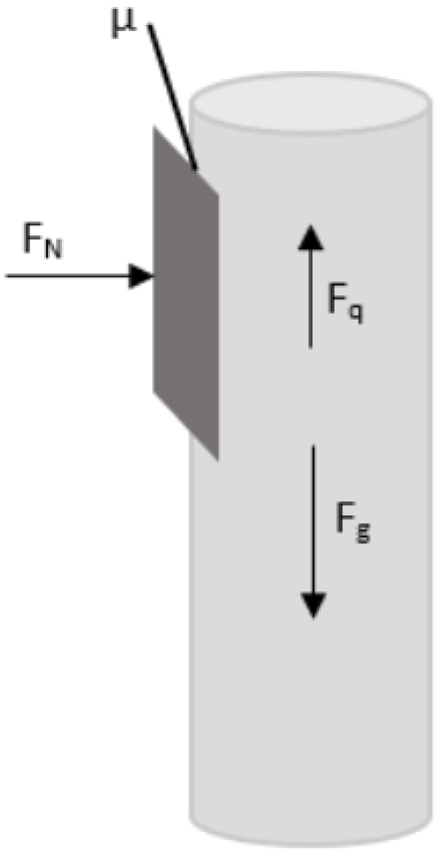

Figure 4:Scetch of forces on monopile. (Hohl, 2020, p.25 figure.4.16)

The force of interest is F_N, the friction force between the monopile and clamp pads. The Force F_g, is stated to be the force of gravity resulting from the weight of the monopile and the gravity constant.

$$F_N = \frac{F_g}{\mu}$$

$$F_N = \frac{1\ 500\ 000\ kg * 9.81\ m/s^2}{0.5}$$

$$F_N = 29\ 430\ 000\ N = 29\ 439\ kN$$

This States that the friction force produced by the decommissioning clamps hydraulic system must be greater than the force listed above.

Calculations for Pad Hydraulics System

In addition to the base design of the decommissioning clamp there will be a need for calculations regarding the hydraulics system and the dimensions of said system. The main power unit and oil tank for the system can be placed onboard the vessel. The smaller components of the hydraulic system will have to be placed closer to the clamps within the aft clamp opening. It is therefore important to complete these hydraulic component calculations to verify the possibility of the proposed solution. When designing hydraulic systems, it is important to consider convenience in regard to procuring the parts needed for the system setup. In this case it would be preferable to have a system with a pressure of 400 bar as pistons with this pressure specification is readily available.

It is stated that the minimum force that the clamps must be able to provide is 29,430 kN. A safety factor of 2X will be implemented within the design. There is in the conceptual designed planned eight hydraulic pads per clamp and a total of three clamps stacked. For the Pad mechanism a total of 24 pads are needed.

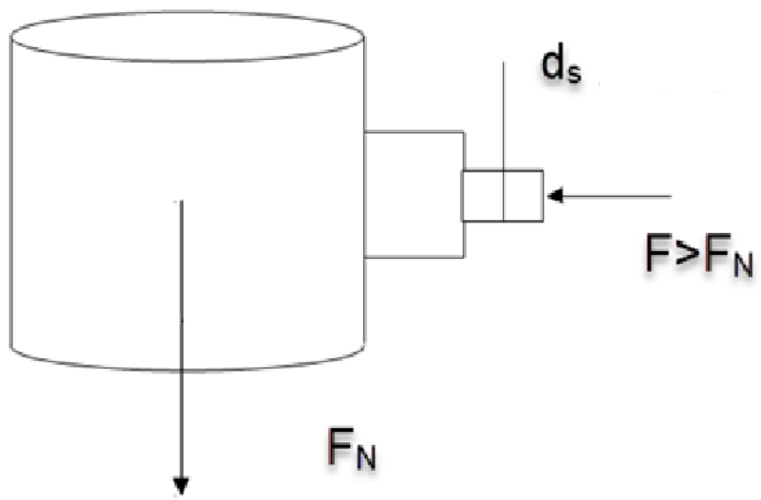

Figure 5:Scetch of force requirements for single hydraulic driven pad.

When calculating the diameter of hydraulic piston cylinder for the pad mechanism the following formula is used:

$$A = \frac{F}{P}$$

$$F = \frac{2 * 29\,430\ kN}{8 * 3} = 2453\ kN$$

$$A = \frac{2453 * 10^3\ N}{300 * 10^3\ Pa} \approx 0.062\ m^2$$

$$d = 2 * \sqrt{\frac{A}{\pi}}$$

$$d = 2 * \sqrt{\frac{0.082\ m^2}{\pi}} = 0.28\ m$$

A piston with a diameter of 0.32 m was chosen for this purpose.

From these specifications a sample cylinder can be found. For the case of the pad mechanism cylinder from the producer Bosch Rexroth is used as an example piston. The chosen mounting for the pistons is foot mountings.

The pads are expected to move a distance of 1.5 m in a span of 10 seconds which gives a speed of 0.15 m/s. Area of the chosen cylinder is Flow rate will then be 0.08m^2.

$$Q = A * v$$

$$0.08\ m^2 * 0.15\ m/s^2 = 0.012\ m^3/s$$

$$Q = 720\ LPM$$

Calculation for Shear Strength of Friction Pads

The contact points between the monopile and the clamp will be retractable pads. The minimum diameter the clamp may handle in the concept design is 7 m. Each of the clamps will have installed pads that extend 1.5 m from within the clamp's modules. With a total of eight clamps in a single clamp module. This leaves a distance of 0.5 m overlap between the pad and the clamp unit. The design is based on the force transferring from the pads to the clamp unit and further to the ship itself. It is therefore necessary to ensure that the pads are able to handle the stain.

The pads are designed with dimensions are 1,5x1x1 m. The proposed material is construction steel S355 as it is readily available and relatively inexpensive. This steel has a shear yield stress of 170 MPa. The material must be able to withstand a minimum of this value. The area will in this case be 0.5 m^2.

From the previous section "calculations for pad hydraulics system" it is calculated that each pad must be able to hold a force of 1472 kN.

$$170 * 10^5 \; Pa \geq \frac{1472 * 10^3 \; N}{0.5 \; m^2}$$

$$170 * 10^5 \; Pa \geq \; 29.44 * 10^5 \; Pa$$

The planned material and dimensions are confirmed to be well within the float limit specifications.

Calculations for Closing Hydraulics System

When it comes to design the closure system for the clamp the solution will involve a hydraulic motor to provide the closing force.

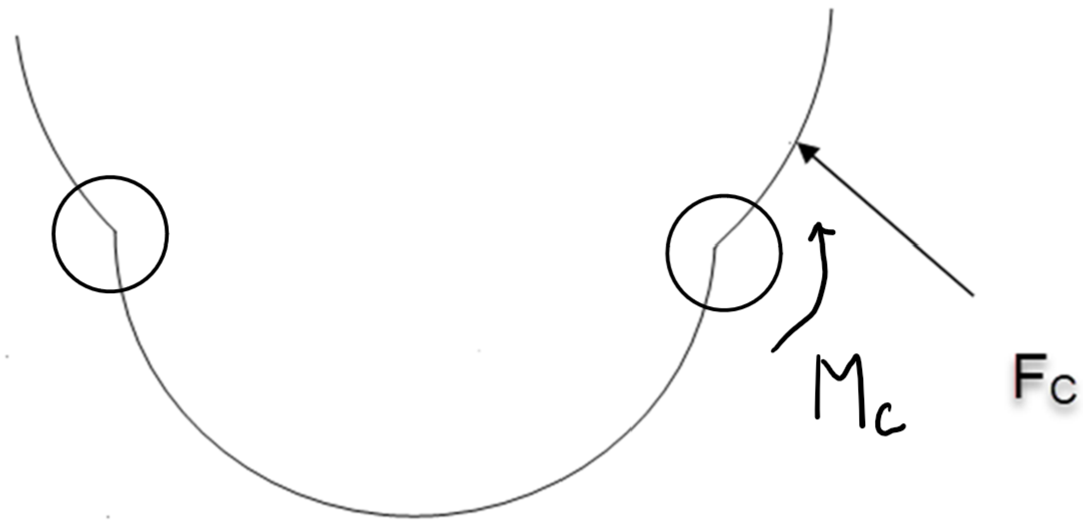

Figure 6:Scetch of momentum for clamp

The approximate weight of one moving clamp unit is 257 tons.

The clamp must be able to close a minimum distance of 5 m each. Acceleration assumed to be $0.001\ m/s^2$. The time is assumed to be a minimum of 30 seconds. As the main power unit for the hydraulics system is expected to deliver a pressure of 400 bar there is a requirement that the motor is able to run with said pressure.

A motor with a volume of 150 cc is chosen for the purpose.

$$M_c = m * v$$

$$M_c = 257 * 10^3\ kg * \ 0.001\ m/s^2 * 3.5\ m \ = 0.9\ kNm$$

$$P = \frac{900\ Nm}{150\ cm^3/rev * \left(\frac{1\ m}{100\ cm}\right)^3 * \frac{1\ rev}{2\pi\ rad}} = 377\ bar$$

Due to the specifications necessary to close the clamps the motor will be rather big and slow.

Calculations for Closing Pin Hydraulics System

To be able to keep the clamp closed there will be a closing pin lowered into an opening in the clamp when it is fully closed. Hydraulic pistons will be used for this process. Assume an upward acceleration of $0.1 m/s^{\wedge}2$. The basic pin design is a cylinder with a diameter of 1 m and a length of 2 m. This gives an approximate weight of 12.3 ton.

$$m_p = 12.3\ ton$$

$$F = ma = 12.3 * 10^3\ kg * (9.81 + 0.1\ m/s^2) = 121.9\ kN$$

$$A = \frac{121.9 * 10^3\ N}{400 * 10^3\ Pa} \approx 0.003\ m^2$$

$$d = 2 * \sqrt{\frac{0.003\ m^2}{\pi}} = 0.061\ m$$

A piston with stroke length of 2 m and a diameter of 0.08 m is chosen for the purpose. The cylinder will move a distance of 2 m in a minimum of 20 seconds. This gives a speed of $0.1\ m/s$. Area of piston is 0.005 m^2. The flow rate of the piston will then be 30 LPM.

To provide increased structural stability of the design two pistons will be used.

Final Design

The final design includes a total of eight different parts, three main units and five smaller parts. In addition, there is 2 different hydraulic cylinder types as well as one hydraulic motor. The largest part of the clamp is non-moving and has an inner diameter of 10 m. This unit will be fastened to the ship. Two moving arms will open as the ship moves closer to the monopile. When the monopile is within the main unit of the clamp the two smaller arms will close around the monopile and lock together and the closing pin inserted.

There is a total of eight pads in each clamp module, four in the largest unit and two in each of the smaller clamp units. The total number of pads over three clamps will be 24 pads. The pads will be able to move out of the clamp units with a total reach of 1.5 meters. The clamp is therefore able to extract monopiles with diameters between 7 and 10 meters. The last parts are the bolts in the connection between the main clamp unit and the two smaller clamp units. There are three bolts in each clamp, two in relation to movement of the clamp and one for the closing mechanisms. Total of 9 bolts over three clamp modules.

The clamp is designed with a distance of two meters across to make room for a walkway for inspections and maintenance.

In addition, there are H-beams added to the final design. These are to support the hydraulic cylinders for the pads. Standard H-beams 350x350 mm, with a length of 1 meter.

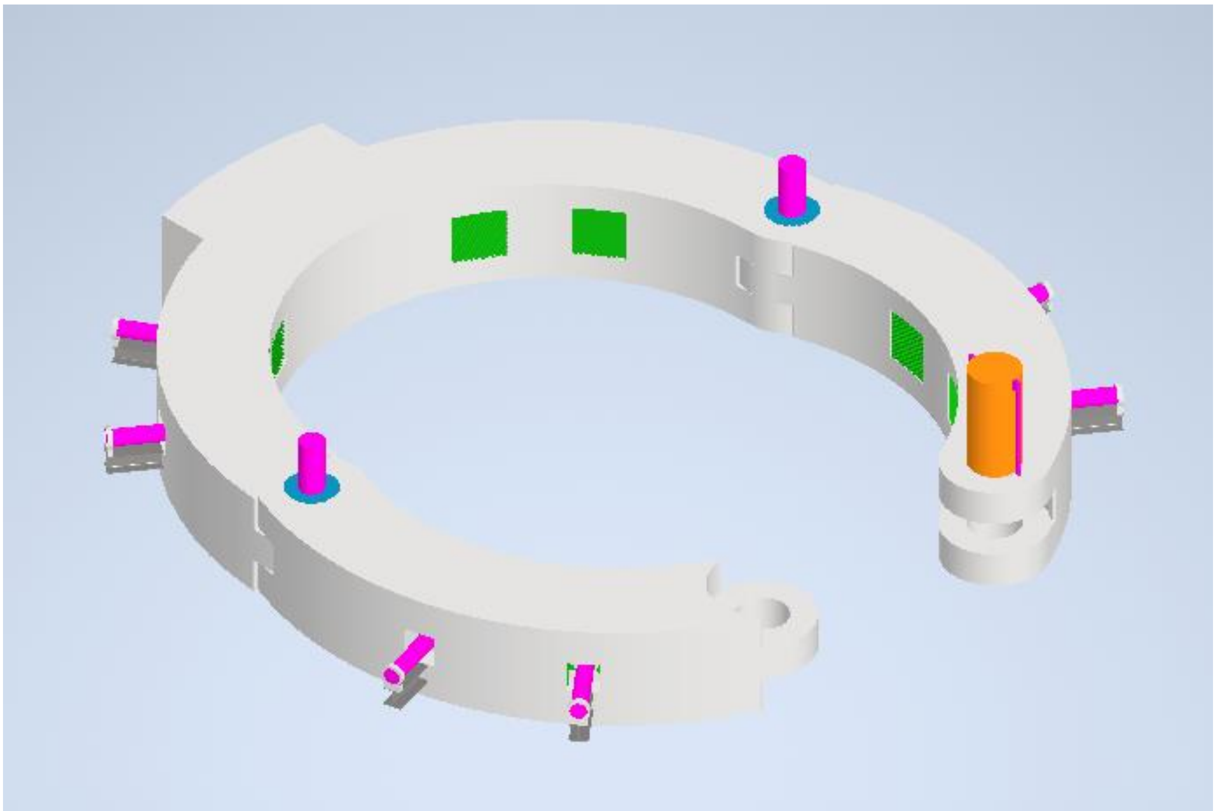

Figure 7: Decommissioning clamp single unit. Pins marked in blue, closing pin in orange, pads in green and hydraulic components in magenta.

Single clamp module part list

Part Number	**Part Name**	**Quantity**
1	Non-Moving Part	1
2	Moving Part 1	1
3	Moving Part 2	1
4	Inner Cylinder Holders	8
5	Outer Cylinder Holders	8
6	Cylinder Beam	8
7	Clamp Pad	8
8	Closing Pin	3

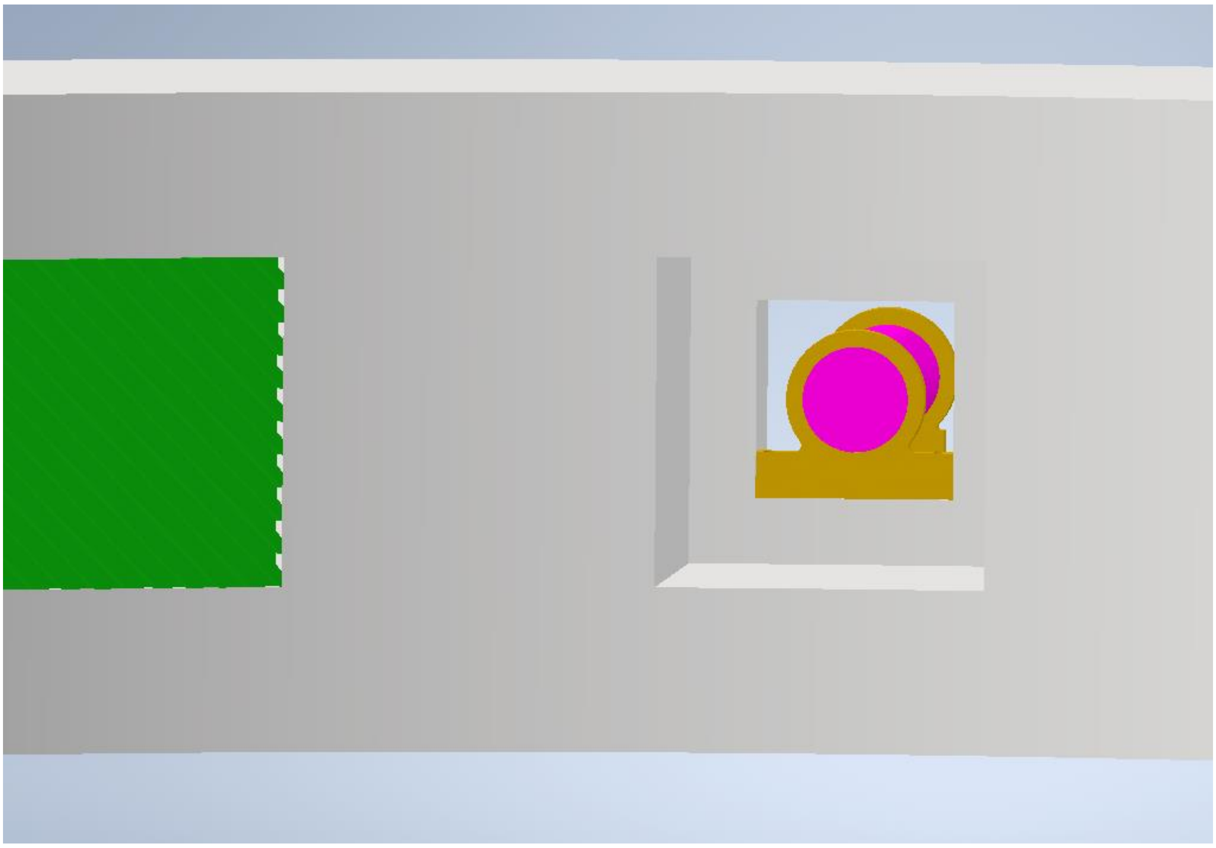

Figure 8: View from the inside of the clamp with the pad removed. Hydraulic pad cylinder in magenta, cylinder holders in yellow and pad in green.

The Hydraulic pad cylinders are held in place with two foot mountings. Due to space limitations, they have slightly different dimensions. The inner mounting is placed within the clamp itself and the outer mounting is placed in a 1 m support beam.

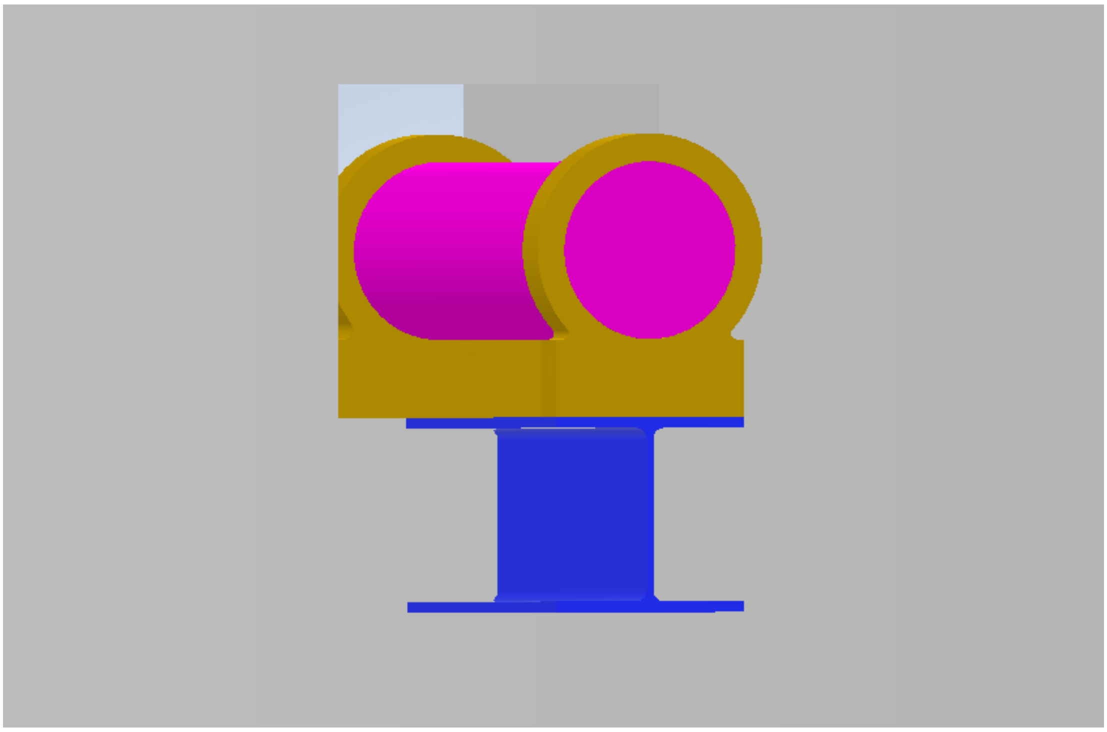

Figure 9: Outer hydraulic cylinder mounting. Hydraulic pad cylinder in magenta, cylinder mountings in yellow and support beam in blue.

The final design includes a total of three main clamp modules. These modules will be installed with a distance of 4 m between each module to a connection unit. The main connection unit will be fixed to the opening in the back of the ship. This way it will be possible to remove all three clamps in one operation or one at a time dependent on maintenance needs.

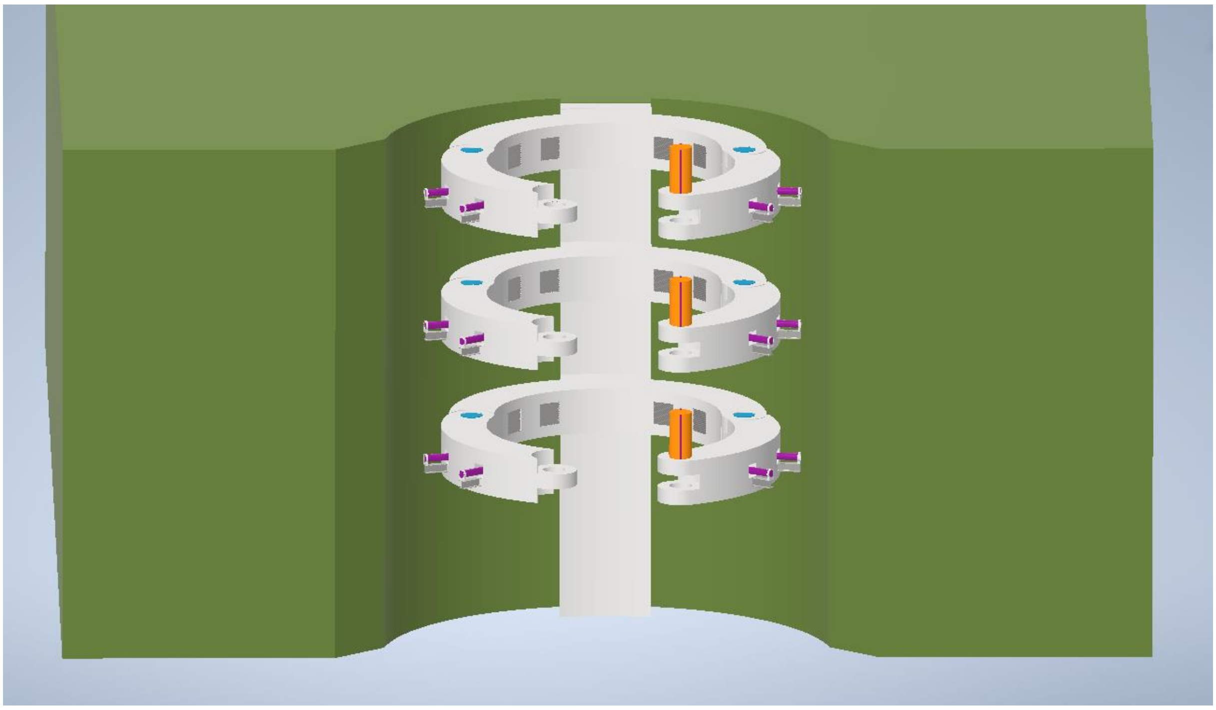

Figure 10: Full decommissioning unit. Green represents the ship. Closing pins are marked in orange, hydraulic cylinders in pink and connecting pins in blue.

It will be necessary to modify the proposed decommissioning vessel to be able to house the clamp module. The final clamp design has a diameter of 14 m with additional space between the clamp units and the ship hull of 2 m.

When using the Autodesk Inventor tool for finding the weight of the units we get the following values. Density of carbon steel S355 is 7850 kg/m^3.

Weight of components for one clamp module

Part Name	**Weight in tons**	**Quantity**
Non-Moving Part	590.6	1
Moving Part 1	256.9	1
Moving Part 2	256.8	1
Inner Cylinder Holders	Negligible	8
Outer Cylinder Holders	Negligible	8
Cylinder Beam	0.13	8
Clamp Pad	1.17	8
Closing Pin	12.3	3
Total	1151.6	

The total weight of the three clamps is 3454.8 tons.

The completed design drawings for the main clamp module units are located in Appendix A.

Original 3D and 2D drawings located in attached folder, AppendixB.301.

Hydraulic Equipment Specifications

Summary of piston values over three clamp modules

Cylinder type	**Total number of units**	**Stroke length**	**Cylinder diameter**	**Flow rate**	**Speed**	**Acceleration**	**Pressure**
Pad cylinder	24	1,5 m	0.3 m	720 LPM	0.15 m/s	0.1 m/s^2	400 bar
Closing pin	6	2 m	0.08 m	30 LPM	0.1 m/s	0.1 m/s^2	400 bar

Summary of motor values over three clamp modules

Total Number of units	**Volume**	**Necessary Momentum**	**Acceleration**	**Pressure**
6	150 cc	0.9 kNm	0.001 m/s^2	400 bar

It is established that the power unit needs to deliver a pressure of 400 bar for the system. A total flow rate of 720 LPM. This gives a minimum power of 480 kW.

Future works

As this monopile decommissioning clamp is a conceptual design it is going to be necessary to continue the development if the project is expected to be viable. Some of these challenges and future works are listed below.

- Calculations of assembly method. During this project the units are assumed to be connected by welding unless otherwise specified. Strength calculations of the welds and best placement must be conducted.
- The total weight of the three main clamp modules can be described as excessively heavy. Completion of further research in possible methods of reducing the weight of the decommissioning clamps is necessary.
- Choosing an appropriate bearing solution for the clamp closing mechanism.

Conclusion

To be able to produce a versatile and adaptable solution for the decommissioning clamp there are still challenges that need to be resolved. As it stands the vessel design proposed in the master thesis written by Askari, H. & Halimah, A. is in need of modifications to house the designed decommissioning clamp module. The decommissioning clamp concept design proposed in this paper is a good starting point and inspiration for future works. The final design includes all initial requirements.

Reference list

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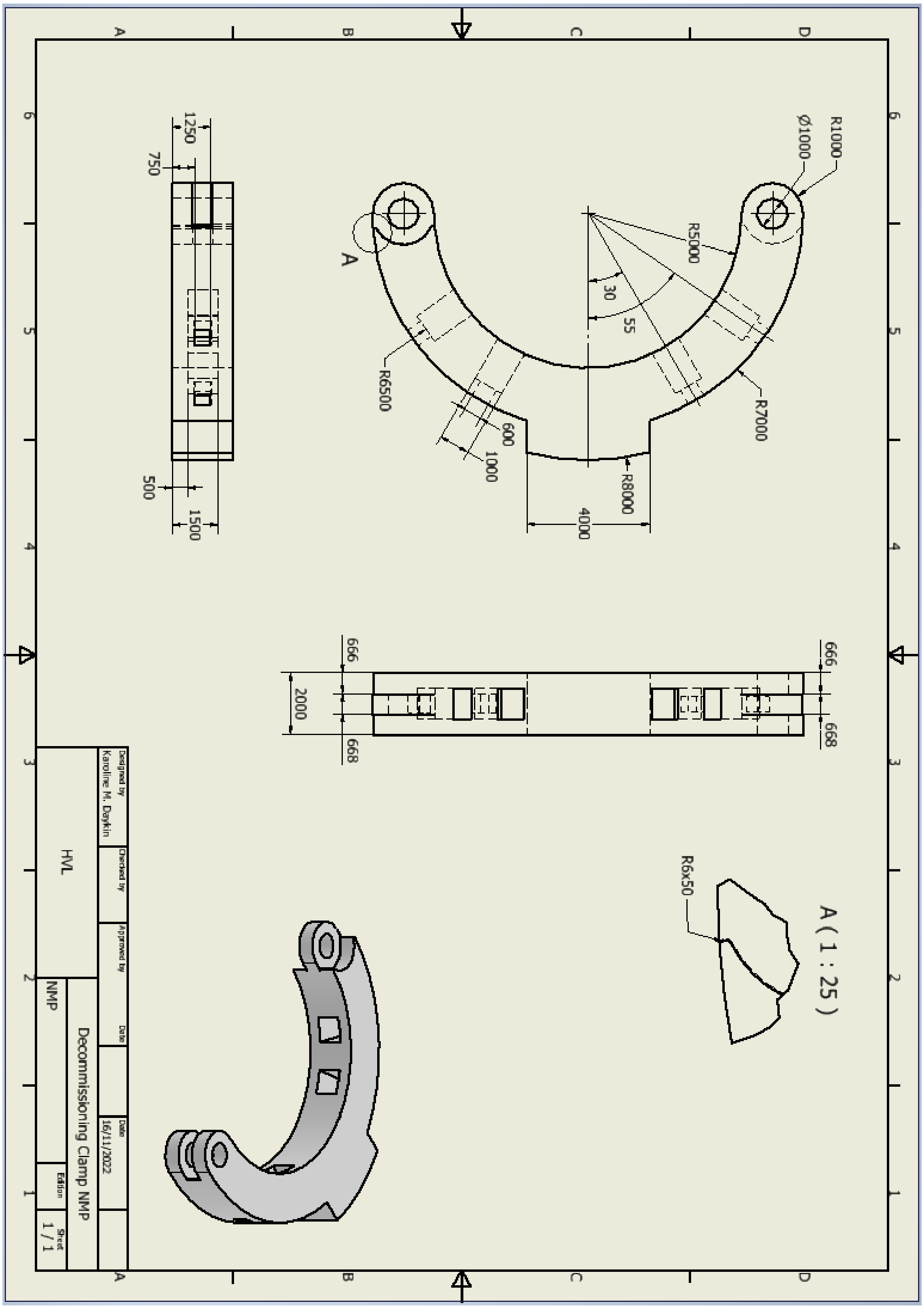
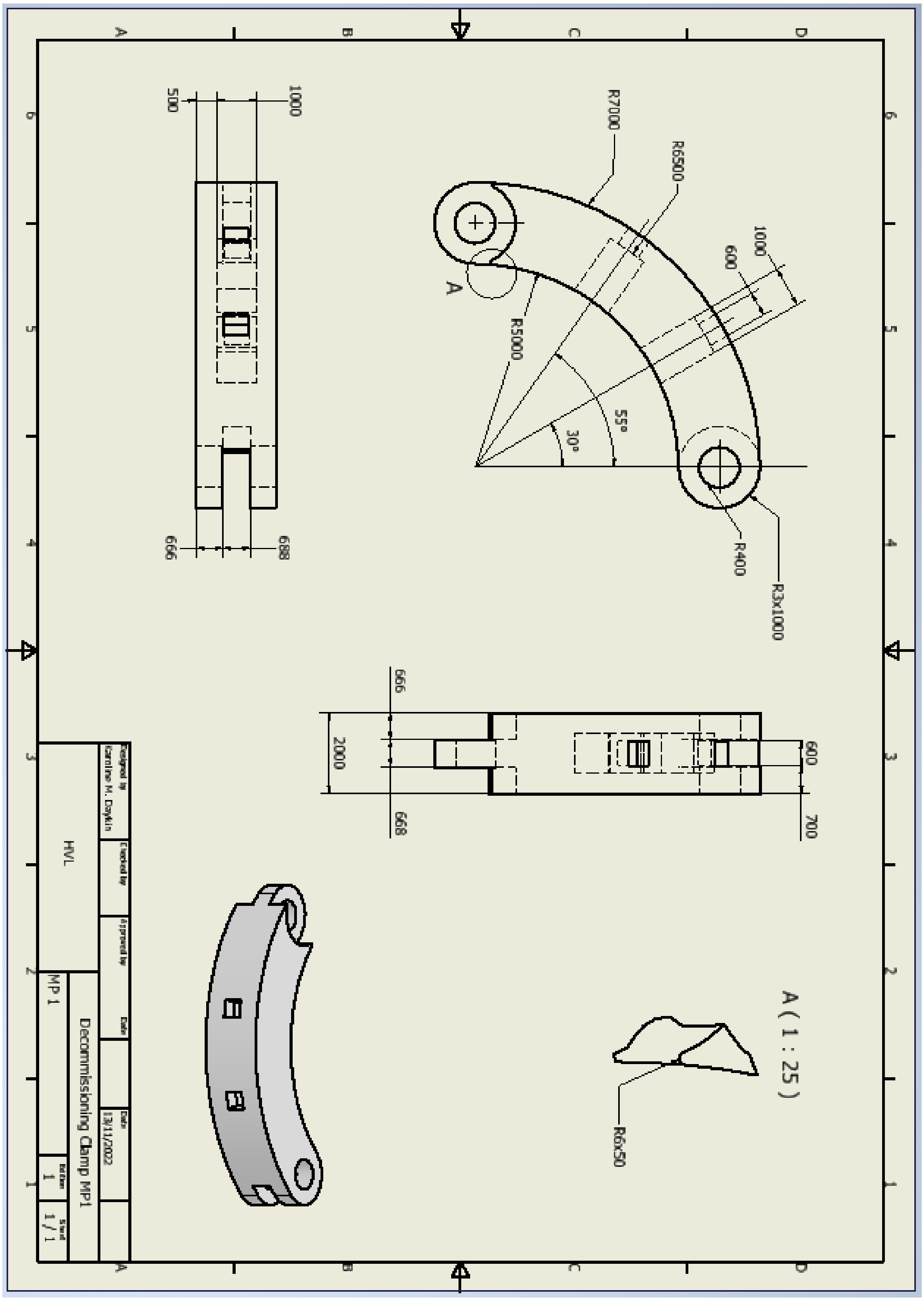
Appendix A

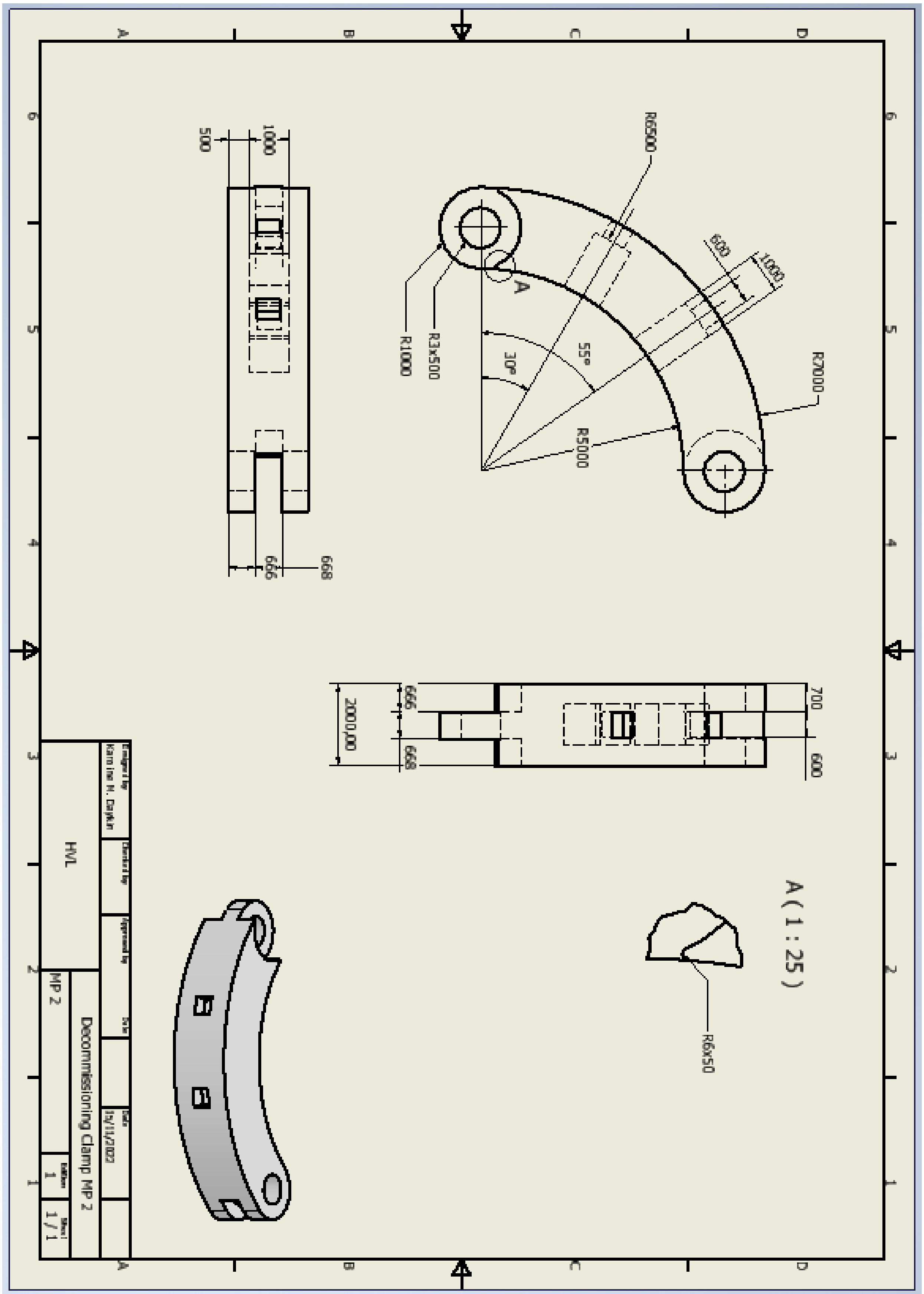
Non-moving clamp module unit dimensions



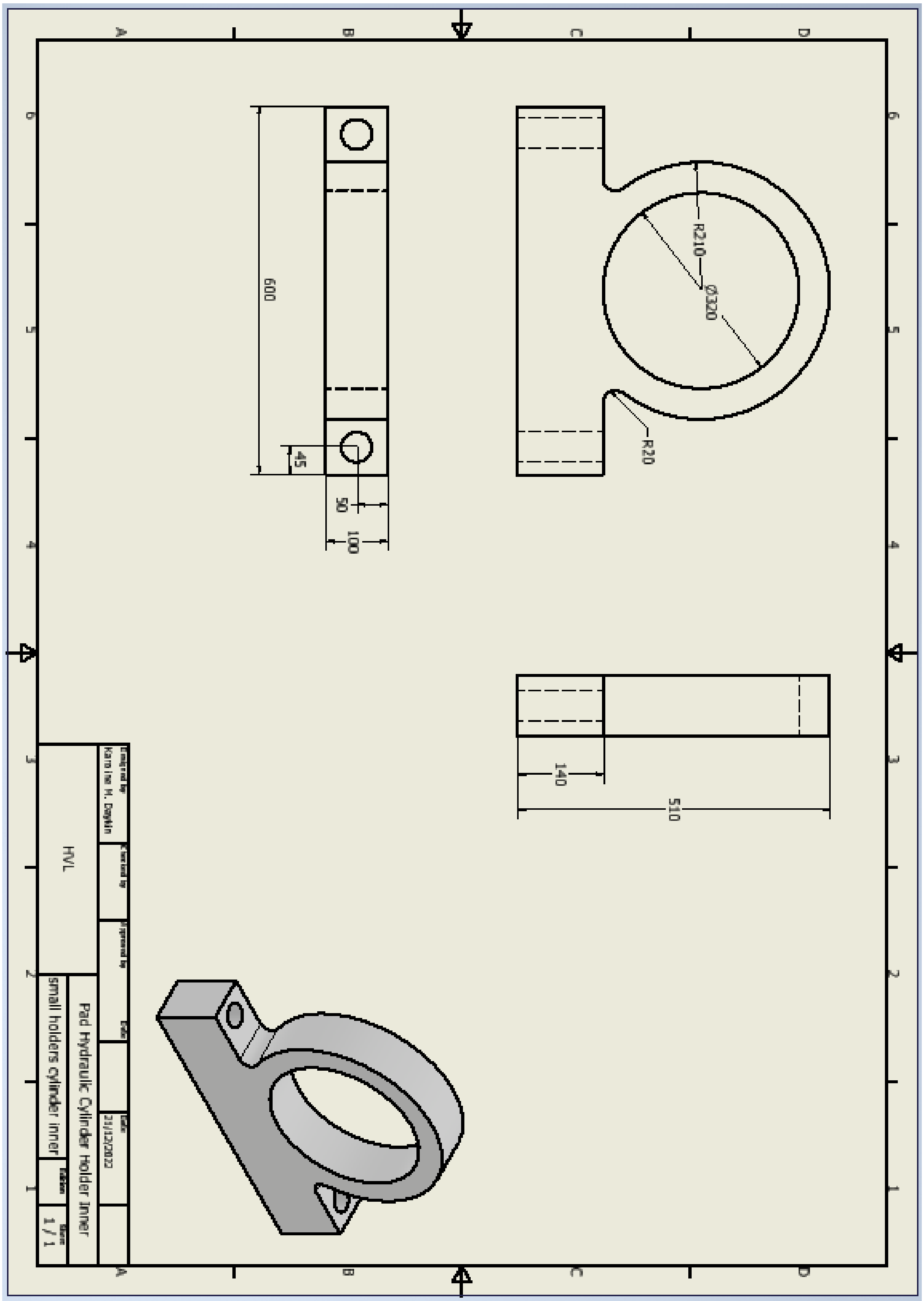
Moving part 1



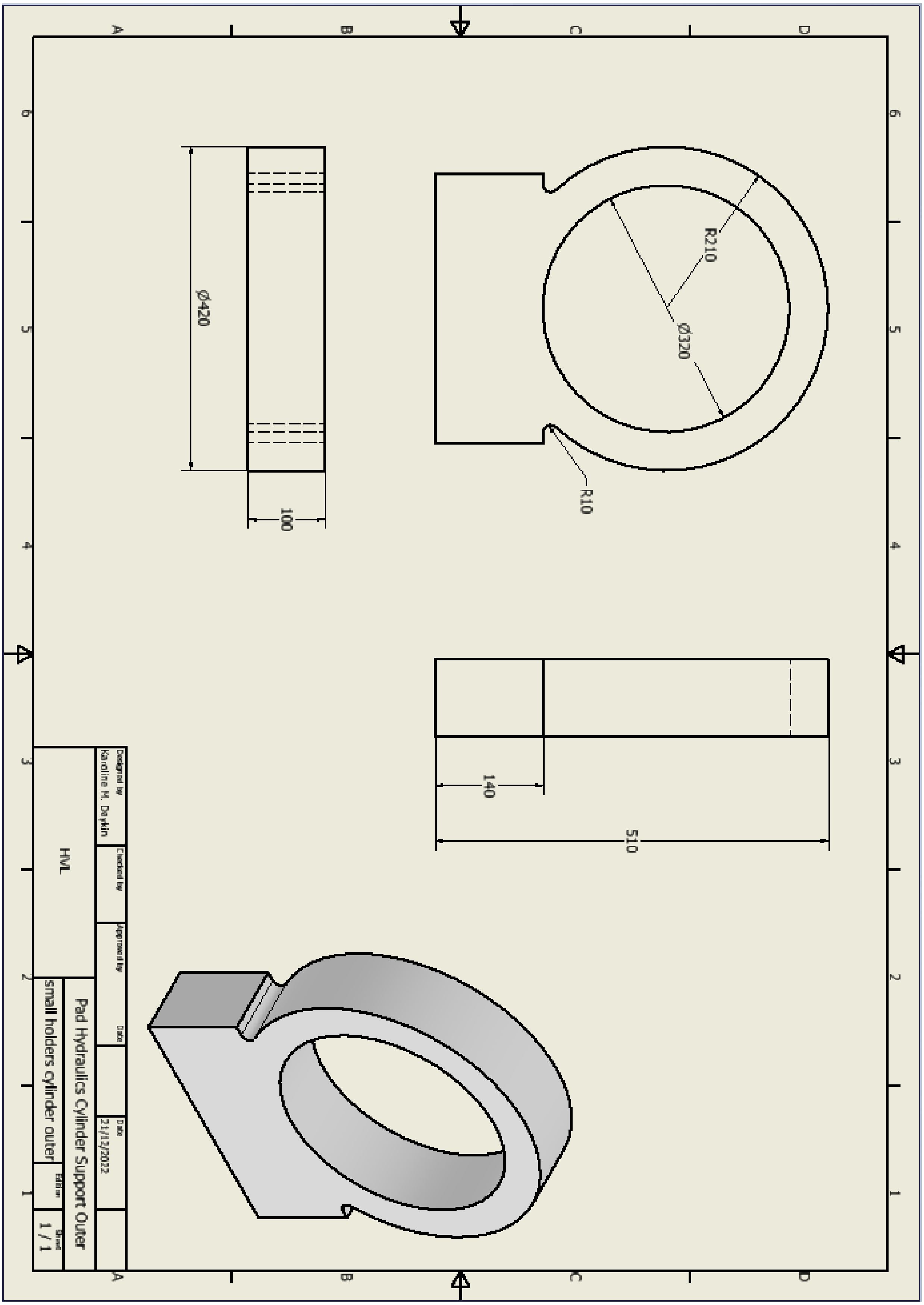
Moving Part 2



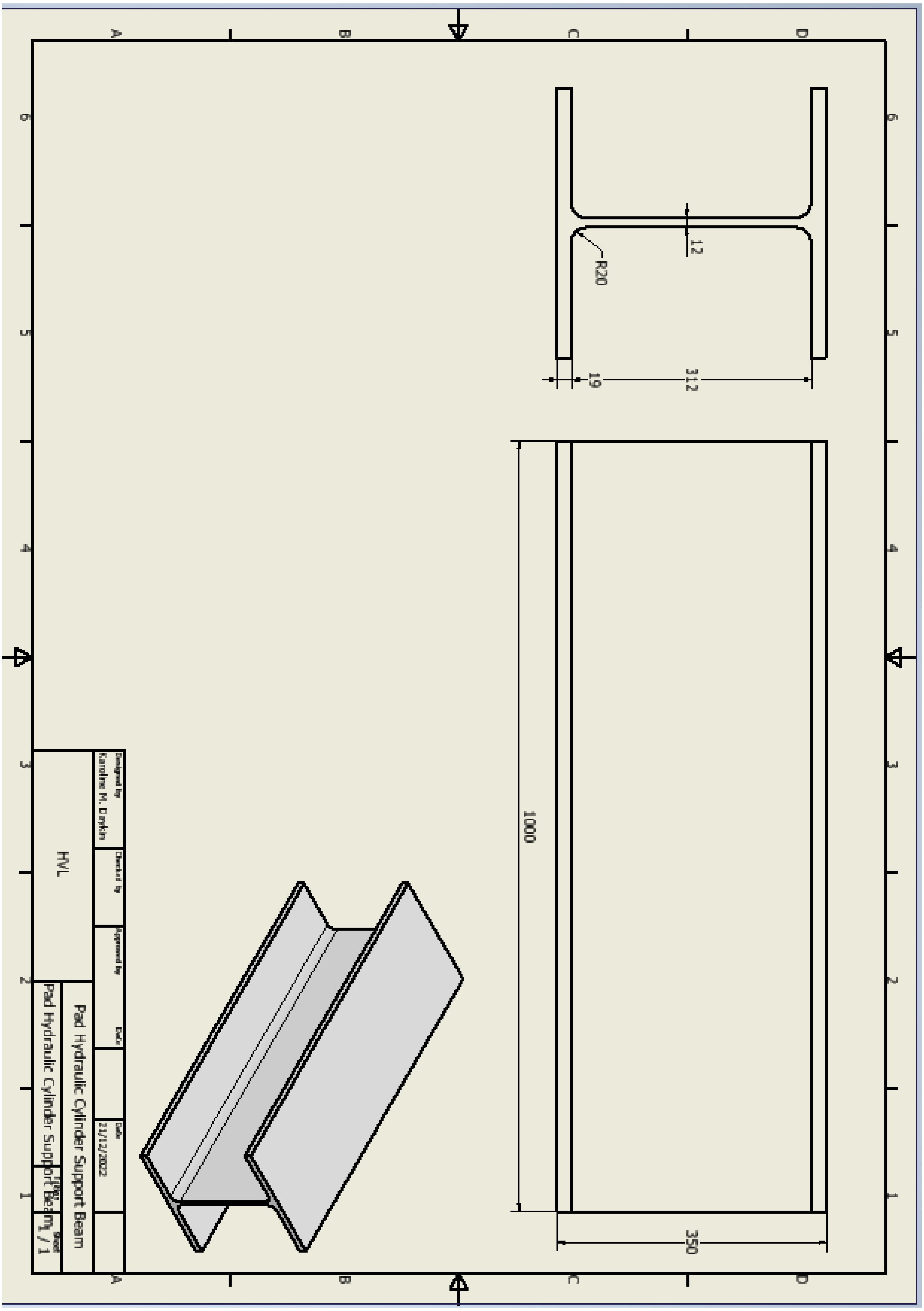
Hydraulic Pad Cylinder Holder Inner



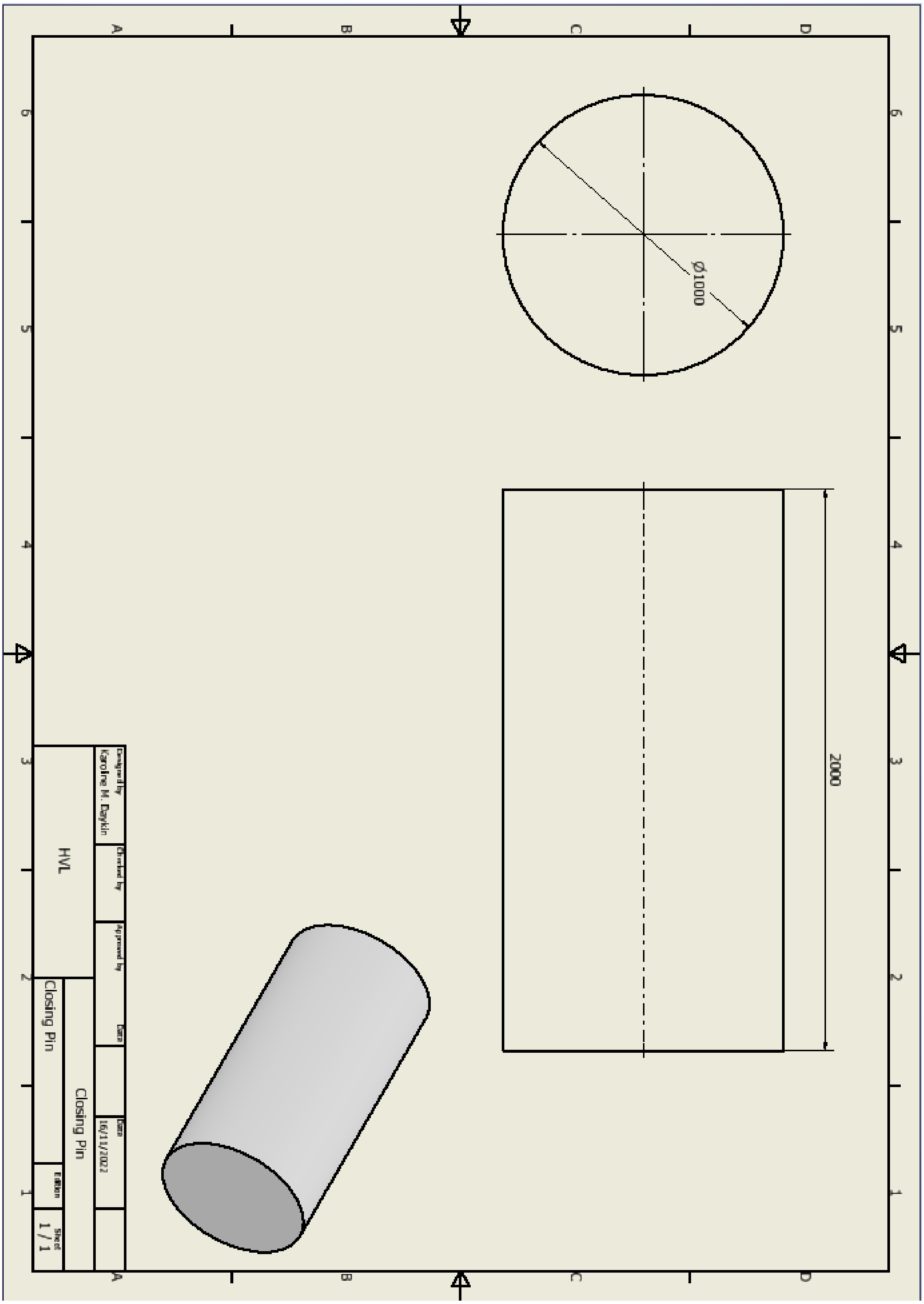
Hydraulic Pad Cylinder Holder Outer



Pad Hydraulic Cylinder Support Beam



Closing Pin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Approved by
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