# Development of Floating Small-Scale Offshore Wind Turbine Construction

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Bachelor's thesis

Mechanical Engineering and Production Technology

May 2019

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ABSTRACT

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**Subject** Offshore Small-Scale Floating Wind Turbine Construction Development

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ABSTRACT

Report describes the process that followed in order to design a device Offshore Small-Scale Floating Wind Turbine Construction. The said purpose included developing a conceptual design for an offshore floating small-scale wind turbine for Nordic Folkecenter for Renewable Energy, is order to make a prototype for showcasing and testing purposes. This shall be attained by making use of the suitable of mechanical engineering tools and by applying project methodology techniques.

This report shows in detail how the presented problem was approached, first executing concept analysis of the floating wind turbine with the guidance of Nordic Folkecenter for Renewable Energy, once the concept analysis had been provided, then every effort devoted into designing the proper solution, one in accordance with requirements previously set.

Following the requirements of Nordic Folkecenter, a final design concept solution was developed with consideration to simplicity of manufacturing and usage of custom components.

The said final design concept of offshore floating small-scale wind turbine consists of a buoyant construction made of three barrels and a steel tube jointing construction, a ballast for stabilization of the floating construction, predefined electric components for wind turbine functional, corrosion resistance and an anchoring system which consists of concrete anchors.

For future projects a detailed design analysis of the conceptual design, a list of components and 2D drawings are provided here.

**Keywords** Design analysis and development, floating wind turbine, offshore

**Pages** 32 pages, including appendices 63 pages

CONTENTS

# 1 INTRODUCTION

The project about the small floating wind turbine design concept development was offered by Nordic Folkecenter for Renewable Energy during the internship. The idea of the project was to create a conceptual design of floating construction for wind turbine which will be possible to produce in Folkecenter's workshop for showcasing purposes, as it was decided in the beginning. The aim of the project was to start the chain of other projects, where the aerodynamics, hydrodynamics and FEM analyses, design optimization, manufacturing and testing will be provided. If each step will be successful for the small wind turbine, the similar project for bigger 10 kW turbine will be provided, based on development steps from previous projects.

In this project the research about floating wind turbines construction was provided. Based on the requirements of the Nordic Folkecenter and evaluations of main classifications of floating wind turbines, existing floating wind turbines on the market and environment, the conceptual design was chosen. The external influences, like wind and waves were defined and buoyancy calculations were made for creation of sustainable concept design. The FEM analysis, aerodynamics and hydrodynamics analyses were not included in this project. They will be provided in the future during the project of design optimization. Finally, the design concept of floating wind turbine construction was developed.

# 2 BACKGROUND

## 2.1 Wind Energy

One of positive aspects of wind energy is that there are no direct emissions produced at the process of electricity generation. While power and effectiveness of wind energy turbines are increasing, prices of manufacturing and construction are rising as well. The wind energy is available almost everywhere in the world, despite most of other ways of electricity generation wind turbines do not require water. As main arguments against wind turbines are noise, visual disturbance and avian impacts, still the negative influence of wind power on environment is greatly smaller comparing to fossil fuels. For this moment wind energy is one of the major renewable resources on the earth and has a great potential for further development.

## 2.2 Offshore Wind Power

Offshore wind turbines have advantages and disadvantages when comparing them with wind turbines on the ground. The location of offshore wind turbines is usually far in the sea, far from buildings, therefore noise is not be a problem for humans, moreover construction cannot harm them in case if it will fall. The wind speed is much faster in offshore areas, so the effectivity and power production of wind turbines are potentially much bigger. The construction of Offshore farms is more expensive, because of the necessity of a special structure, which should be sustainable to all environmental influences and which can hold the wind turbine in the working position and connect it to the ground.

## 2.3 Definition of Purpose

“Basing on skills and available knowledge to make a small-scale Floating Wind Turbine design concept, which can be produced for Nordic Folkecenter for showcase purposes.”

# 3 PROBLEM STATEMENT

## 3.1 Design Criteria for the Solution

Below there is a list of questions which Nordic Folkecenter set up for this current project and future projects. Answers on these questions will provide an understanding of how future tasks will look like.

1. *What are the different solutions present on the market or under development?*

- To provide research of existing design concepts of floating wind turbines. Define their pros and cons and to evaluate them regarding to requirements of the project

2. *How are the connections to the mainland made?*

- To find out what kind of connections between wind turbine and mainland are existing and can be developed in case of floating wind turbine for transportation of electricity.

3. *Is there any storage involved? If so, what is the selected technology?*

- Define the main components of wind turbine, analyze the storage necessity. If it is required, define what kind of components there can be stored, where is the best place for storing and what is the proper way to store these components, basing on environment impacts and accessibility for humans.

4. *How are the fundaments structured? What are the key elements that allow the turbine to remain stable?*

- Define the main functions of components of floating structure for wind turbine.
- Define the key elements on each level of floating construction and their functions.

5. *How is the anchorage placed?*

- Define different anchoring solutions for floating wind turbines, their functions and set up specifications.

6. *How depth of water influence on anchoring?*

- Define the anchoring specifications dependency according to the depth of water

7. *What kind of main forces are influencing on the construction, which should be considered during design?*

- Define the environmental impact on the construction and impact of the construction on itself.

8. *Which materials will be suitable for the construction?*

- Define what kind of materials and coverage usually used for offshore floating wind turbines. According to environment specifications define suitable materials for the floating wind turbine construction.

## 3.2 Main Problem

The main challenge in the project was to provide research and evaluation of existing solutions of floating wind turbines for defining the most suitable concept for realization or creation of a new design, based on environmental factors and the manufacturing opportunities of Nordic Folkecenter.

## 3.3 Sub-problems

With respect to requirements and criteria, the following sub-problems were stated:

- Examining floating wind turbine design concepts and choose the most suitable.
- Examining environmental conditions, where turbine will be set up. Find out environmental impacts on the construction.
- Examining about existing design solutions and evaluate them in case of suitability for the final design.
- Examining the connection to the mainland concepts and choose one for the design.
- Providing a solution of storing electrical components on floating wind turbine.
- Defining the main components of floating construction and their functions.
- Choosing anchoring system for the floating wind turbine
- Choosing materials, which will be sustainable to the environmental impacts.
- Creating a new design or choosing an existing one for the floating wind turbine.
- Developing the solution, which can be produced at Nordic Folkecenter.

## 3.4 Delimitations

When delivering a proper solution to the target of the project, significant delimitations had to be stated, considering the purpose of the project, available knowledge and skills and time limitations for task completion.
As it was written, the main goal of the project was to create a model of floating wind turbine, which would be possible to be produced at Nordic Folkecenter for Renewable Energy company and to set up for showcasing purposes. It means that the components of floating wind turbine were to

be defined, but to make functional prototype is not the requirement of the project as well as the originality and innovation.

The serious time limitation and lack of knowledge have to be considered. It will influence on the research, calculation and modelling phases on the project. In this project there will not be provided the detailed hydrodynamic, aerodynamic and FEM analyses and calculations. The floating construction will be analyzed by basics of buoyancy for being sure, that the floating construction will not drown. The external influences such as wind and waves will be identified, but not calculated. The design concept will be developed with respect to external influences and stabilization needs. The optimization of the design of floating wind turbine construction will be provided in future projects after aerodynamics, hydrodynamics and FEM simulations. It is not required, that the model of the floating wind turbine will be original, due to factors described above, the opportunity of developing a small-scale design solution from already existed design concepts is a potential way of the project development. The manufacturing of the prototype and testing will not be included into the project requirements, as they will be provided in future projects.

## 3.5 Choice of Models and Methods

A table of choice of models and methods was created for defining main tasks and steps of the project [table 7]. Table 7 contains the tasks of the project and questions which will help to understand the importance, difficulty and workload of each task. The choice of models and methods hekped to manage the project and to build effective and not overloaded timetable. The table located in the Appendix 1.

## 3.6 Time Schedule

The time schedule for the project was created for setting up deadlines for each task and effective distribution of the workload during the project development. [figure 29] Appendix 2

## 3.7 Risk Assessment

During the project development phase, it was necessary to understand what kind of problems could appear. It will help to monitor risks of project failure and to react promptly with a decision for not losing time and being able to finish tasks before deadline. For this purpose, the Risk Assessment table was created, where all possible risks, their likelihood, severity and possible solutions are described. [table 6] Appendix 3

# 4 ANALYSIS OF DESIGN CONCEPT

In order to develop a proper design of an offshore floating construction was necessary to make a research about basic design concepts of floating constructions for wind turbines. In other words, a research about classification types of offshore floating wind turbines and already existing solutions on the market was done. An analyzation of three main classifications of floating wind turbines and lists of existing floating turbines are described in next paragraphs.

## 4.1 Classification of Floating Construction

There are two types of wind turbines as illustrated in Figure 1: onshore (turbine located on the ground) and offshore (turbine located in the water). Besides, offshore wind turbines are divided into two types as well: foundation type (wind turbine grounded on the bottom of the sea) and by floating type (wind turbine is floating on the water surface). The existence of offshore wind turbines is profitable because of the wind in big water areas like seas and oceans, is stronger, more constant, and the turbulence is smaller.

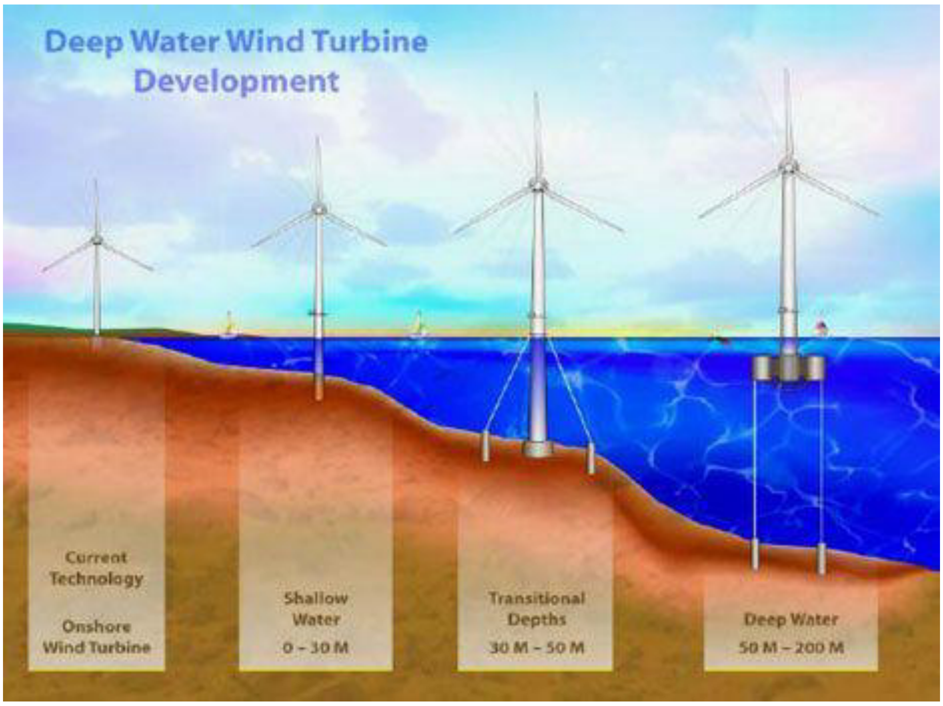


*Figure 1: Class of wind turbine to depth of water (Wind Technology, n.d.)*

There are three main categories of floating wind turbines which are based on the stabilization techniques: Ballast Stabilized, Mooring Line Stabilized and Buoyancy Stabilized. The visual interpretation of categories as shown in Fihure 2 and description of each category with their pros and cons are provided below.

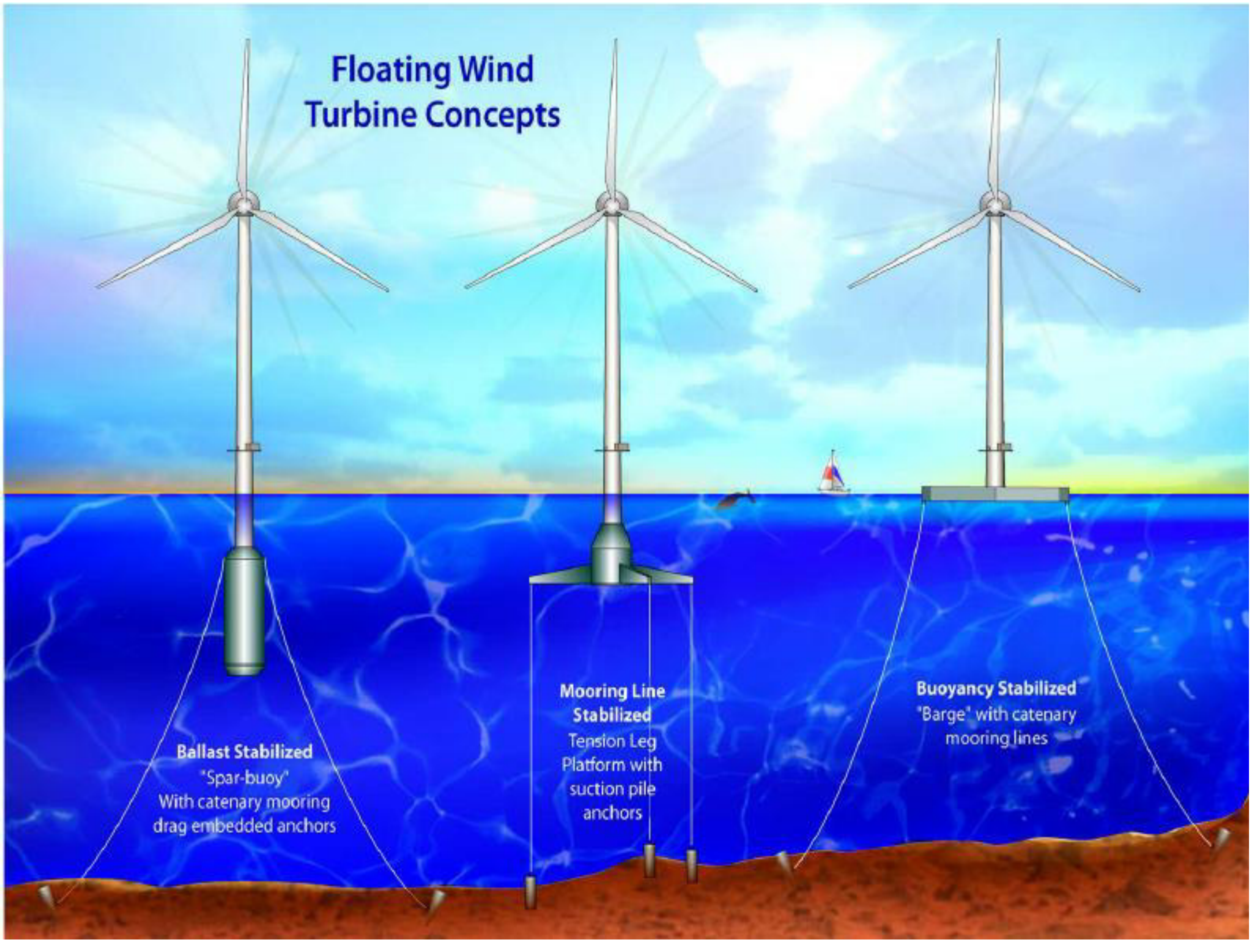


*Figure 2: Classification of Floating wind turbines (Butterfield, 2005, p. 3)*

### 4.1.1 Ballast Stabilized

The Ballast Stabilized platform is achieving stability by using ballast weights hung under it and central buoyancy tank which is holding ballast and wind turbine's tower. The righting moment is created by buoyancy tank which is holding all construction on the right level. The righting moment is appeared because of the wind and underwater streams. If the righting moment will be bigger than maximum, the wind turbine can fall horizontally. The ballast used for resistance to rolling, pitching and heaving of construction. Catenary mooring (anchoring system) is needed to hold the floating construction on one place and prevent axial rotation. (Butterfield, 2005)

*Table 1: Ballast Stabilized pros/cons (Andersen, 2016, p. 11)*

| Pros | Cons |
|---|---|
| Inherent stable | Large draft limits towing |
| Low wave exposure | Material usage |
| Simple structural design | Floating turbine installation |

The Ballast Stabilized structure is very stable, but at the same time it is hard to produce and install this construction due to the complicated structure of the ballast. The preinstallation starts in a port, after that specialized vessel ships it to the required place. Finally, the wind turbine is installed by a crane.

“The biggest upside for the spar buoy is the inherently great stability. This stability comes at a price; the draft. The deep hull provides challenges in launching the vessel from port and handling the towing from port to site. Most concepts try to circumvent this issue by towing the structure at an inclined angle and then only adding the total ballast when arriving at site. Generally, spar buoys are not suitable for installation in water depths of >100 m. Catenary moorings are well known and relatively simple to pre-install at site.” (Andersen, 2016, p. 12)

### 4.1.2 Mooring Line Stabilized

The Mooring Line Stabilized type of construction is achieving stability by using the tension in mooring line. On the [figure 2] it is possible to see that Mooring lines are going vertically from the buoyancy tank to the ground. In this case, cables are always under tension which is preventing the movement of platform in any direction. (Butterfield, 2005)

*Table 2 Mooring Line Stabilized pros/cons (Andersen, 2016, p. 12)*

| Pros | Cons |
|---|---|
| Low material usage | Inherently unstable |
| Excellent stability | Complex anchoring |
| Cheap depth scaling due to taut mooring | Specialized vessel needed for installation |

The Mooring Line Stabilized construction is consisting of fully submerged buoyant structure (it is when the buoyancy tank is under water) and Mooring system. It means that the construction can be very light, which is making the production price lower comparing to Ballast Stabilized type. The installation requires the specialized vessel for setting up Mooring lines. The usage of Mooring lines can cause big problems during installation and functioning phase. If one of cables fails, then the whole construction will lose the stability. (Andersen, 2016)

### 4.1.3 Buoyancy Stabilized

The Buoyancy Stabilized achieving stability by buoyancy tank or tanks which are taking the area around the wind tower and preventing influence of external forces from wind and waves, suppressing them by size and weight of construction. (Butterfield, 2005)

*Table 3: Buoyancy Stabilized pros/cons (Andersen, 2016, p. 12)*

| Pros | Cons |
|---|---|
| Inherently stable for towing | Complex fabrication |
| Low draft | Active ballast system |
| Port installation of turbine | Structural mass |

The Buoyancy Stabilized type is easy for installation, because all installation is possible to make in a port, then transport it to the needed place without any special tools and set it up by anchors. This is the simplest and cheapest type of construction for installation, comparing to two others. The manufacturing is problematic due to the size and weight of construction, which is making the transportation very difficult and the manufacturing price extremely high. To set up the Buoyancy Stabilized type construction in places with big waves the specialized active ballast system is required. This system is controlling the buoyancy construction in the way that it will always be in the horizontal position which will minimize the swinging of the wind turbine. Moreover, it is also expensive to manufacture. (Andersen, 2016)

## 4.2 **Existing Design Concepts**

All these three types of floating wind turbines construction have their own advantages and disadvantages. For this reason, in the reality most of design concepts and existing solutions are having hybrid structure. Such structures usually include two types (sometimes three) of stabilization techniques in their design. At this moment, it is hard to say which concept is the best due to the relatively young and unexplored industry of floating wind turbines. It is also difficult to identify which concept will occupy all expenses. Examples of several already existing and those that are still under development designs are shown on figure 3. In this project only three chosen existing designs will be described as main influencers on the project’s concept design.

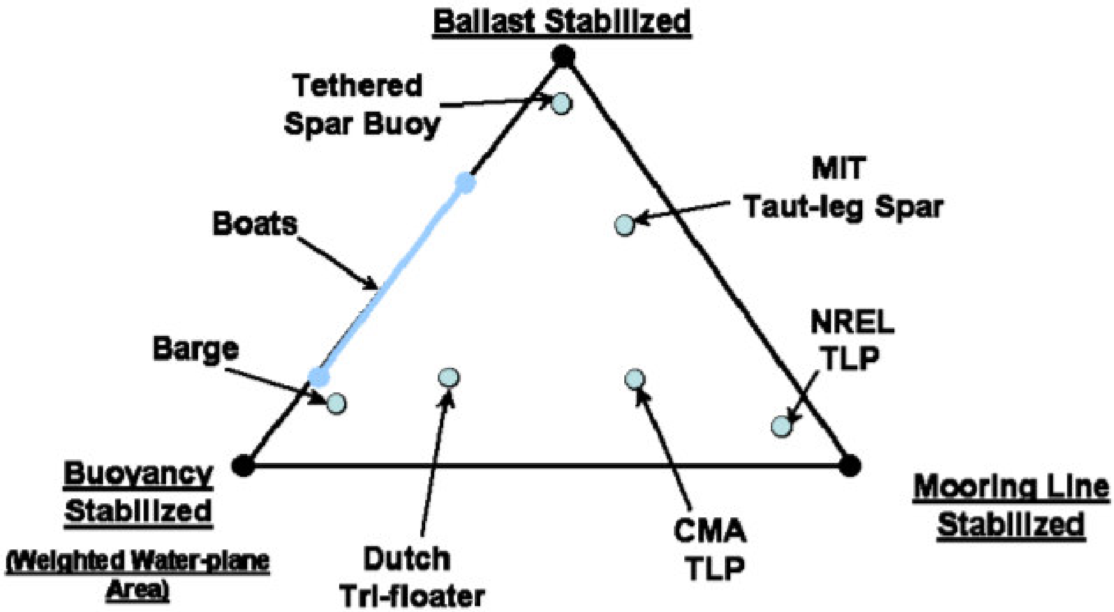


*Figure 3: Existing design concepts classification gradation (Butterfield, 2005, p. 4)*

### 4.2.1 TetraSpar® Floating foundation of Stiesdal

TetraSpar® Floating foundation is the one of the new design concepts, which was developed by Stiesdal Offshore Technologies company. The first floating wind turbine will be produced and tested in 2020. On the figure 4 you can see the conceptual design of the wind turbine. The construction includes the tetrahedron-like fully submerged buoyancy tank, the triangular ballast, which is assembled to the buoyancy tank by cables and Catenary mooring system. The submerged buoyancy tank is useful in the case when it is necessary to decrease the area of wave influence. The interesting detail of this case is that the ballast is not connected to the buoyancy tank directly, it is held by cable system. It is needed for keeping the ballast on the level, where the influence from waves is minimal. Looking from the front, it is visible that ballast is flattened — it was done in order to decrease the influence of underwater streams. The good point of this kind of ballast is that it will stabilize the construction, it will not take forces by waves and streams, and, at the same time, will not give additional righting moment to the buoyancy tank. Moreover, in some situations this kind of ballast can play a role of Mooring line as the second stabilization type.

The method of transportation is shown in Figure 5. The construction is installed in a port, afterwards it is transported on site, assembled to anchors, then the ballast is drowned, finally, the level of the buoyancy tank is regulated. (Joshua, 2019)

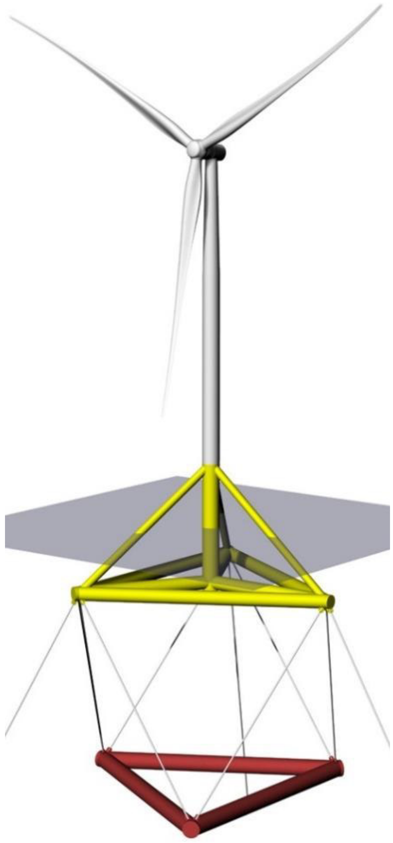

*Figure 4: TetraSpar® Floating foundation, isometric view*

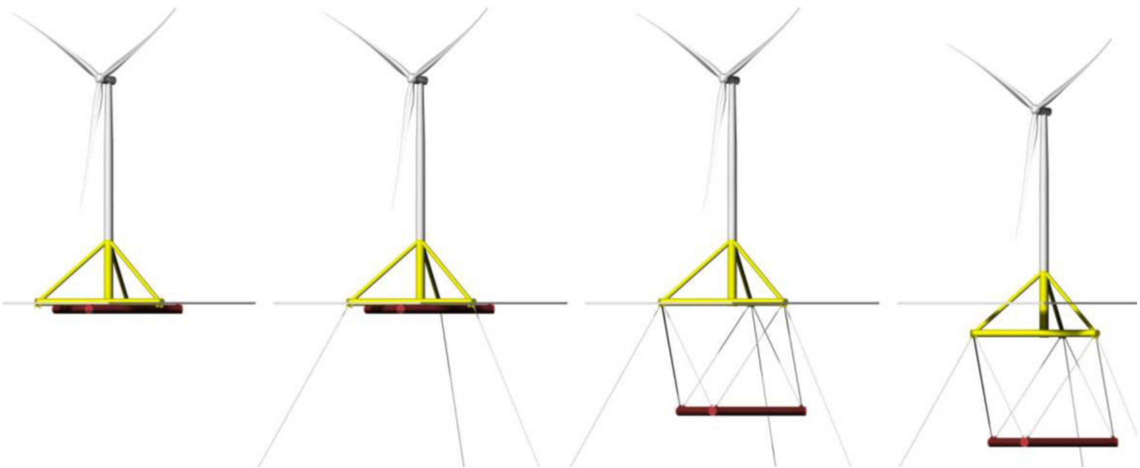

*Figure 5: TetraSpar® Floating foundation, installation*

### 4.2.2 Hywind Scotland pilot park of Statoil

This is the classic interpretation of Ballast stabilized type of floating wind turbine. It is a concept of floating wind turbines that was developed by Statoil company. The development started in 2001, then first floating wind turbines were installed in Karmøy, Norway in 2009. Tests were successful and in 2017 the first wind turbines park was developed and started the electricity production as can be seen in Figures 6 and 7. (Hywind Scotland was officially opened by Nicola Sturgeon in October 2017., n.d.) (Statoil Sets Aside EUR 214 Million for Hywind Scotland Pilot Park, 2015)

*Figure 6: Hywind Scotland wind turbine, concept design*

*Figure 7: Hywind Scotland pilot park, concept design*

### 4.2.3 Dutch Tri-floater Concept

Dutch Tri-floater Concept design is a classical Buoyancy stabilized type of construction. It has three buoyancy tanks with ballasts hung under them. The triangular form is providing good resistance to external forces, which can influence the construction. In this case a simple catenary anchor system is used for preventing the axial movement of construction and keeping it on one place. The installation of its wind turbine is made in a port as illustrated in Figure 8.

*Figure 8: Dutch Tri-floater concept design (Savenije, 2013)*

## 4.3 **Evaluation of Design Concept**

To define the future concept design, it was necessary to understand which things are important for consideration of further development. The design of a floating wind turbine is based on needs of Nordic Folkecenter for Renewable Energy company. The main goal is to make a design for showcasing purposes of a small-scale floating wind turbine which additionally will be possible to manufacture in Folkecenter's workshop. Despite the main purpose of the project, it is necessary to create the design concept in a way that it will be possible to use it for future projects, where the prototype will be manufactured and tested. Therefore, the determinative role of evaluation took the simplicity of manufacturing. In case of testing it is important to know the area in which it is possible to install floating wind turbine: what kind of waves are there and especially the depth of the water. The installation is important as well, because the manufacturing will be done in the Folkecenter's workshop and after it will be transported to the water facility. The evaluation table of three main types of floating wind turbine construction is shown in the next paragraph. According to this table, the basis of construction will be chosen. It will be also interesting to apply some unusual decisions for the structure for example the ballast system, which was appeared in the TetraSpar® Floating foundation.

### 4.3.1 Evaluation Table

Hereby you can see the evaluation table. [table 4] It was necessary to provide the classification evaluation with respect to requirements of the project for identifying clearly how the future concept design will look like and which classification will be chosen as the main one. The evaluation was provided through four main criteria. The Manufacturing, the simplicity and ability to manufacture that type of chosen concept design in Nordic Folkecenter. The Installation Simplicity, the difficulty of setting up of chosen concept design. The Depth Independence, considering the environmental conditions of installation place, classifications will be evaluated. Finally, the Wave Sensitivity which will be evaluated with respect to environment of floating construction's placement and construction's behavior of each certified class.

*Table 4: Concept design evaluation table*

| Criteria | Ballast Stabilized | Mooring Line Stabilized | Buoyancy Stabilized |
|---|---|---|---|
| Manufacturing | 2 | 3 | 4 |
| Installation Simplicity | 3 | 1 | 3 |
| Depth Independence | 3 | 3 | 4 |
| Wave Sensitivity | 4 | 5 | 2 |
| Total | 11 | 12 | 13 |

### 4.3.2 Manufacturing

The Manufacturing is playing an important role in making the decision. The difficulty of manufacturing was provided according to the workshop of Nordic Folkecenter for Renewable Energy company and what kind of machine tools and resources are available. The Ballast Stabilized type is relatively hard for manufacturing: it requires a complicated ballast made of steel and concrete, additionally, the assembly between ballast and buoyancy tank is also difficult to manufacture. The buoyancy tank for Ballast Stabilized and Mooring Line Stabilized types is in the centre and assembled directly to the ballast and tower of wind turbine. It means that the construction will require the specialized type of buoyancy tank, which is complicated for manufacturing as well. The Buoyancy Stabilized type could consist of many buoyancy tanks which are assembled together: it is providing a good opportunity to set up the tower for wind turbine between buoyancy tanks in the centre, as it is made in Dutch Tri-floater concept design. Moreover, it is providing a possibility of using custom buoyancy tanks, for example, oil barrels. The main problem of Buoyancy Stabilized type is that it requires additional materials which can increase the manufacturing cost, and make it more expensive, comparing to other types. At the same time, it is possible to reduce the price by using custom parts in the construction, which are available on the market and simplified assembling techniques.
The ideal variant in case of manufacturing simplicity is Buoyancy Stabilized type of floating construction from custom parts.

### 4.3.3 Simplicity of Installation

The small-scale floating wind turbine of all types are reliable in case of transportation by hindcarriage. However, during the installation of anchoring system in the water, Ballast and Buoyancy Stabilizing types face difficulties with the transportation of anchors. Anchors are heavy, and it could be dangerous to transport them to the final destination without using specialized boats. The most difficult case is the installation of Mooring Line Stabilized type of construction. The reason for it is that it is necessary to set up the anchors manually. The installation process requires high accuracy and additional work with foundation.

### 4.3.4 Environmental Conditions (Water and Waves Conditions)

As a place for future test of floating wind turbine the Helligsø Teglværk on Nissum Bredning fjord was chosen. It is a place near Folkecenter for Renewable Energy, where the test field for wave energy power plants is allocated.

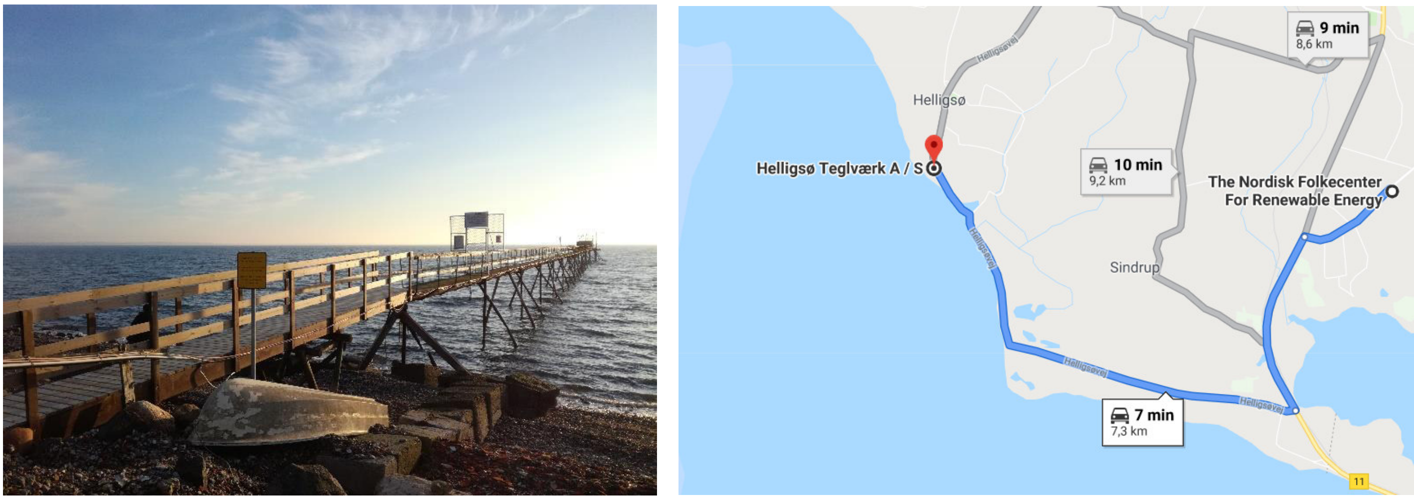


*Figure 9: Nissum Bredning, Helligsø Teglvær*

The depth of water in the area varies from 2 to 7 meters. It means that the installation of Ballast Stabilized or Mooring Line Stabilized type of floating construction is problematic it this location. Therefore, the ideal solution in this case is to use the Buoyancy Stabilized type of construction. The wave height varies from 0,2 to 1 meter. These waves will make an influence on the stability of small-scale floating wind turbine construction. In the case of waves, the best solution will be to use the Mooring Line Stabilized type. The Mooring line is still difficult in installation, however, an advantage in here is a submersible buoyancy tank, which can be drowned under the water surface and will help to decrease the wave influence.
The information about wind on the test field was not available, because the main purpose of the field is to test wave power plants, not offshore wind turbines. The wind was considered during design development. The further evaluation about wind influence will be provided in future projects.

As a result of evaluation by environmental conditions, the best decision is to provide the hybrid type of a construction, the solution which can be suitable in case of waves as well as water depth – hybrid between Buoyancy Stabilized type and submersible buoyancy tank of Mooring Line Stabilized type.

## 4.4 **Chosen Design Concept**

The design concept of the offshore wind turbine floating wind turbine will be based on the hybrid construction of Buoyancy Stabilization type and submersible buoyancy tank. Was decided to use the ballast system like in one of existing design concepts - TetraSpar® Floating foundation: it will drown the buoyancy tank, keep it underwater for minimizing the wave influence on the construction and will give to the construction the additional stabilization likewise in the Mooring Line Stabilization class.

# 5 CALCULATIONS

To start the development of the design of offshore floating wind turbine construction it was necessary to define what kind of external influence the construction is experiencing. Then what should be calculated first to start design development. The design concept of the offshore floating wind turbine will be based on the hybrid construction of Buoyancy Stabilization type and submersible buoyancy tank. Was decided to use the ballast system like in one of existing design concepts — TetraSpar® Floating foundation: it will drown the buoyancy tank and keep it underwater for minimizing influences from waves and underwater streams.

## 5.1 Environmental Impact

For better understanding of the construction design it was necessary to define, what kind of influence the environment can cause. On the figure 10 below there is visualization of possible external influential factors. The first important question which should be solved for making the sustainable design is buoyancy, because the construction must float. Factors for the second expectation are wind, waves and corrosion factors. The stability of the wind turbine is important in case of energy production. Without any particular resistance to waves and wind, the construction will destabilize, start shaking and wind blades will not be able to catch wind correctly. Therefore, the productive energy generation will not be possible. The corrosion is important, because the impact will go to the lifetime of the construction. The salty water in the sea is a huge problem for materials like steel and iron. Because of the corrosion in the construction could appear holes, jointing elements will become weaker. As a result, the construction can drown.

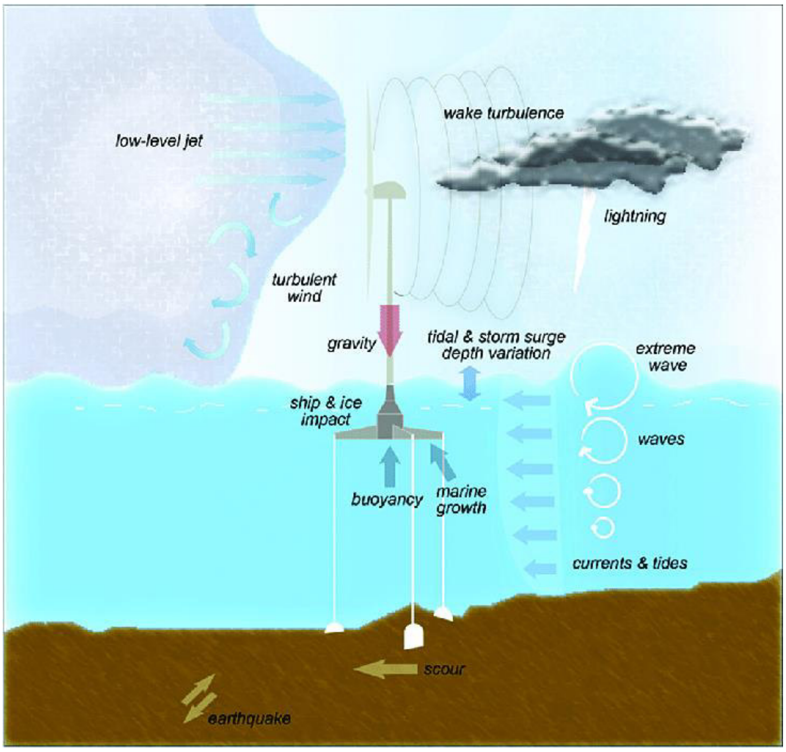


*Figure 10: Visualization of external influences on the floating wind turbine construction (Sequiera, 2017)*

There are other influences on the floating construction are wind and waves. The wind is mostly influencing on the wind turbine, which is creating the normal force and bending moment on the tower of the wind turbine. Waves are providing to the construction constant dynamic loads, which are putting floating construction up and down and moreover creating normal force by pushing. Such environmental influences like marine growth, turbulent wind, earthquake, lightning, scour and other were not analysed in this project, because the detailed analysis will be provided in future projects.

## 5.2 Stabilization Considerations

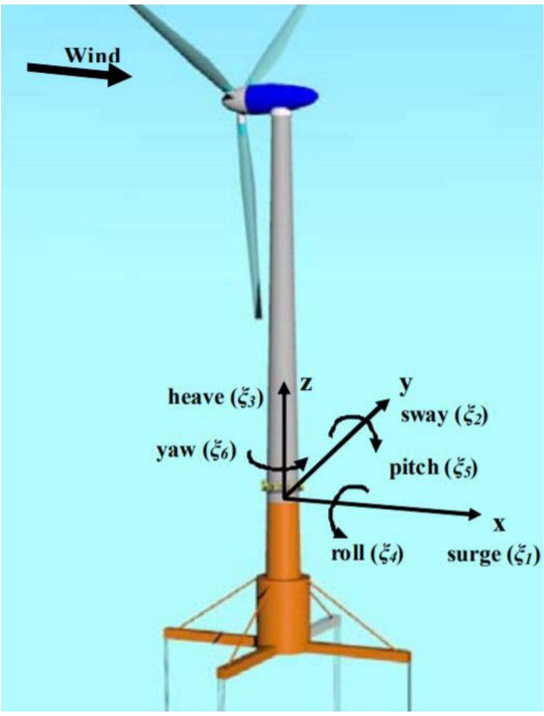


*Figure 11: Support Platform Degrees-of-Freedom (Butterfield, 2005)*

Due to the project requirements it was necessary to create the sustainable conceptual design, at the same time delimitations on what can be calculated are existing. On the figure 11 there are several degrees of freedom by which floating construction can move and should be stabilized. The movement by degrees of freedom will be calculated in future projects and during this project of concept design development they will be expected.

## 5.3 Buoyancy

Buoyancy is the force acting opposite the direction of gravity that affects all objects submerged in a fluid. The buoyancy is the most important part of calculations, that should be provided before design development could be started. An object could be considered as buoyant, if the weight of this object is smaller than or equal to the buoyant force. The floating construction should float on the water and not drown under its own weight. It was necessary to identify the volume of air, that will be required to hold all structure on the water. In the beginning was decided to calculate what exact amount of volume of air is needed to hold on the water the wind turbine and the tower. The mass of the turbine is 5.85 kg and the mass of tower is 13 kg.

$$F_b = V_s \times D \times g$$

$F_b$ is buoyant force.
$V_s$ is volume of the object.
D is density of the fluid.

g is the gravity force (9.8 $\frac{m}{s^2}$).

As an object, the wind turbine with the tower will be considered. The summary of their volumes will be considered as Vs. The density of the fluid is the density of the saltwater. D is equal to 1029 $\frac{kg}{m^3}$. The buoyant force, which is appearing from the tower and wind turbine is 111 Newtons. If the weight of them will be smaller than the buoyant force, than it will mean, that the construction is floating. To calculate the weight is needed the sum of mass to multiply it on the gravity force. The weight is 185 N. The weight is bigger than buoyant force of the object, it means that object will drown. The problem could be solved if to add to the volume the volume of air, which will be used to make an object float. To make the buoyancy force equal to the weight of the object was needed to add additionally 0.0074 $m^3$ of air.

It is important to mention, if the buoyant force is equal to the weight of the object it will identify that the object will not be exactly on the surface of the water. It will float freely somewhere inside the water. Therefore, to make the floating construction, the expected buoyant force should be bigger than the weight of the construction.

After the design of the floating construction was created, the buoyancy calculations were provided one more time. The total mass of the floating construction (mass of ropes and anchors were not included) is 263 kg and weight is 2579 Newtons. The total buoyancy force is 6057 Newtons. The buoyancy force became that high because of 200 L barrels which were used as buoyancy tanks in the construction. The buoyant force can become lower, if inside of barrels the water will be added. I could be useful in case of submersing the buoyant construction. (Ruff, 2019), (The buoyant force, n.d.), (Archimedes' Principle, n.d.)

# 6 DEVELOPMENT OF DESIGN

The main goal of the project is to create a concept design of small floating wind turbine construction. It should be created with respect to simplicity of manufacturing and usage of custom parts and materials. The design was created, parts for construction were defined. The description of chosen parts and full assembly will be provided in next paragraphs.

In the beginning, it was necessary to define what should be designed and what kind of parts should be also included to the construction and which are possible to find on the market as well. First of all, the buoyancy construction should be designed. Then, the ballast of the floating construction, anchoring system, electric parts, tower and wind turbine.

The model of the floating construction and 2D drawings were made in Siemens NX 12 modelling software. Custom parts were found in internet stores and in Nordic Folkecenter. The material and galvanization process descriptions were provided from CES Edupack library and could be found in the Appendix 4.

## 6.1 Wind Turbine

The wind turbine for the floating construction was selected with the help of Nordik Folkecenter. It was important to find cheap wind turbine on the market, because main purpose is for showcasing and prototyping, or the one which is already available in Folkecenter. On the [figure 12] it is possible to see the chosen wind turbine: Air X 400-watt wind generator for marine purposes. Specifications of the wind turbine and dimensions will be mentioned below.

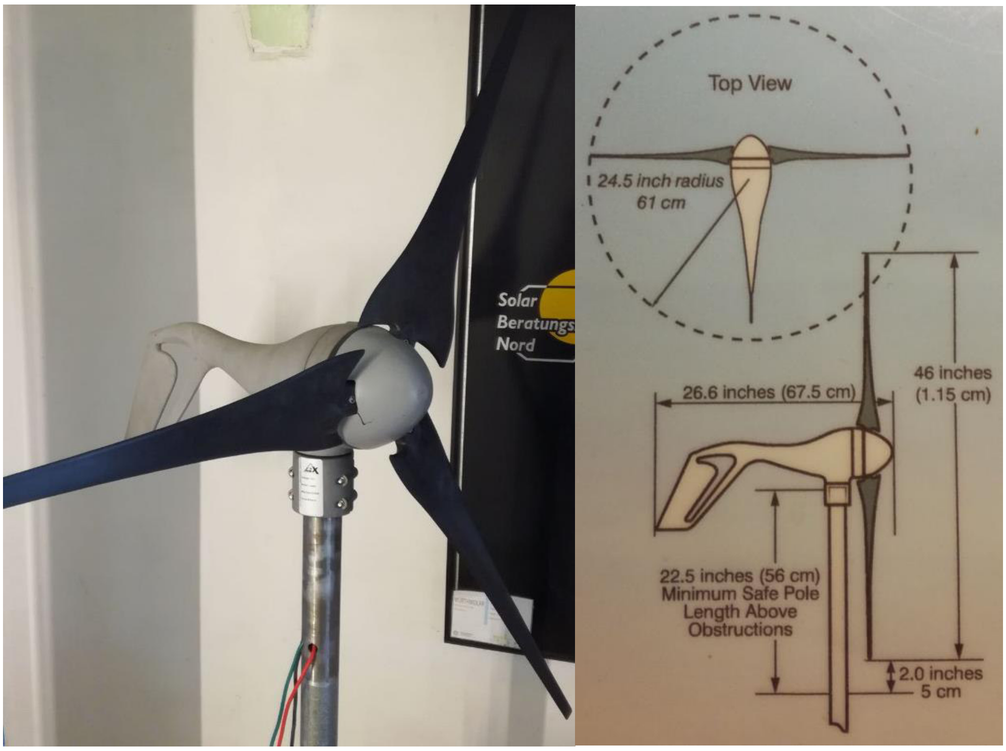


*Figure 12: Air X 400-watt wind turbine for marine purposes*

Specifications of Air X wind turbine

Rotor diameter: 1.15 m
Weight: 5.85 kg
Shipping Dimensions: Shipping: 686x38x228 mm/7.7 kg
Mount: 1.5” schedule 40 pipe (1.9” OD, 48 mm)
Start-up wind speed: 8 mph (3.58 m/s)
Voltage: 12, 24, 34 and 48 VDC
Rated Power: 400 watts at 28 mph (12.5 m/s)
Turbine Controller: Microprocessor-based smart internal regulator with Peak Power Tracking
Body: Cast aluminum (Air-X Marine is powder coated for corrosion protection)
Blades (three): Carbon Fiber Composite
Over-speed Protection: Electronic torque control
Kilowatt hours per month: 38 kWh/mo @12 mph (5.4 m/s)
Warranty: 3 Year Limited Warranty
Survival wind speed: 110 mph (49.2 m/s)

## 6.2 **Buoyancy Construction**

In the Design Concept Analysis part was decided to make a buoyancy construction which will have an opportunity to be submersible. At the same time, it should be simple for manufacturing and, if possible, buoyancy construction could be done from custom parts which are available on the market. [figure 13]

*Figure 13: Buoyancy construction of the floating construction*

The decision was to make a buoyant structure from three barrels and steel tubes, which will be assembled together by welding type of manufacture.

The triangular form of the buoyancy construction is making it very sustainable to external forces which are influencing on the construction and providing good stability from dynamic loads.

The barrel as itself is a potential buoyant tank. It was produced for keeping fluids inside. Therefore, it is waterproof, which is one of the main sustainable parameters for the buoyant structure. The barrel has holes [figure 14] through which is possible to add water inside of the barrel as well as to extract water, if there will be that kind of need.

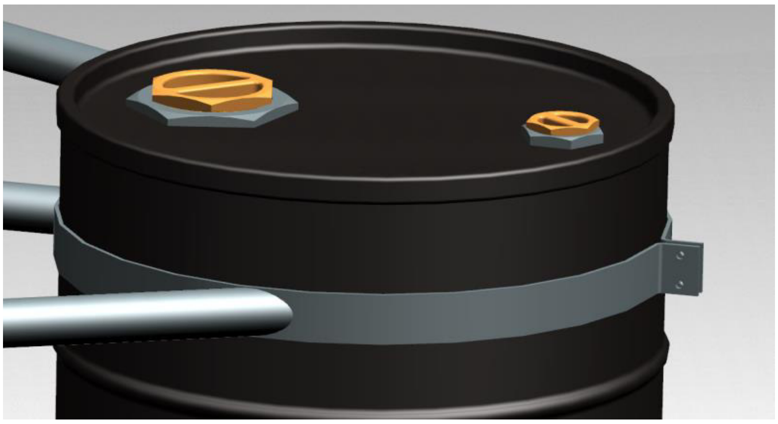

*Figure 14: Openings for filling barrels with water*

It makes barrel a perfect candidate to be a buoyant tank for the floating wind turbine construction. For the buoyant construction was decided to use three barrels of 200 litres volume. The main issue of the barrel is significantly small thickness of walls 1,6 mm. Because of the thickness it is unacceptable to use welding technique to the barrel directly. In that case was decided to use for assembling barrels together with a 4 mm thick steel rings [figure 15]. The ring will be used to assemble to it other elements of the buoyant construction like tubes for example. The ring will be held on the barrel because of the pressure in between, caused by coupling element of the ring. The coupling holds the ring by two bolts M8.

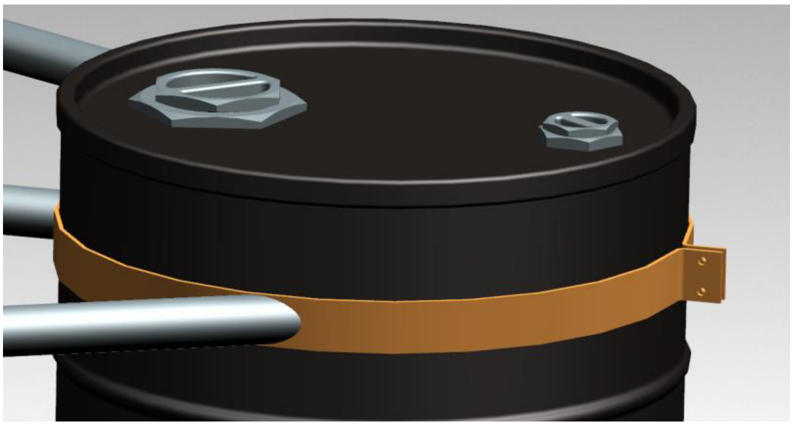

*Figure 15: Steel rings*

Barrels of the buoyant construction are assembled together by horizontal steel tubes. The OD (outer diameter) of them is 48 mm and thickness of wall is 4 mm. Barrels are located on the perimeter of buoyant construction, and in the centre, there is a main support tube [figure 16]. The OD of support tube is 60 mm and thickness of the wall is 5 mm. It means that ID (inner diameter) of the support tube is 50 mm. Considering the 48 mm OD of the tower of wind turbine, the ID of the support tube is compatible for assembling between the support tube and the tower.

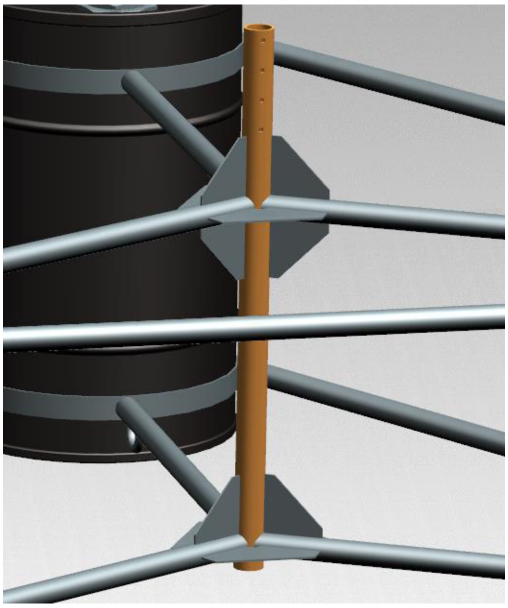

*Figure 16: Central support tube*

Tubes on the perimeter [figure 17] of the buoyant construction are used for giving to the construction the additional resistance to external forces. They will increase strength and stability of the construction, prevent undesirable deflections and greatly increase life length of floating construction.

Figure 17: Perimetral support tubes

For better stress distribution in the centre of the buoyant construction between welded tubes, it was decided to use corners. Steel sheets of 4 mm thickness will be welded in the corners between central support tube and horizontal tubes [figure 18].

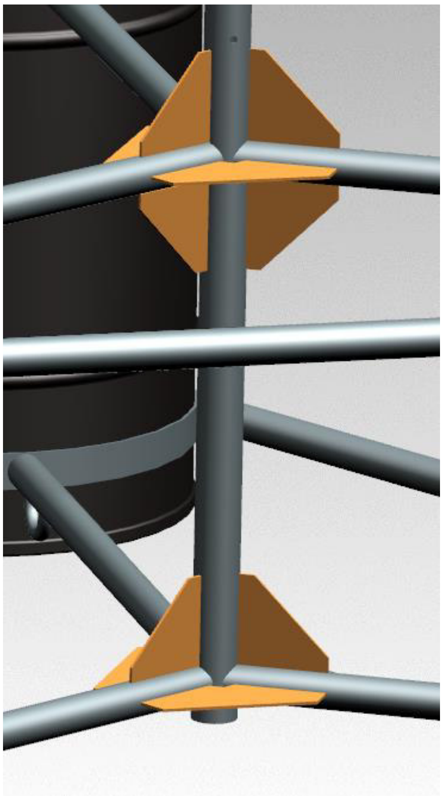

Figure 18: Stress distribution corners

For assembling the buoyant construction and tower of the wind turbine together, four holes of M8 bolts were created [figure 19]. The tower is located in the centre of the construction. The OD of the tower is 48 mm, the wall thickness is 4 mm and the height of it is 2 meters above the water level and the length of the tower is 3 m.

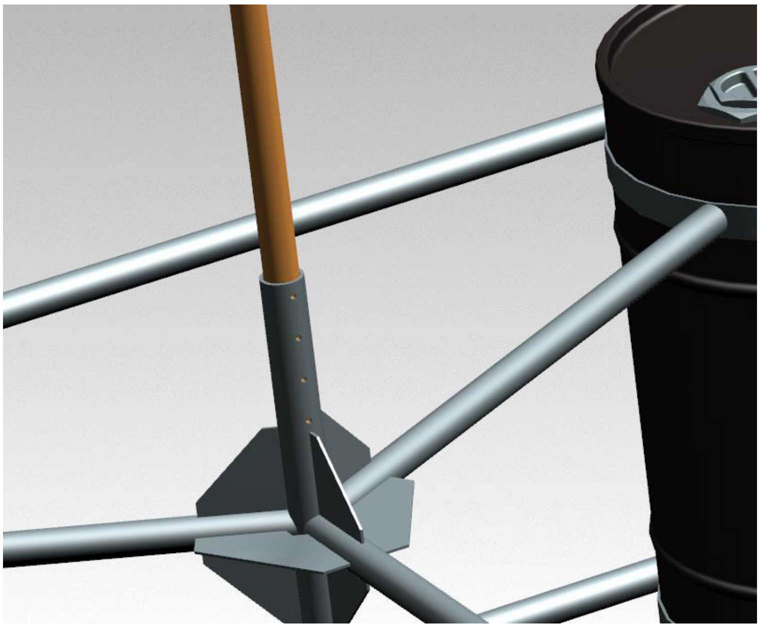

*Figure 19: Tower to central support joint*

For holding the ballast of the floating construction, on the buoyant construction were added steel rings which are welding to the bottom of the structure on horizontal tubes [figure 20].

*Figure 20: Steel rings for buoyant construction to ballast connection*

## 6.3 **Ballast**

For the floating construction was decided to add a ballast system simple to the TetraSpar Buoy design from Stiesdal company. [figure 20]

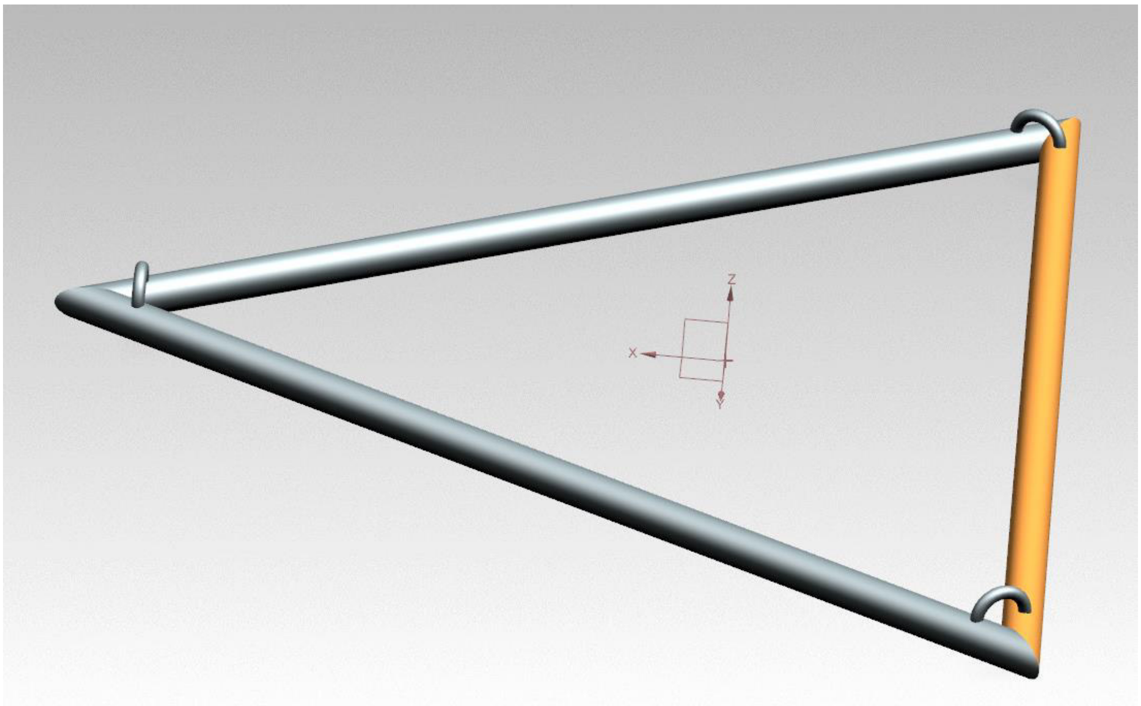

*Figure 21: Ballast*

The ballast constructed from three tubes of OD 60 mm and wall thickness 5 mm which are welded together in triangular form. The same steel rings are welded to the ballast above for connection between buoyant construction and ballast. The mass of the ballast is 35 kg.

The connection between ballast and buoyant structure is provided by ropes, which are using in marine purposes on ships for anchoring them in the port. The diameter of the rope is 16 mm. The same kind of ropes will be used for anchoring floating construction to the sea ground [figure 21].

*Figure 22: Ropes for ballast and anchors connection (PESmix – anchoring and mooring, n.d.)*

## 6.4 **Anchor**

For keeping the floating construction in one place in the sea and for preventing axial rotation while it is floating, the anchoring system was needed. In many cases as anchors in the sea are used blocks of concrete with steel rings. The same king of anchors was decided to use for the floating construction design. It will be easy for manufacturing and the price is not high. For anchoring system there will be used three blocks of 80 kg, which will be assembled to the buoyant construction to the same rings as were used for the ballast assembly. Ropes for concrete anchors will be the same as for the ballast. [figure 22]

*Figure 23: Concrete anchor for the floating wind turbine construction (Mooring Blocks, n.d.)*

## 6.5 **Electric Components**

For functionable offshore floating wind turbine construction was needed to identify, where the generated power will be stored: directly transferred to the mainland or stored in the battery which is located on the floating construction. The variant with the connection to the mainland is not profitable. The length of cables is too big. Moreover, it will be necessary to provide the protection against water and corrosion. That will increase price of floating wind turbine even more. Therefore, it was decided to make a system on the floating construction without connection to the mainland.

For creation of such system it was decided to use next components: charge controller and the battery. The electric system of floating wind turbine is shown on the figure 23.

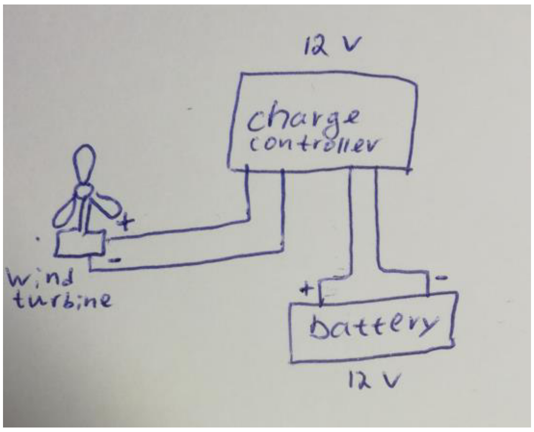


Figure 24: Electric scheme of the floating wind turbine

As it already known the minimal voltage of Air X wind turbine is 12 Volt, when it is able to run the electricity generation cycle. Electric components of floating wind turbine are located on the construction. It means they should be protected from water. Therefore, the waterproof box for electric components should be defined as well. For choosing charge controller and battery is necessary to know their size, depending from waterproof box size, and their voltage which is 12 Volts.

The choice of electric components below was made for clearer visualization of what kind of components could be used for the concept design. The research, evaluation and decision about which exactly electric components will be used will be provided in future projects during design optimization process.

### 6.5.1 Charge Controller

The chosen charge controller [figure 24] is light, small, waterproof. The size of the controller is 9,7 x 9,3 x 2,7 cm.

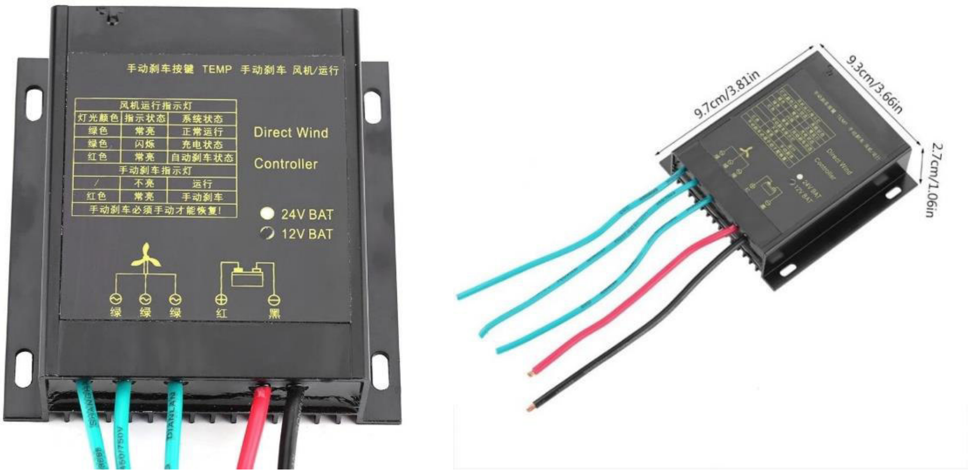


Figure 25: Charge controller for floating wind turbine (400W Waterproof Wind Charge Controller, n.d.)

### 6.5.2 Battery

Was chosen 12 Volt battery. Size of the battery is 2,5 x 6,3 x 10,5 cm.


*Figure 26: Battery for floating wind turbine (12V DC Portable 6800mAh Li-ion Rechargeable Battery Pack CCTV, 2019)*

### 6.5.3 Electric Box

The electric box is big enough to fit inside battery and charge controller, the size of it is 12 x 20 x 5,6 cm. At the same time, it is waterproof.
The location of waterproof junction box, battery and controller is upon the water surface on 1 meter.


*Figure 27: Junction box for floating wind turbine (LeMotech Waterproof Dustproof IP65 ABS Plastic Junction Box, n.d.)*

## 6.6 Corrosion resistance

As one of the external influences on the floating wind turbine construction is the saltwater, the solution against corrosion should be defined. Considering the peculiarities of manufacturing, was decided to orient on the cheapest solution available. Two categories should be researched: materials and coverage. It was necessary to find materials for tubes as a main part of the floating construction. The coverage for the construction should be defined as well, the painting which is resistant to the environment and could be used on metal surfaces. The decision was to find a paint which is usually used for painting bottom of boats. This kind of paint has resistance to sea water corrosion and compatible for steel coverage.


*Figure 28: Paint for corrosion resistance coverage (COELAN Marine Coating-High Quality Coating I i farven blank, n.d.)*

The second option was the definition of material for tubes. For marine applications the galvanized steel is widely used. The galvanization is a process of coating of steel with a layer of zinc, by passing the steel through a molten bath of zinc at a temperature of around 460 °C. For metal parts, as corners and tubes of the floating construction, the stainless steel was decided to use. If the painting will not be enough for corrosion resistance, the galvanization process could be also included into manufacturing process. The detailed information about stainless steel and galvanization process could be found in the Appendix 4.

# 7 SUMMARY

During the project and an analysis of offshore floating wind turbines was provided, the existing design of floating wind turbines was analysed. Based on an evaluation of the classifications of floating wind turbines, the environment, the needs of Nordic Folkecenter for Renewable Energy such as showcase and testing requirements as well as simplicity of manufacturing, a conceptual design of an offshore floating small-scale wind turbine was developed. An overview of the external influences on a floating wind turbine and buoyancy calculations were made for a better understanding of the behaviour of a floating construction and to provide a sustainable conceptual design for future projects, where design optimization, manufacturing and testing will be achieved. The components for the electric system of a wind turbine and the components and methods for corrosion resistance are included into this project report as well. Drawings of the conceptual design of the floating wind turbine construction were created in this project.

In future projects, a structural analysis of the floating construction, an analysis of aerodynamics and hydrodynamics should be provided for the optimization of the design of a floating construction. In the future, the first prototype will be manufactured and tested.

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Appendix 1: Table of Choice of Models and Methods

*Table 5: Table of Choice of Models and Methods*

| What | Why | Which | Which | Who | What |
|---|---|---|---|---|---|
| Partial problem | study this problem-related to the purpose | Level of outcome is expected | Methods/models theories will be used | In the group is the main responsible person for this point | Estimated workload |
| Analyze and evaluate existing design solutions. | To research design concepts of Floating wind turbines constructions | Design concepts description, pros and cons | To research existing design solutions using literature and internet. | Nikita Vinogradov | 7 days |
| Define the main components of floating wind turbine. | To define, which parts will be included in the design. | Parts which are used in every design concept are described | Research using literature and internet, analyze, evaluate and choose. | Nikita Vinogradov | 3 days |
| Choose the connection of turbine to the mainland. | To find the design solution of connection of wind turbine to the mainland. | Different solutions described, evaluated. One of them chosen | Research existing design solutions using internet and literature, evaluate and choose the most suitable. | Nikita Vinogradov | 1 day |
| Provide a solution of storing electrical components on floating wind turbine. | To find the design solution of storing electrical components on floating wind turbine. | Based on criterias, the solution will be developed | Research, find solutions and choose the most suitable for the design. | Nikita Vinogradov | 3 days |
| Choose anchoring system for the floating wind turbine. | To define what kind of anchoring system will be included in the design. | Existing Design concepts will be described, evaluated | Research using literature and internet, analyze, evaluate and choose. | Nikita Vinogradov | 3 days |

| | | | | | |
|---|---|---|---|---|---|
| Choose materials for the floating wind turbine. | To define what kind of materials will be used for components. | | Research using literature and internet, analyze, evaluate and choose. | Nikita Vinogradov | 3 days |
| Choose the most suitable design concept of floating wind turbine. | To evaluate concepts of Floating wind turbines constructions and define a future model design. | | Evaluation of design concepts and ideas. | Nikita Vinogradov | 1 day |
| Find out environmental impacts on the construction. | To understand what kind of forces appearing in the construction for proper design. | | To find out impacts on the construction, to calculate this impact, if possible. | Nikita Vinogradov | 15 days |
| Make a design of floating wind turbine. | The requirement of the project. | | Using CAD software, create a design of floating wind turbine. | Nikita Vinogradov | 15 days |
| Develop the solution, which will be possible to produce in Nordic Folkecenter | The design must be easy to manufacture. | | Define production methods, make models of parts considering to chosen manufacturing method. | Nikita Vinogradov | 15 days |

## Appendix 2: Timetable

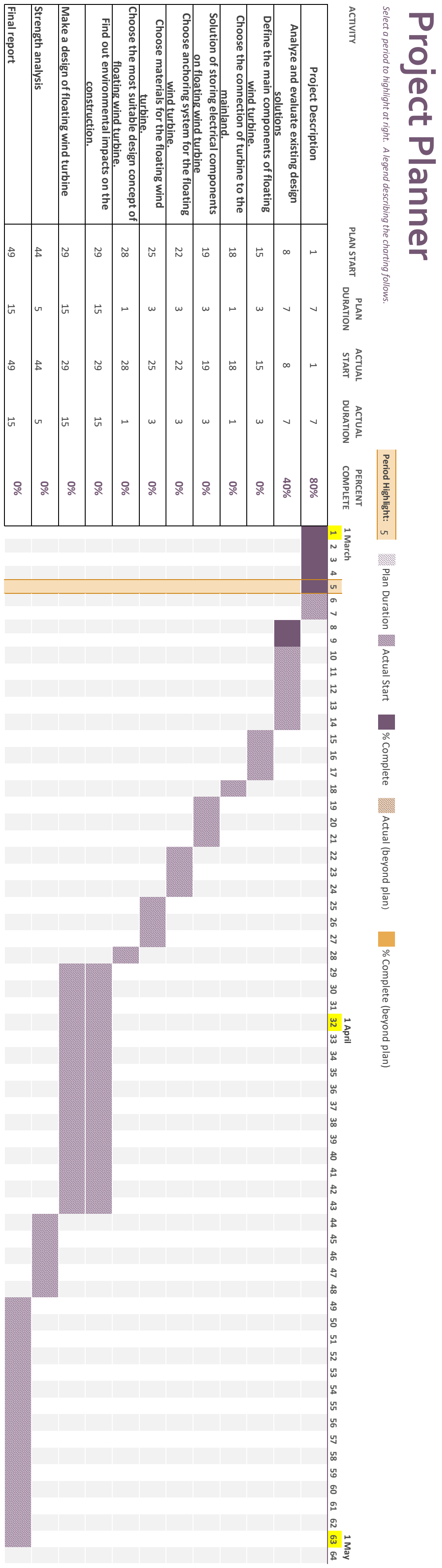



*Figure 29: Gantt chart*

## Appendix 3: Risk Assessment Table

*Table 6: Risk Assessment*

| Risks | Description | Likelihood | Severity | Risk mitigation | Identifiers | Responsible |
|---|---|---|---|---|---|---|
| Risk 1 | Loss of data | Low | High | Perform backups | Lost files | Nikita Vinogradov |
| Risk 2 | Lack of time | Medium | High | Detailed schedule | Not completing the planned tasks | Nikita Vinogradov |
| Risk 3 | Failing in fulfilling the purpose | Medium | High | Regular feedback to the supervisor | Regular feedback from the supervisor | Nikita Vinogradov |
| Risk 4 | Tasks' delay | High | Medium | Work extra hours | Gantt chart & scheduled tasks | Nikita Vinogradov |
| Risk 5 | Lack of knowledge | High | Medium | Fulfill lack of knowledge by studying literature or by practicing | Missed meetings / work undone | Nikita Vinogradov |
| Risk 6 | Health problems | Low | Medium | Set up the additional worktime on weekends | Delay of the task | Nikita Vinogradov |

Appendix 4: CES Edupack Library

# Stainless steel

## Description

**Image**

**Caption**

1. Siemens toaster in brushed austenitic stainless steel (by Porsche Design) © Granta Design 2. Scissors in ferritic stainless steel; it is magnetic, austenitic stainless is not. © Granta Design

**The material**

Stainless steels are alloys of iron with chromium, nickel, and - often - four of five other elements. The alloying transmutes plain carbon steel that rusts and is prone to brittleness below room temperature into a material that does neither. Indeed, most stainless steels resist corrosion in most normal environments, and they remain ductile to the lowest of temperatures.

**Composition (summary)**

Fe/<0.25C/16 - 30Cr/3.5 - 37Ni/<10Mn + Si,P,S (+N for 200 series)

## General properties

| | | | | | |
|---|---|---|---|---|---|
| Density | | 7.6e3 | - | 8.1e3 | kg/m^3 |
| Price | * | 5.68 | - | 5.95 | USD/kg |
| Date first used | | 1915 | | | |

## Mechanical properties

| | | | | | |
|---|---|---|---|---|---|
| Young's modulus | | 189 | - | 210 | GPa |
| Shear modulus | | 74 | - | 84 | GPa |
| Bulk modulus | | 134 | - | 151 | GPa |
| Poisson's ratio | | 0.265 | - | 0.275 | |
| Yield strength (elastic limit) | | 170 | - | 1e3 | MPa |
| Tensile strength | | 480 | - | 2.24e3 | MPa |
| Compressive strength | | 170 | - | 1e3 | MPa |
| Elongation | | 5 | - | 70 | % strain |
| Hardness - Vickers | | 130 | - | 570 | HV |
| Fatigue strength at 10^7 cycles | * | 175 | - | 753 | MPa |
| Fracture toughness | | 62 | - | 150 | MPa.m^0.5 |
| Mechanical loss coefficient (tan delta) | * | 2.9e-4 | - | 0.00148 | |

## Thermal properties

| | | | | | |
|---|---|---|---|---|---|
| Melting point | | 1.37e3 | - | 1.45e3 | °C |
| Maximum service temperature | | 750 | - | 820 | °C |
| Minimum service temperature | | -272 | - | -271 | °C |
| Thermal conductor or insulator? | | Poor conductor | | | |
| Thermal conductivity | | 12 | - | 24 | W/m.°C |
| Specific heat capacity | | 450 | - | 530 | J/kg.°C |
| Thermal expansion coefficient | | 13 | - | 20 | µstrain/°C |

## Electrical properties

| | |
|---|---|
| Electrical conductor or insulator? | Good conductor |
| Electrical resistivity | 64 - 107 µohm.cm |

## Optical properties

| | |
|---|---|
| Transparency | Opaque |

## Critical Materials Risk

| | |
|---|---|
| High critical material risk? | Yes |

## Processability

| | |
|---|---|
| Castability | 3 - 4 |
| Formability | 2 - 3 |
| Machinability | 2 - 3 |
| Weldability | 5 |
| Solder/brazability | 5 |

## Durability: water and aqueous solutions

| | |
|---|---|
| Water (fresh) | Excellent |
| Water (salt) | Excellent |
| Soils, acidic (peat) | Excellent |
| Soils, alkaline (clay) | Excellent |
| Wine | Excellent |

## Durability: acids

| | |
|---|---|
| Acetic acid (10%) | Excellent |
| Acetic acid (glacial) | Excellent |
| Citric acid (10%) | Excellent |
| Hydrochloric acid (10%) | Excellent |
| Hydrochloric acid (36%) | Limited use |
| Hydrofluoric acid (40%) | Limited use |
| Nitric acid (10%) | Excellent |
| Nitric acid (70%) | Limited use |
| Phosphoric acid (10%) | Excellent |
| Phosphoric acid (85%) | Excellent |
| Sulfuric acid (10%) | Acceptable |
| Sulfuric acid (70%) | Limited use |

## Durability: alkalis

| | |
|---|---|
| Sodium hydroxide (10%) | Excellent |
| Sodium hydroxide (60%) | Excellent |

## Durability: fuels, oils and solvents

| | |
|---|---|
| Amyl acetate | Acceptable |
| Benzene | Acceptable |
| Carbon tetrachloride | Excellent |
| Chloroform | Excellent |
| Crude oil | Excellent |
| Diesel oil | Excellent |
| Lubricating oil | Excellent |
| Paraffin oil (kerosene) | Excellent |
| Petrol (gasoline) | Excellent |
| Silicone fluids | Acceptable |
| Toluene | Excellent |
| Turpentine | Acceptable |
| Vegetable oils (general) | Excellent |
| White spirit | Excellent |

## Durability: alcohols, aldehydes, ketones

| | |
|---|---|
| Acetaldehyde | Excellent |
| Acetone | Excellent |
| Ethyl alcohol (ethanol) | Excellent |
| Ethylene glycol | Acceptable |
| Formaldehyde (40%) | Acceptable |
| Glycerol | Excellent |
| Methyl alcohol (methanol) | Excellent |

### Durability: halogens and gases

| | | | | |
|---|---|---|---|---|
| Chlorine gas (dry) | Excellent | | | |
| Fluorine (gas) | Excellent | | | |
| O2 (oxygen gas) | Excellent | | | |
| Sulfur dioxide (gas) | Excellent | | | |

### Durability: built environments

| | | | | |
|---|---|---|---|---|
| Industrial atmosphere | Excellent | | | |
| Rural atmosphere | Excellent | | | |
| Marine atmosphere | Excellent | | | |
| UV radiation (sunlight) | Excellent | | | |

### Durability: flammability

| | | | | |
|---|---|---|---|---|
| Flammability | Non-flammable | | | |

### Durability: thermal environments

| | | | | |
|---|---|---|---|---|
| Tolerance to cryogenic temperatures | Excellent | | | |
| Tolerance up to 150 C (302 F) | Excellent | | | |
| Tolerance up to 250 C (482 F) | Excellent | | | |
| Tolerance up to 450 C (842 F) | Excellent | | | |
| Tolerance up to 850 C (1562 F) | Excellent | | | |
| Tolerance above 850 C (1562 F) | Unacceptable | | | |

### Geo-economic data for principal component

| | | | | |
|---|---|---|---|---|
| Annual world production, principal component | 3.87e9 | | | tonne/yr |
| Reserves, principal component | 8.1e10 | | | tonne |

### Primary material production: energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production | * 93.7 | - | 103 | MJ/kg |
| CO2 footprint, primary production | * 6.9 | - | 7.61 | kg/kg |
| Water usage | * 129 | - | 142 | l/kg |

### Material processing: energy

| | | | | |
|---|---|---|---|---|
| Casting energy | * 10.8 | - | 11.9 | MJ/kg |
| Extrusion, foil rolling energy | * 14.7 | - | 16.3 | MJ/kg |
| Roll forming, forging energy | * 7.5 | - | 8.29 | MJ/kg |
| Wire drawing energy | * 54.4 | - | 60.1 | MJ/kg |
| Metal powder forming energy | * 37 | - | 40.6 | MJ/kg |
| Vaporization energy | * 1.09e4 | - | 1.2e4 | MJ/kg |
| Coarse machining energy (per unit wt removed) | * 1.56 | - | 1.72 | MJ/kg |
| Fine machining energy (per unit wt removed) | * 11.3 | - | 12.5 | MJ/kg |
| Grinding energy (per unit wt removed) | * 22.1 | - | 24.4 | MJ/kg |
| Non-conventional machining energy (per unit wt removed) | * 109 | - | 120 | MJ/kg |

### Material processing: CO2 footprint

| | | | | |
|---|---|---|---|---|
| Casting CO2 | * 0.809 | - | 0.894 | kg/kg |
| Extrusion, foil rolling CO2 | * 1.1 | - | 1.22 | kg/kg |
| Roll forming, forging CO2 | * 0.562 | - | 0.621 | kg/kg |
| Wire drawing CO2 | * 4.08 | - | 4.51 | kg/kg |
| Metal powder forming CO2 | * 2.96 | - | 3.25 | kg/kg |
| Vaporization CO2 | * 815 | - | 900 | kg/kg |
| Coarse machining CO2 (per unit wt removed) | * 0.117 | - | 0.129 | kg/kg |
| Fine machining CO2 (per unit wt removed) | * 0.847 | - | 0.936 | kg/kg |
| Grinding CO2 (per unit wt removed) | * 1.66 | - | 1.83 | kg/kg |
| Non-conventional machining CO2 (per unit wt removed) | * 8.15 | - | 9 | kg/kg |

### Material recycling: energy, CO2 and recycle fraction

| | | | | |
|---|---|---|---|---|
| Recycle | True | | | |
| Embodied energy, recycling | * 18.9 | - | 20.9 | MJ/kg |
| CO2 footprint, recycling | * 1.48 | - | 1.64 | kg/kg |
| Recycle fraction in current supply | 35.5 | - | 39.3 | % |
| Downcycle | True | | | |
| Combust for energy recovery | False | | | |
| Landfill | True | | | |
| Biodegrade | False | | | |
| Toxicity rating | Non-toxic | | | |
| A renewable resource? | False | | | |

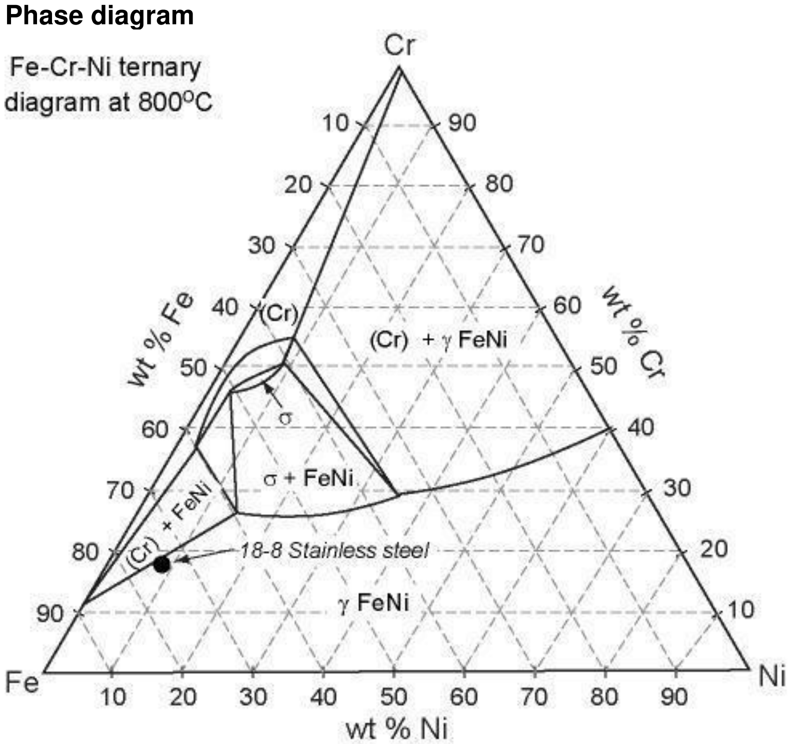
**Environmental notes**
Stainless steels are FDA approved -- indeed, they are so inert that they can be implanted in the body and are widely used in food processing equipment. All can be recycled.

## Supporting information

**Design guidelines**
Stainless steel must be used efficiently to justify its higher costs, exploiting its high strength and corrosion resistance. Economic design uses thin, rolled gauge, simple sections, concealed welds to eliminate refinishing, and grades that are suitable to manufacturing (such as free machining grades when machining is necessary). Surface finish can be controlled by rolling, polishing or blasting. Stainless steels are selected, first, for their corrosion resistance, second, for their strength and third, for their ease of fabrication. Most stainless steels are difficult to bend, draw and cut, requiring slow cutting speeds and special tool geometry. They are available in sheet, strip, plate, bar, wire, tubing and pipe, and can be readily soldered and braised. Welding stainless steel is possible but the filler metal must be selected to ensure an equivalent composition to maintain corrosion resistance. The 300 series are the most weldable; the 400 series are less weldable.

**Technical notes**
Stainless steels are classified into four categories: the 200and 300 series austenitic (Fe-Cr-Ni-Mn) alloys, the 400 series ferritic (Fe-Cr) alloys, the martensitic (Fe-Cr-C) alloys that also form part of the 400 series, and precipitation hardening or PH (Fe-Cr-Ni-Cu-Nb) alloys with designations starting with S. Typical of the austenitic grades of stainless steel is the grade 304: 74% iron, 18% chromium and 8 % nickel. Here the chromium protects by creating a protective Cr2O3 film on all exposed surfaces, and the nickel stabilizes face-centered cubic austenite, giving ductility and strength both at high and low temperatures; they are non-magnetic (a way of identifying them). The combination of austenitic and ferritic structures (the duplex stainless steels) provide considerably slower growth of stress-induced cracks, they can be hot-rolled or cast and are often heat treated as well. Austenitic stainless steel with high molybdenum content and copper has excellent resistance to pitting and corrosion. High nitrogen content austenitic stainless steel gives higher strength. Superferrites (over 30% chromium) are very resistant to corrosion, even in water containing chlorine. More information on designations and equivalent grades can be found on the Granta Design website at www.grantadesign.com/designations

**Phase diagram**




**Phase diagram description**
Most stainless steels are alloys of iron (Fe) with chromium (Cr) and nickel (Ni). This is the ternary phase diagram, at a temperature of 800 C, for those three elements. The position of AISI 302 stainless steel (Fe-18%Cr-8%Ni) is shown.

**Typical uses**

Railway cars, trucks, trailers, food-processing equipment, sinks, stoves, cooking utensils, cutlery, flatware, scissors and knives, architectural metalwork, laundry equipment, chemical-processing equipment, jet-engine parts, surgical tools, furnace and boiler components, oil-burner parts, petroleum-processing equipment, dairy equipment, heat-treating equipment, automotive trim. Structural uses in corrosive environments, e.g. nuclear plants, ships, offshore oil installations, underwater cables and pipes.

## Links

ProcessUniverse
Producers
Reference
Values marked * are estimates.
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# Hot dip coating (Galvanizing)

## Description

### Image

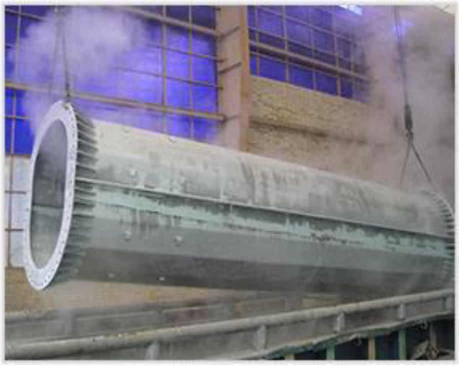



**Image caption**

(1) Galvanizing © Cheugui at Wikimedia Commons (CC BY 3.0) (2) Hot dip galvanizing © Galataxi at Wikimedia Commons (CC BY 4.0) (3) Hot-dip galvanizing on a relatively new steel handrail © By TMg (Own work) [Public domain], via Wikimedia Commons

**The process**

Hot dipping is a process for coating a metal, mainly ferrous metals, with low melting point metals usually zinc and its alloys. The component is first degreased in a caustic bath, then pickled (to remove rust and scale) in a sulfuric acid bath, immersed (dipped) in the liquid metal and, after lifting out, it is cooled in a cold air stream. The molten metal alloys with the surface of the component, forming a continuous thin coating. When the coating is zinc and the component is steel, the process is known as galvanizing. The process is very versatile and can be applied to components of any shape, and sizes up to 30 m x 2 m x 4 m. The cost is comparable with that of painting, but the protection offered by galvanizing is much greater, because if the coating is scratched it is the zinc not the underlying steel that corrodes ("galvanic protection"). Properly galvanized steel will survive outdoors for 30-40 years without further treatment.

**Process schematic**

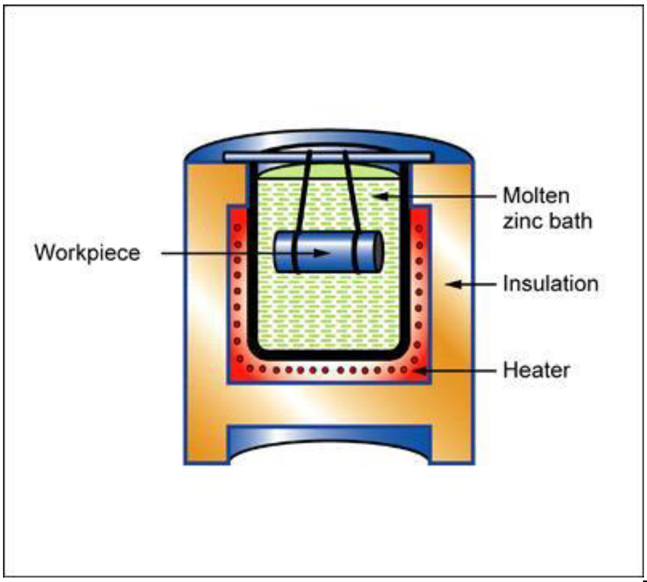



**Figure caption**

Galvanizing

**Tradenames**

Galvanizing

## Material compatibility

| | |
|---|---|
| Metals - ferrous | True |

## Function of treatment

| | |
|---|---|
| Corrosion protection (aqueous) | True |
| Corrosion protection (gases) | True |
| Wear resistance | True |
| Thermal conduction | True |

## Economic compatibility

| | |
|---|---|
| Relative tooling cost | low |
| Relative equipment cost | medium |
| Labor intensity | low |

## Physical and quality attributes

| | | | | |
|---|---|---|---|---|
| Surface roughness (A=v. smooth) | B | | | |
| Curved surface coverage | Very good | | | |
| Coating thickness | 85 | - | 170 | μm |
| Surface hardness | 10 | - | 12 | HV |
| Processing temperature | 325 | - | 500 | °C |

## Process characteristics

| | |
|---|---|
| Discrete | True |

## Supporting information

**Design guidelines**

When properly selected, hot-dip metallic coatings provide excellent long-term corrosion protection. Because of the high temperature of the process, there can be some distortion of the workpiece. Galvanizing is preferred over painting because a metallurgical bond between the coating and underlying steel or iron. It can protect steel from corrosion for 30 years or more. Galvanizing is not always satisfactory for machined, threaded or mating parts because of the thick and uneven coating which has to be removed from the threads by retapping. The galvanizing process is limited by the batch size: specialized work can handle parts up to 30 m long and fabrications 18*2*5 m. Thickness control is poor, and the coating is less uniform than with electroplating.

**Technical notes**

The hot-dipping process is rapid (fraction of a minute for small objects to several minutes for structural parts). Postcoating treatment varies according to the needs of the coated component.

Hot dipping is principally applied to ferrous metals, commonly cast iron or steel. In specialized situations, materials such as high-strength low-alloy steel may be used.

Coatings are low melting point metals: aluminum, zinc, tin, lead, terne (lead alloy with 10 to 20 % tin). Zinc, aluminum and terne perform well in providing corrosion protection under atmospheric conditions, in soils and aqueous media. Lead and tin do not provide galvanic protection but may be resistant to soils that are highly aggressive to zinc coatings. Lead has good resistance to sulfuric and hydrochloric acids, brines, etc. However, owing to its tendency to coat unevenly and to pit, it is not used extensively as a coating for steel in the atmosphere or in most soils. Alloying lead with tin, antimony, cadmium, mercury, and arsenic produces coatings that have been used with success.

**Typical uses**

Aluminized steel or cast iron: refinery process piping and equipment, appliance parts, furnace heater tubes, brazing fixtures.

Galvanized steel: roofing and siding, nails, wire, tanks (water storage), boilers, pails, hardware for indoor and outdoor use, structurals, guard rails, lighting standards, pipes and fittings, fencing.

Lead on steel or copper; wire, pole-line hardware, bolts, washers, tanks, barrels, cans, air ducts. Tin is a good base for paint.

Tin on steel, cast iron or copper: milk cans, food grinders, cooking pans, kitchen utensils and electronic parts.

Terne on steel or copper: roofing, lining cabinets used in chemical laboratories, gasoline tanks, oil filters.

**The economics**

Galvanizing is inexpensive, despite being energy intensive. Hot-dipped coatings can be applied on either a short-run or a mass-production basis. Galvanizing is particularly cost effective compared to other coating methods because it lasts longer and requires less maintenance: a hot dip galvanized coating has outstanding resistance to mechanical damage in transport, erection and service.

**The environment**

With tin, certain hazardous chemicals are used. The rate of immersion should be slow enough to prevent dangerous spluttering or explosions caused by trapped water or moisture being added to the molten tin.

Fumes are produced at nearly every stage of the tinning and galvanizing processes, requiring an efficient ventilating system.

## Links

MaterialUniverse

Reference

No warranty is given for the accuracy of this data

## Appendix 5: Buoyancy Calculations

$V_1 := 1657137.619231826\text{mm}^3$ $V_2 := 0.0097\text{m}^3$ $V_1$ - volume of the tower; $V_2$ - volume of the turbine

$$V_1 + V_2 = 0.011\,\text{m}^3$$

$$V_s := 0.011\text{m}^3$$

$$D := 1029\,\frac{\text{kg}}{\text{m}^3}$$

$$F_b := V_s \cdot D \cdot g$$

$$F_b = 111.001\,\text{N}$$

$F_b$ is buoyancy force
$V_s$ is submerged volume of the object
D is density of fluid
g is gravity

$(5.85\text{kg} + 13\text{kg}) \cdot g = 184.855\,\text{N}$ weight of turbine and tower

$$M := 184.855\text{N}$$

$$x := \frac{M}{D \cdot g} - V_s$$

$$x = 7.319 \times 10^{-3}\,\text{m}^3$$

x -the volume of air which should be added to the construction for equalling buoyancy force with weight of object

Final buoyancy calculations

volume of buoyant tanks (200 litre barrels)

$$V_s := 600\text{L}$$

$$D := 1029\,\frac{\text{kg}}{\text{m}^3}$$

$$F_b := V_s \cdot D \cdot g$$

### Mass properties of floating construction

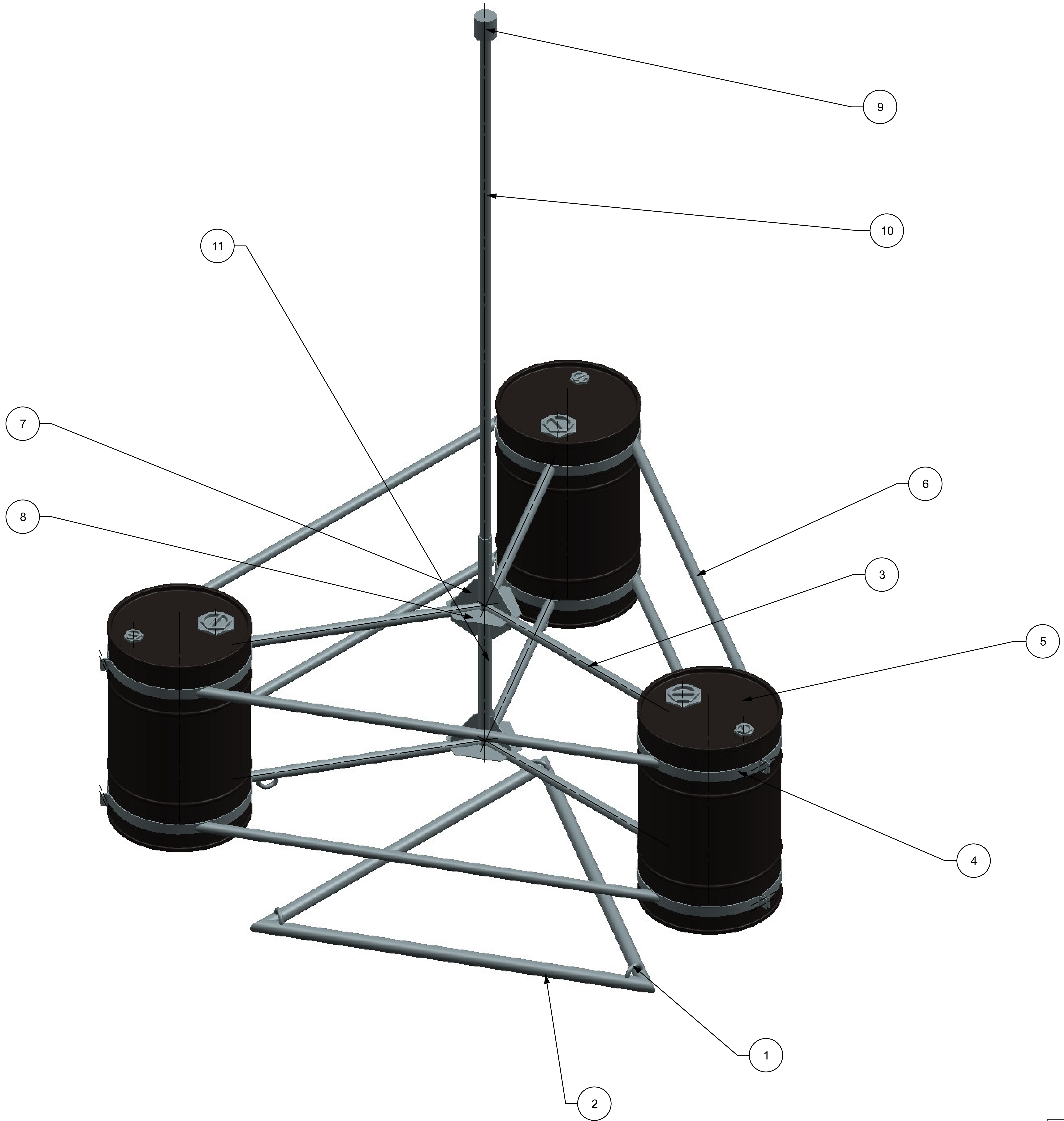
```
Measurement Mass Properties

Displayed Mass Property Values
Volume                          = 33585109.877057806 mm³
Area                            = 24490946.739658531 mm²
Mass                            =  262.974630055 kg
Weight                          = 2578.900155828 N
Radius of Gyration              = 1354.543536286 mm
Center of Mass                  =   -0.267581478,    1.125782937,  435.143129110 mm
```

$$F_b = 6.055 \times 10^3\,\text{N}$$

The weight of the assembly is 2578.9 Newtons

Appendix 6: 2D Drawings




| | | |
|---|---|---|
| I | FLOATING CONSTRUCTION VAR 2 | 1 |
| 11 | CENTRAL PART | 1 |
| 10 | TOWER | 1 |
| 9 | TURBINE | 1 |
| 8 | CORNER | 6 |
| 7 | CORNER 2 | 9 |
| 6 | HORIZONTAL TUBE 2 | 6 |
| 5 | 55 GALLON STEEL DRUM_STP | 3 |
| I | 4464K593_TYPE 304 STAINLESS STL THREADED PIPE FITTING V1 | 3 |
| I | 4464K589_TYPE 304 STAINLESS STL THREADED PIPE FITTING V1 | 3 |
| I | 4464K259_TYPE 304 STAINLESS STL THREADED PIPE FITTING V2 | 3 |
| I | 4464K246_TYPE 304 STAINLESS STL THREADED PIPE FITTING V2 | 3 |
| 4 | BARRELRING | 6 |
| 3 | HORIZONTAL TUBE | 6 |
| I | ANCHOR 1 | 1 |
| 2 | ANCHOR TUBE | 3 |
| 1 | ANCHOR HOLDER | 6 |
| PC NO | PART NAME | QTY |

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| | | | | |
|---|---|---|---|---|
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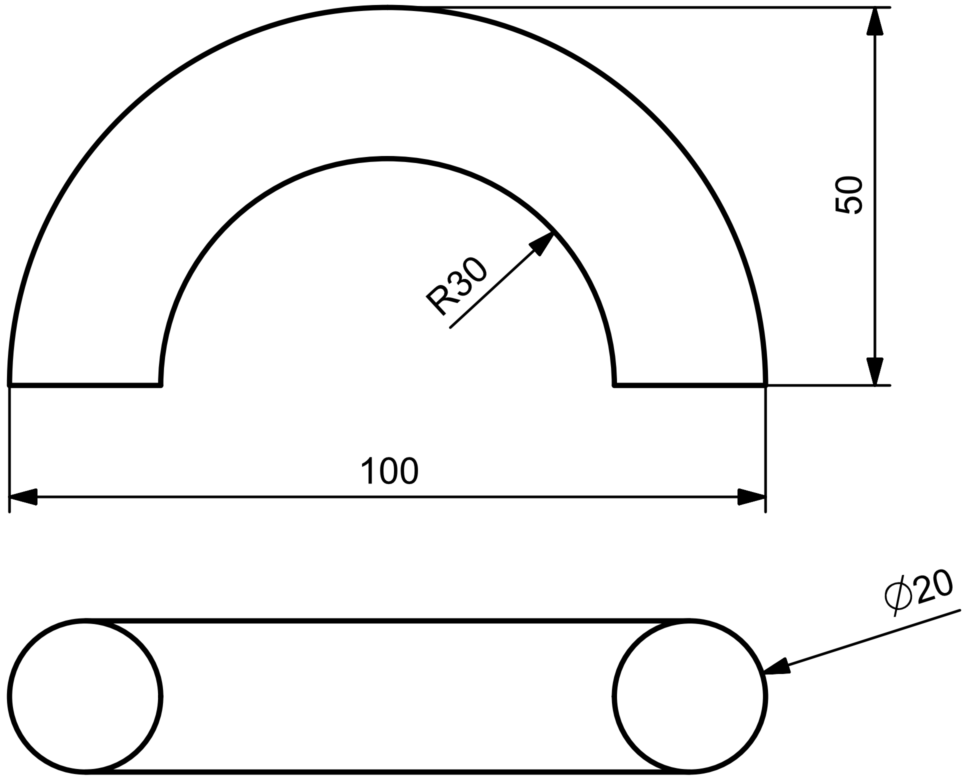
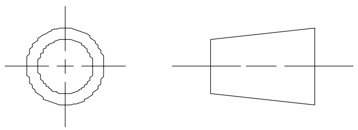
| CHECKED BY | Esa Murtola | | | |
| APPROVED BY | Esa Murtola | SIZE A1 | DRG NO. floating construction full assembly_dwg1 | SHEET REV A |
| | | SCALE 1:10 | | SHEET 1 OF 1 |




| | |
|---|---|
| Material | Stainless Steel |
| Tolerances | ±0.5 |

ALL DIMENSIONS IN MM



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| APPROVED BY | Esa Murtola 24.05.2019 |

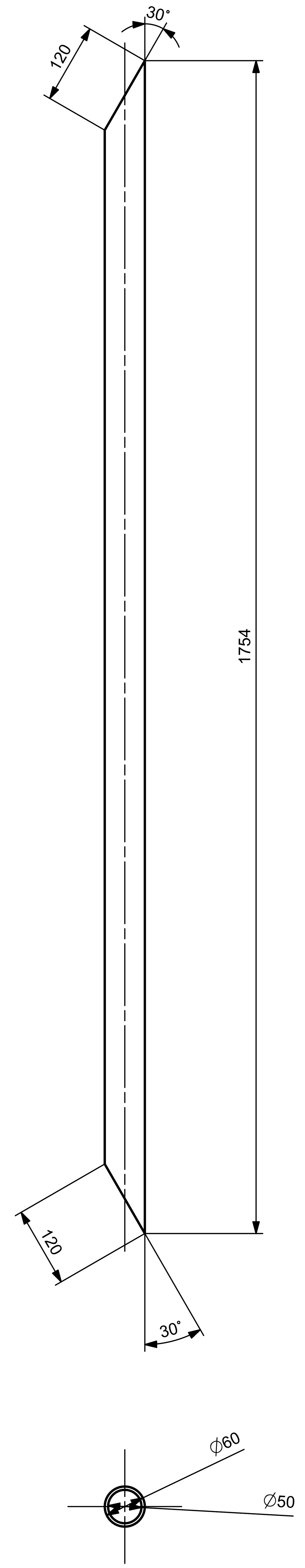
TITLE

Anchor holder ring

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A4 | anchor holder_dwg1 | C |

SCALE 1:1 | SHEET 1 OF 1

A4




| | |
|---|---|
| Material | Stainless Steel |
| Tolerances | ±0.5 |

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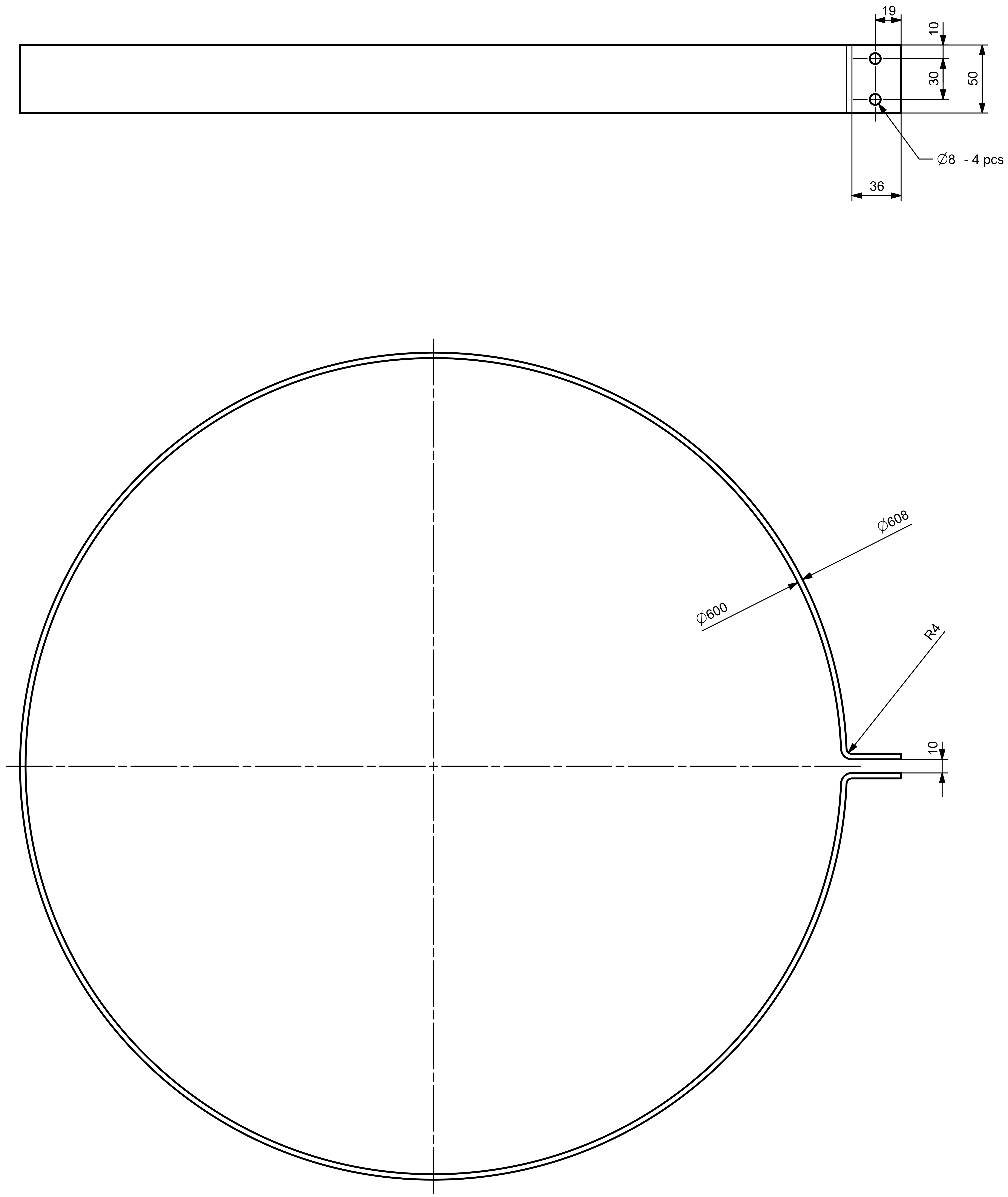
| APPROVED BY | Esa Murtola 23.05.2019 |

TITLE: Anchor tube

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A1 | anchor_tube_dwg1 | A |

SCALE 1:5 — SHEET 1 OF 1




| | |
|---|---|
| Material | Stainless Steel |
| Tolerances | ±0.5 |

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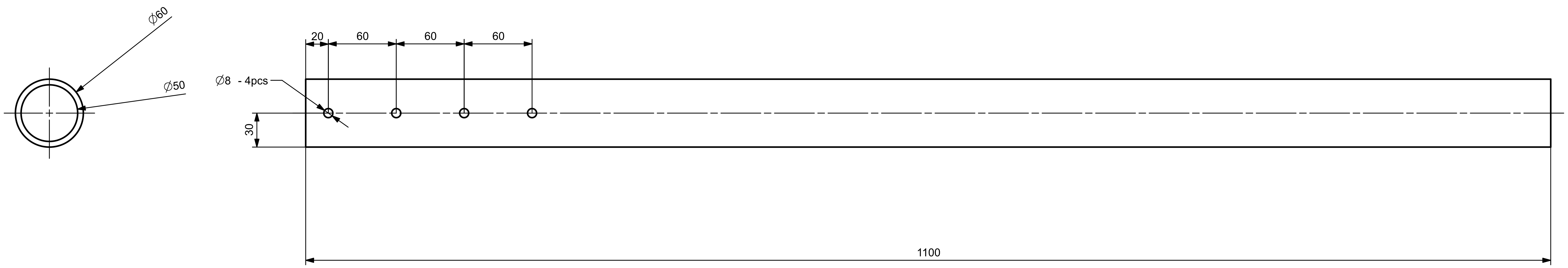
TITLE: Barrel ring

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A1 | barrelring_dwg1 | A |

SCALE 1:2 — SHEET 1 OF 1




| Material | Stainless Steel |
|---|---|
| Tolerances | ±0.5 |

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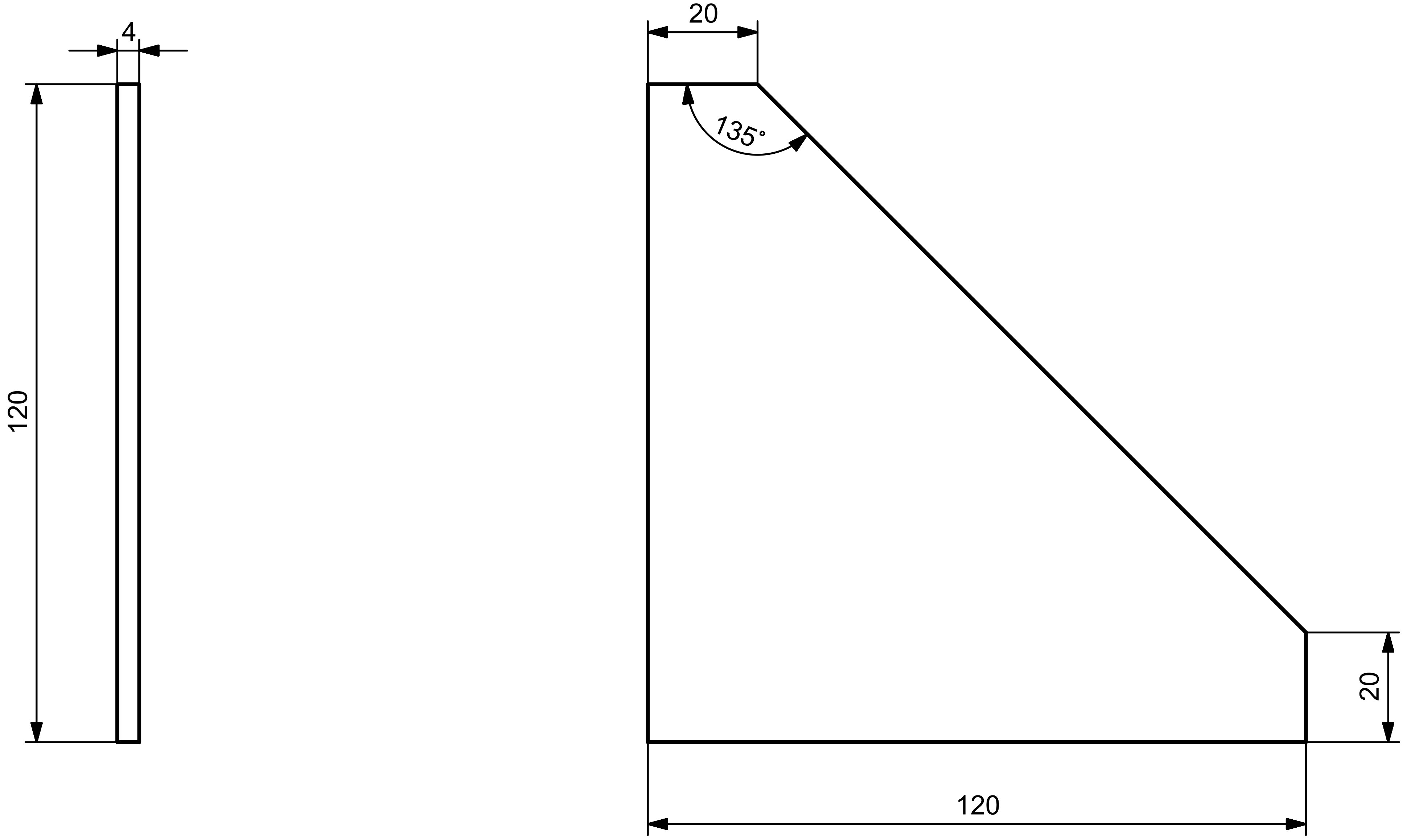
TITLE

Central support tube

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A1 | central part_dwg1 | A |
| SCALE 1:2 | | SHEET 1 OF 1 |




| | |
|---|---|
| Material | Stainless steel |
| Tolerances | ±0.5 |

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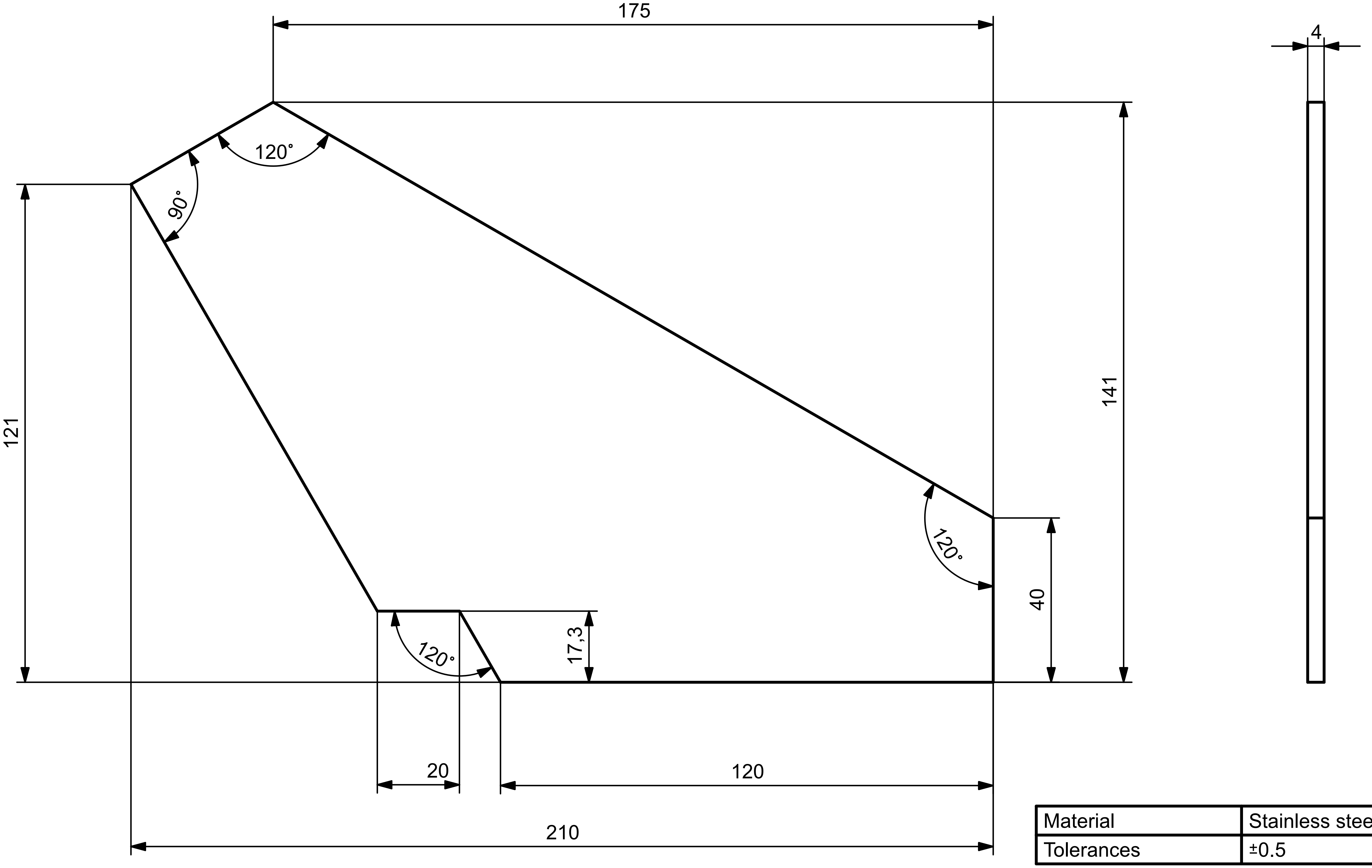
TITLE

Corner type 2

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A3 | corner 2_dwg1 | A |
| SCALE 1:1 | | SHEET 1 OF 1 |




| | |
|---|---|
| Material | Stainless steel |
| Tolerances | ±0.5 |

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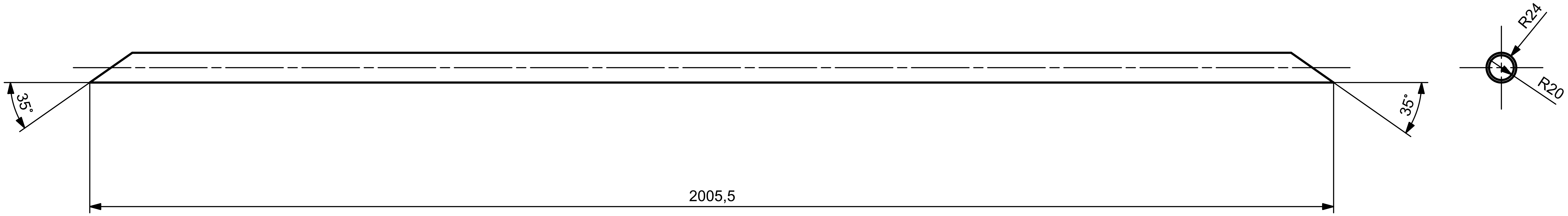
TITLE

Corner type 1

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A3 | corner_dwg1 | A |
| SCALE 1:1 | | SHEET 1 OF 1 |

A3




| | |
|---|---|
| Material | Stainless steel |
| Tolerances | ±0.5 |

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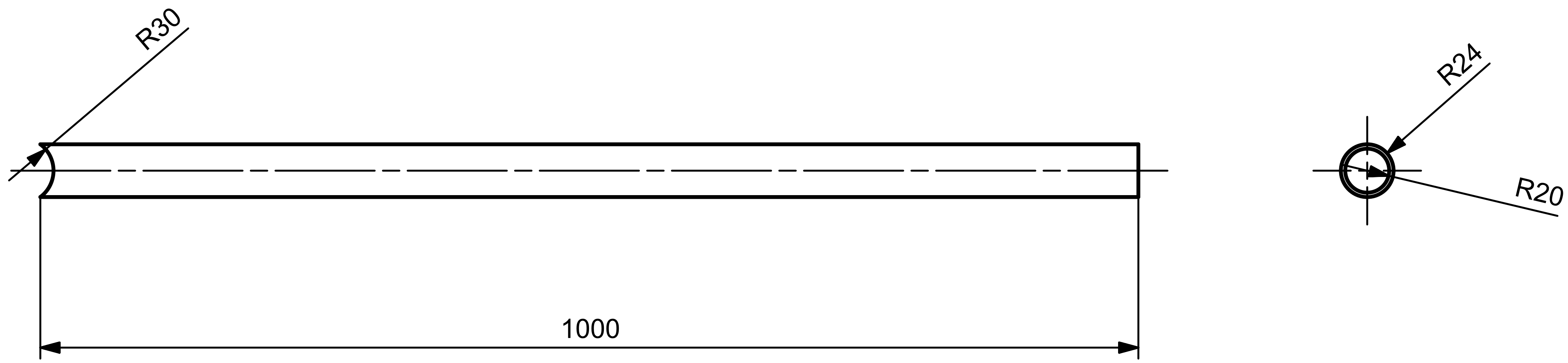
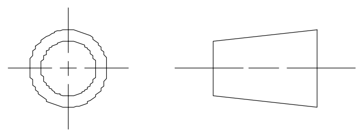
TITLE
Horizontal tube type 2

| SIZE | DRG NO. | SHEET REV |
|---|---|---|
| A2 | horizontal_tube_2_dwg1 | A |

SCALE 1:5
SHEET 1 OF 1




| Material | Stainless steel |
| --- | --- |
| Tolerances | ±0.5 |



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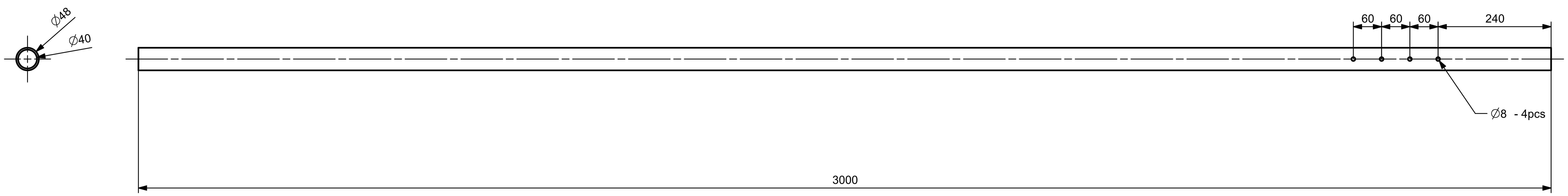
TITLE

Horizontal tube

| SIZE | DRG NO. | SHEET REV |
| --- | --- | --- |
| A3 | horizontal_tube_dwg1 | A |

SCALE 1:5

SHEET 1 OF 1




| | |
|---|---|
| Material | Stainless steel |
| Tolerances | ±0.5 |

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| | | |
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| APPROVED BY | Esa Murtola 24.05.2019 | SIZE: A1 / DRG NO.: tower_dwg1 / SHEET REV: A |
| | | SCALE 1:5 / SHEET 1 OF 1 |

A1