Eastern Mediterranean University

Department of Mechanical Engineering

Capstone Team Project

MENG/MECT 411

Name of Project: *OCEAN WAVES ENERGY TANK*

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ABSTRACT

This project primarily focuses on designing and developing a Water Tank specifically designed for generating Ocean Waves for testing various types of Wave Energy Convertor (WEC) Prototypes. The main objective is to create a cost-effective, scalable, and environmentally friendly testing facility that can simulate different wave conditions accurately. The Water Tank aims to provide a reliable, durable, and safe environment for conducting experiments and evaluating the performance of wave energy converters (WECs). Key considerations include ease of assembly and maintenance, safety, economic feasibility, sustainability, scalability, and overall power performance. By creating a robust testing facility, this project aims to contribute to the advancement of wave energy technology and promote long-term economic viability in harnessing the power of ocean waves.

ACKNOWLEDGEMENT

We wish to express our deep gratitude to several individuals and organizations who played pivotal roles in the successful completion of our graduation project. Their unwavering support, dedication, and expertise were invaluable throughout this journey.

First and foremost, we extend our heartfelt appreciation to Mr. Zafer Mulla. His guidance and unwavering assistance in shaft manufacturing and placement, as well as wave flapper manufacturing, were indispensable. Mr. Mulla's expertise and commitment greatly contributed to the project's success.

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Furthermore, we must acknowledge the Sudanese Society for their generous financial support. Their contribution played a vital role in making this project a reality, and we are truly thankful for their belief in our vision.

Lastly, we want to express our heartfelt gratitude to our entire team. Their hard work, dedication, and collaborative spirit were instrumental in bringing this project to fruition. Each team member's unique skills and tireless efforts were essential components of our success.

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Sincerely,

EMU Oceanic Energy Squad

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LIST OF SYMBOLS AND ABBREVIATION

WEC	Wave Energy Converter
UNDP	United Nations Sustainable Development Goals
CF	Capacity factor
OWC	Oscillating Water Column
PTO	Power Take Off
CAD	Computer Aided Design
LPMG	Linear Permanent Magnet Generator
Fr	Froude number
Re	Reynolds number
Mn	Mech number
Wn	Weber number
Pm	model power
Hmo or Hs	the significant wave height
Tp	The peak wave period
Ts	The scaled peak wave period
H	Wave height
D	water depth

T	Wave Period,
λ	Wavelength
c	Wave celerity
M_w	Mass of Water
ω	Angular Frequency
k	Wave Number
$\mathrm{F.O.}S$	Factor Of Safety
p_{iW}	impulsive hydrodynamic pressure
$\mathrm{D_{buoy}}$	Diameter Of the buoy
ε	Electric Field
LCOE	levelized cost of energy
PI	Performance Index
WT	Wave Tank
FMEA	Failure Modes and Efect Analysis
CFD	Computational Fluid Dynamics
VoF	Volume of Fluid
RANS	Reynolds-Averaged Navier Stokes

CHAPTER 1 - INTRODUCTION

1.1. Detailed definition of the project

To comprehensively explore the performance of ocean waves, a state-of-the-art testing tank will be constructed. This testing facility will enable controlled experimentation with various wave frequencies and amplitudes, mirroring real-world ocean conditions. The tank's design, with precise dimensions and materials, will ensure the accurate simulation of diverse wave types. Equipped with a sophisticated wave generation system, the tank will be capable of replicating different wave patterns, from regular to irregular. Advanced measurement instruments, including sensors for wave height, frequency, and amplitude, will enable detailed data collection. Environmental factors like water temperature and salinity may also be monitored to enhance the accuracy of testing.

Ocean waves are among the most promising sources of renewable energy. A force of generation creates waves. Moving on or near the ocean's surface. The most prominent generating forces are the lunar and solar gravitational fields' surface, winds, seismic disturbances, and waves. Point absorber wave energy converters are the subject of this project. Point absorbers are wave energy converters (WECs) with dimensions much smaller than the wavelength. They oscillate with the ocean waves in one or more degrees of freedom. Point absorbers are a basic technology consisting of a buoy or floating body used to collect the heaving action of the waves and a power take-off. Wave direction is irrelevant for point absorbers since they operate at a single location and may catch waves from any direction. Power take-off systems, also known as linear generators, transform the mechanical energy captured from a rotating point absorber into electrical power by direct linkage.[1]

The proposed project entails the establishment of an ocean wave testing tank featuring an automated wave maker and a point absorber for energy generation, presenting a transformative initiative with far-reaching significance. At its core, the project addresses the pressing need for sustainable energy solutions by providing a controlled environment to assess and enhance wave energy conversion technologies. The automated wave maker within the tank ensures precise replication of various wave conditions, enabling thorough analysis of point absorber performance across a spectrum of scenarios.

The project's focus on point absorber technology bears strategic importance due to its compact size, adaptability to different wave directions, and potential for energy harnessing from even small wave motions. Through systematic testing within the tank, researchers can collect vital data on point absorber behaviour, stability, and power generation potential. This knowledge drives scientific advancement and accelerates commercial viability, bridging the gap between theoretical innovation and real-world application.

1.2. Detailed project objectives

Design for Cost: The design of the Wave Tank incorporates cost-saving measures by utilizing existing components and parts from easily accessible systems. By incorporating components such as Permanent Magnets, Stator, and a mover from pre-existing systems, the need for custom manufacturing or expensive specialized parts is reduced. This approach helps in lowering the overall cost of the project.

Design for Assembly: The Wave Tank design emphasizes simplicity and ease of assembly. By utilizing materials that do not require mechanical force or power tools, the assembly process becomes more straightforward and less time-consuming. The use of preassembled elements further simplifies the construction process, allowing for quicker and more efficient assembly.

Design for Maintenance: The Wave Tank is designed to be easily accessible for maintenance purposes. Critical components can be examined and repaired, if needed, without major disassembly or requiring the WEC to be brought back to dry land. This design approach ensures that maintenance can be performed conveniently, potentially even in situ (out at sea), reducing downtime and maximizing operational efficiency.

Design for Manufacturability: The Wave Tank design prioritizes the selection of readily available and easy-to-manufacture materials. By using commonly available materials, the manufacturing process becomes more streamlined and cost-effective. Additionally, certain components, such as the linear generator, can be outsourced to specialized manufacturers, further enhancing the overall manufacturability of the WEC.

Design for Safety: The Wave Tank design focuses on the safety of marine life and the maritime environment. Non-hazardous materials are chosen to ensure that the point absorber device poses minimal risks to marine ecosystems. Furthermore, the design incorporates a dependable mooring system and a passive safety mechanism. The mooring system ensures the stability of the WEC during extreme marine conditions, while the passive safety mechanism automatically engages to minimize the device's exposure to harsh weather conditions, without the need for external factors such as power.

By incorporating these design considerations, the Wave Tank project aims to create a cost-effective, easy-to-assemble, scalable, and environmentally friendly testing facility that meets the objectives of cost reduction, ease of assembly and maintenance, safety, manufacturability, and overall power performance.

1.3. Detailed project constraints

Several obstacles and constraints were encountered during the design of the ocean wave tank and energy converter.

• Economic: In every engineering project, the design team must make every effort to spend the money effectively and produce a project that is economically feasible.

• Sustainability: Durability and dependability are essential characteristics of the finished product. Having a well-defined lifespan under common or standard operating circumstances is synonymous with sustainability.

• Manufacturability: Manufacturing operations are straightforward and cost and waste effective.

• Safety: Does not pose any harm to the user, whether from the electrical components or the products outside dimensions.

• Ethical: Design that considers the public, such as worker/consumer safety

Some restrictions:

• Scalability: The wave energy tank should have the potential for scalability. It should be designed in a way that allows for easy expansion or modification to accommodate larger or different types of wave energy converter systems. Additionally, For the WEC to be a long-term, economically viable solution, the device must be scalable, which means it must be able to increase in size in the same manner as offshore wind turbines.

• Environmentally friendly: The wave energy tank should not have adverse effects on the surrounding marine environment. Measures should be taken to minimize disturbance to marine life, habitats, and ecosystems. The tank design should prevent leakage of harmful substances or chemicals into the water. Moreover, WECs are anticipated to have a substantial influence on the environment due to their usage of renewable energy. Nevertheless, this criterion also stipulates that WECs must be built using materials that do not pose a threat to marine life or the marine environment in general.

• Overall, Power Performance: The WEC must efficiently transform wave energy to useable power. In addition, the produced energy must be sufficiently smooth for use in the electrical system. Moreover, the WEC must have a high-capacity factor (the ratio between the unit's actual generation output and its maximum generation output maximum yield).

• Maintainability: The WEC should be readily accessible and permit examination of the most vital components if repairs are required. In addition, it would be preferable if maintenance could be performed in situ (out at sea) rather than bringing the WEC back to dry ground.

1.4. UNDP Sustainability Goals

Figure 1 Sustainability goals [2]

Affordable and clean energy: Wave energy is a clean, renewable energy source that can assist coastal communities have better access to electricity and lower their greenhouse gas emissions.

Industry, innovation, and infrastructure: The development of wave energy technology and infrastructure may help to the expansion of the economy and the creation of new products and services.

Climate action: Wave power has the potential to lessen our dependency on fossil fuels and help minimize the negative effects of climate change by lowering our overall carbon footprint.

Life below water: The development of wave energy must be done in a sustainable manner to reduce the likelihood of having a detrimental effect on marine ecosystems and to encourage the preservation of marine biodiversity.

Figure 1 above shows the selected sustainability goals in this project.

1.5. Report Organization

The report is divided into five chapters, and the contents of each chapter are as follows:

• The first chapter introduces the project and discusses the key design elements, such as the importance, aims, and limitations of the ocean wave barrier;

• The second chapter includes a brief history of ocean wave energy converters as well as substantial background information on point absorbers. In addition, it gives a complete literature review of preceding systems influenced by point absorbers. This paper contains a description of each of the concurrent designs, which are compared in the next chapter in terms of their features and operations.

• In the third chapter of the report, the selected plan for the project is explored in detail.this chapter outlines the technique for selecting each component, including more precisely the physical, electrical, and adhesive ones.

• In the fourth chapter, the manufacturing process for the point absorber ocean wave energy converter is examined in more depth. In addition, it implies that the chapter examines several manufacturing processes, including the assembly of electrical components and the methods used to build the various physical components.

• The fifth chapter describes the agreed-upon testing methodologies for the design, which are meant to ensure that the project's functionality is launch-ready. In addition, it describes the design objectives and technical requirements that must be met for the design to be effective.

• Chapter 6 reviews the results of simulations of this project. Finally, in Chapter 7, suggestions are made for future works and improvements on the performance and functionality of the Ocean Wave Tank.

CHAPTER 2 - LITERATURE REVIEW

2.1. Background information

Ocean wave energy converter testing tanks are specialized facilities designed for rigorous evaluation and optimization of wave energy converters (WECs). These controlled environments simulate real-world wave conditions, allowing researchers to assess how WEC prototypes perform under various wave patterns and amplitudes. Constructed with robust materials like reinforced concrete, these tanks withstand the forces generated by large waves. They employ advanced wave-generating mechanisms, replicating both regular and irregular waves to mimic the challenges faced by WECs in the actual ocean environment.

Comprehensive sensor arrays capture detailed data on wave parameters such as height, period, and velocity, providing crucial insights for design and operational decisions. Researchers often use scale models of WECs, applying scaling laws to project results to full-scale applications. Environmental considerations are paramount, with researchers studying potential impacts on marine ecosystems and striving for environmentally responsible technology.[3]

Cost-effectiveness is a key factor, with engineers optimizing power system components and considering engineering design and constraints. These testing tanks also serve as collaborative hubs, bringing together researchers, engineers, and industry stakeholders to advance wave energy technology. In historical context, WECs have a long history, with early attempts dating back to the 1800s. The modern resurgence of interest was catalysed by Professor Stephen Salter's influential 1974 essay during the 1970s energy crisis, though progress slowed in the 1980s and early 1990s.[4]

In conclusion, ocean wave energy converter testing tanks are pivotal in the research and development of wave energy technology. They provide a controlled setting for optimizing

WECs, contributing to the advancement of renewable energy and its potential role in the global energy landscape.[1]

2.2. Wave Heights in Mediterranean Sea:

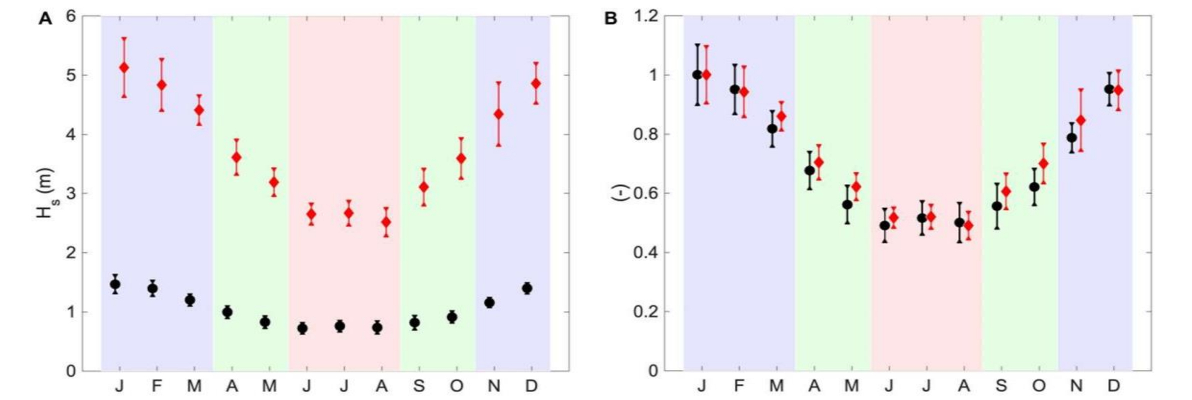


FIGURE 2 | Yearly-averaged monthly 50th (black dots) and 99th (red diamonds) percentiles of H_s over the MS, from eight satellite altimeters (see **Supplementary Table 1**), dimensional [panel **(A)**] and normalized with the maximum value [panel **(B)**]. Dots and diamonds represent the ensemble average over the altimeter percentiles and bars represent the confidence intervals over the altimeter percentiles (± an ensemble standard deviation). Violet shading indicates winter months (NDJFM), red shading summer months (JJA) and green shading spring and autumn (transitional seasons; AM and SO).

Figure 2 the period from November to March of the stormy weather[5]

Figure 2 shows that the large wave heights are further corroborated by the Mediterranean wind wave hind cast performance from 1991 to 2019. summarizes the results of satellite altimeter observations. The 50th and 99th percentiles of significant wave height are currently used in the climatology of wind-wave states in the specific sea, which may indicate the typical wave condition at 50th and extreme sea condition at 99th. The seasonal estimation is done by the colour bar in the chart to indicate the inner annual sea states. The blue represents winter, the green represents spring and autumn, and the red represents summer.

2.3. Mediterranean Sea Amplitude and Frequency:

The University of Naples "Parthenope" simulation used a toroidal shape buoy with a diameter of 5m as the point absorber buoy. This simulation used the Mediterranean Sea's sea state, as shown in where the hydrodynamic properties indicate the amplitude of excitation forces acting on the frequency domain for all possible harmonic waves ranging from 200KN/m to -50KN/m for wave frequencies ranging from 0 to 5 rad/s.

2.4. Generation Capacity

Because WECs were primarily designed and developed for oceans, they may not be economically viable for low-energy seas. The load or capacity factor, which is the ratio of the produced electricity at site to the WEC's rated power (nameplate capacity), is a good indicator for assessing the economic viability of a WEC. Electricity generation on-site is typically estimated by superimposing the bivariate distribution of Hs and Te on the WEC's power matrix. but this is not the case for the low energy seas studied [6].

Table 1 shows the generation capacity of Aqua buoy (point absorber) in different locations [6]

Table 1: generation capacity[6]

WEC type	**Capacity factor (CF) (%)**	**Location**
10 kW point absorber	~30 (utility factor)	Baltic Sea
Aqua Buoy	3.65–8.39	Italy
	3.7–8.7	Italy
	1.33–8.44	Italy
	~2–2.5*	Italy
	~5	Lebanon
	8.2–9.1	Spain
	6–9	Greece
	0.44–2.48	Mediterranean/Black Sea
	8.4–9.5 (winter)	Black Sea
	31-33 (downscaled)	Mediterranean
	6.8 and 26.2 (downscaled)	Turkey

The point absorber's output power is directly proportional to its capacity factor. This means that the greater the capacity factor, the greater the amount of energy the device can generate over time. If the capacity factor is low, the device's output power will be reduced.

2.5 Concurrent solutions:

There are several different approaches to ocean waves energy tanks, each with its own set of advantages and disadvantages. Here are the main solutions for the OWET, the common requirement in each of the tank types is the wave generation system:

2.5.1 Oscillating Water Column (OWC) Tank:

OWCs are a type of WEC that operate an electricity-generating turbine by using the rise and fall of water inside a chamber to move air in and out of the chamber[7] as shown in *Figure 3*. The oscillating water column effect may be simulated in an OWC tank, which enables researchers to evaluate and improve the performance of OWC-based WECs.

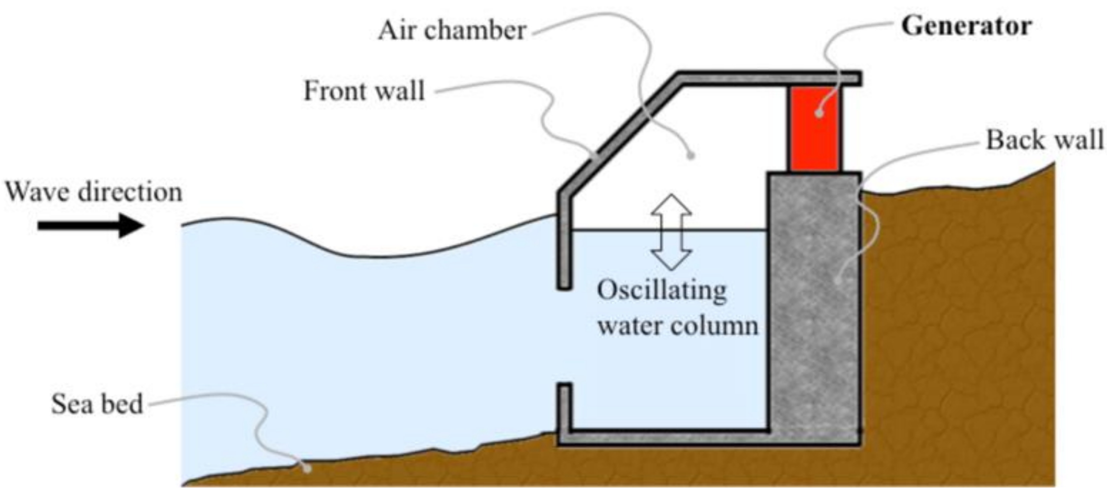


Figure 3 Oscillating Water Column Tank (OWC) energy converter [8]

2.5.2 Point Absorber Testing Tank:

To generate electricity, point absorbers use buoyant components that move up and down with the motion of the waves as shown in *Figure 4*. To evaluate the energy conversion effectiveness of point absorber WECs, different wave patterns can be simulated in a tank with configurable wave conditions[9].

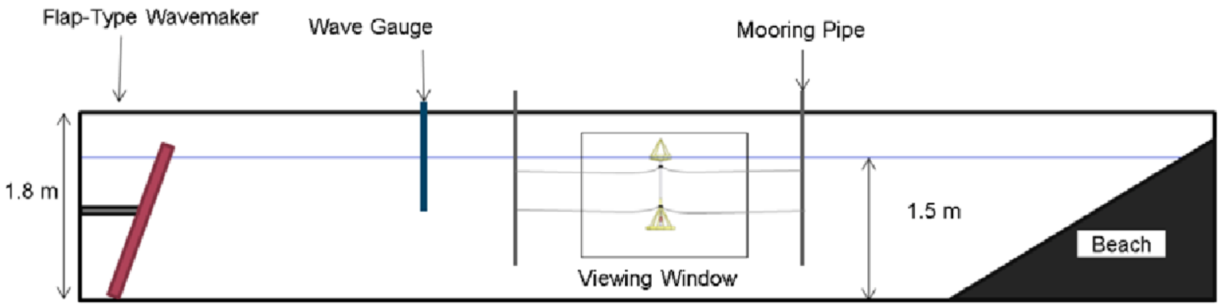


Figure 4 Schematic of the poimt absorber wave tank [10]

2.5.3 Attenuator Tank:

Figure 5 shows the Attenuators which are long floating structures that move with the waves and have mechanical parts that generate electricity as they flex and move[11]. These WECs require tanks that can simulate the long wave patterns experienced in open ocean conditions.

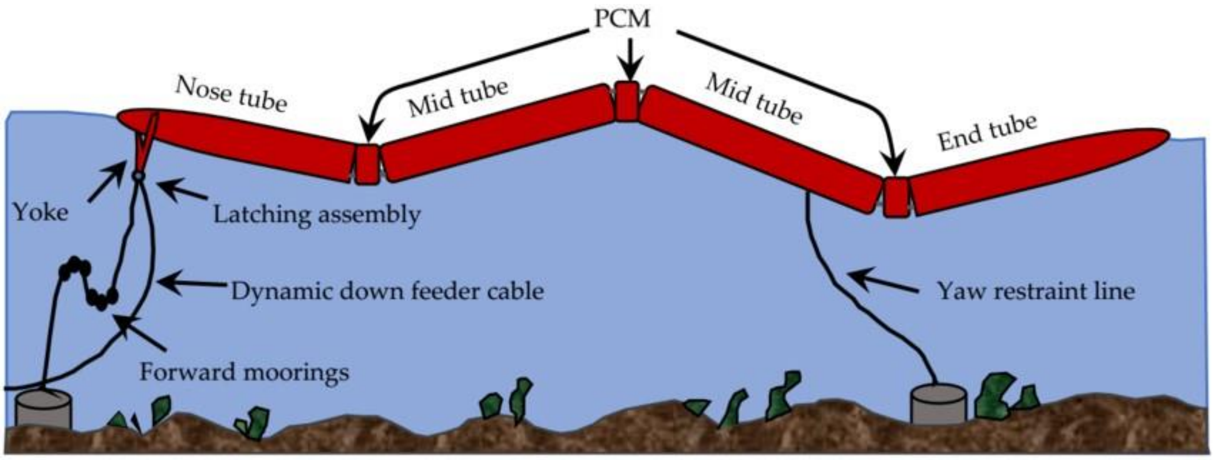


Figure 5 Attenuation Tank [12]

2.5.4 Towing Tank:

These were initially constructed for ship model testing. *Figure 6* shows that they are long and narrow with a movable carriage that can be driven along the tank to propel the model through the water[13]. Large towing tanks can be a few hundred metres long and although this means they are several metres wide only two-dimensional waves can be generated.

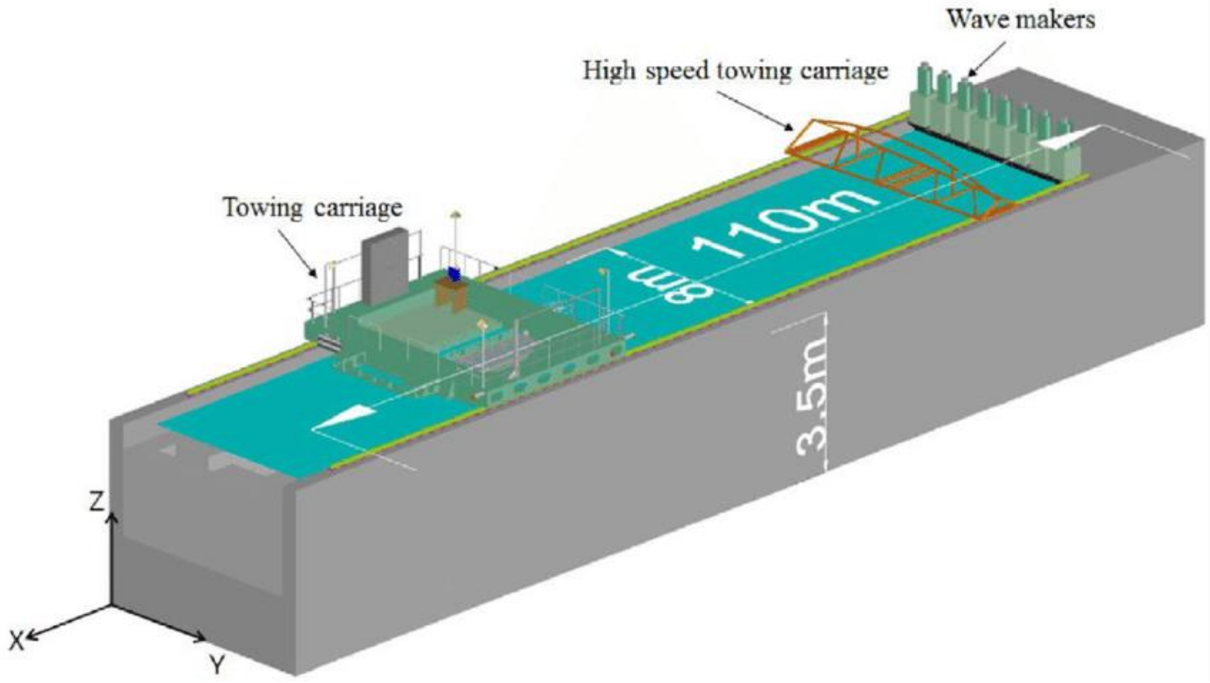


Figure 6: A schematic drawing of the towing tank [14]

2.6. Comparisons of the concurrent solutions

There are four main types of concurrent solutions that have been thoroughly examined and researched:

Error! Reference source not found. presents a comparison summary of all concurrent solutions that were discussed above. This table also shows the advantages and disadvantages of each type and justifies if this type does not satisfy the specific constraints, which was discussed in the Introduction section.

Table 2 comparison of all concurrent solutions

PTO Type	Advantages	Disadvantages	Requirements thatare NOT met for WEC
Oscillating Water Column (OWC) Tank	Accurately simulates the oscillating water column effect, which is the basis of OWC wave energy converters. Provides controlled conditions to study and optimize OWC-based WECs. Allows for detailed analysis of air flow and turbine performance. Well-suited for testing devices that rely on air pressure differentials.	Limited to testing OWC-based designs; not suitable for all types of wave energy converters. Complex setup and maintenance due to the interaction between water and air columns. May not fully replicate open ocean wave patterns.	OWCs can struggle to achieve high energy conversion efficiency, especially in variable wave conditions where the air column resonance might not align with the incoming waves.
Point Absorber Testing Tank	Can simulate a wide range of wave patterns and conditions. Allows for testing the efficiency of point absorber devices under varying wave energy inputs. Provides insights into the device's response to different wave frequencies and amplitudes.	Might not replicate the exact conditions the device would experience in the open ocean. Limited to point absorber-style WECs. More complex than simple wave flumes, requiring careful calibration.	Point absorbers produce energy based on the motion of waves. They may face challenges in providing continuous energy output during periods of calm or highly irregular waves. But it’s the most suitable tanks testing for our project.
Attenuator Tank	Allows testing of attenuator-style WECs, which are designed for longer wave patterns. Simulates the interaction of multiple waves and the device's response. Can provide insights into the behaviour of flexible structures in dynamic conditions.	More complex in design and operation due to the need to simulate long waves. Might require sophisticated control systems to accurately reproduce wave characteristics. Expensive to build and maintain.	. The complex design of attenuator WECs, involving multiple articulated sections, can make manufacturing, assembly, and maintenance more challenging.
Towing Tank	Can simulate a wide range of wave conditions and wave interactions. Useful for testing WECs in more dynamic, real-world scenarios. Provides insights into how the device responds to different wave directions and angles.	Generally larger and more expensive to operate. May require modifications to accommodate WEC testing. Complex setup and calibration needed to ensure accurate testing conditions.	While towing tanks can simulate wave conditions, they might not fully replicate the complex interactions that WECs experience in open ocean environments.

The team agreed on the 2nd concurrent solution during the discussion of our design.

The reason to why the 2nd concurrent solution was picked was because of its low manufacturing cost, lower weight and high compatibility compared to the other design as it's obvious in *Table 3*. The team further agreed to simplify the design and utilize only one section of the design instead of having two modules. The design is improved by replacing the adhesive used with an adhesive that can stick to much more surfaces compared to the original design.

Table 3 matrix for choosing a solution.

Concept Criterion Scale (1 □worst) (10□Best)	Weight	1st Concurrent Solution	2nd Concurrent Solution	3rd Concurrent Solution	4th Concurrent Solution
Cost	4	9	9	8	6
Adhesion	5	6	9	9	10
Stability	4	6	10	6	10
Versatility	5	6	10	8	2
Score		120	141	171	124

2.8. Engineering standards of the concurrent solution

- ISO 19902:2007 - Petroleum and natural gas industries - Fixed steel offshore structures
- ISO 19905:2005 - Petroleum and natural gas industries - Floating offshore structures
- ISO 19906:2007 - Petroleum and natural gas industries - Arctic offshore structures
- IEC 61400-3:2017 - Wind turbines - Part 3: Design requirements for offshore wind turbines.
- ISO 4413: Hydraulic fluid power -- General rules and safety requirements for systems

and their components

- ISO 1219-1: Fluid power systems and components -- Graphical symbols and circuit diagrams.
- ISO 14835: Design of marine structures -- Wind turbines.
- IEC 60034: Rotating electrical machines
- IEC 61400-2: Wind turbines -- Part 2: Design requirements for small wind turbines, may be applicable.
- API RP 2A-WSD - Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design
- API RP 2SK - Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures
- ISO 8887-1:2017Technical product documentation — Design for manufacturing, assembling, disassembling and end-of-life processing.
- ISO/TC 205, Building environment design.
- ISO/TC 184, Automation systems and integration
- ISO/TC 301, Energy management and energy savin

CHAPTER 3 -DESIGN and ANALYSIS

In this chapter of the report, an explicit explanation of the selected design is provided, including the standards for the design, calculation, and the cost analysis.

3.1. Proposed/Selected design.

As shown in *Figure 7* Illustration of , The scalable wave tank design incorporates galvanized steel sheets, frame, and plexiglass for transparency, offering a cost-effective and environmentally friendly solution for wave energy conversion. With its simplified design and assembly, the system can be constructed on a smaller scale using high-quality materials while still achieving significant electricity output. It is well-suited for testing in low wave regions and allows for the use of point absorbers as chargers to gradually charge lithium cells. The integration of a linear generator enables direct conversion of mechanical energy into electrical energy, eliminating the need for complex hydraulic systems. This streamlined approach ensures a direct interface between the wave energy converter and the electrical generator.

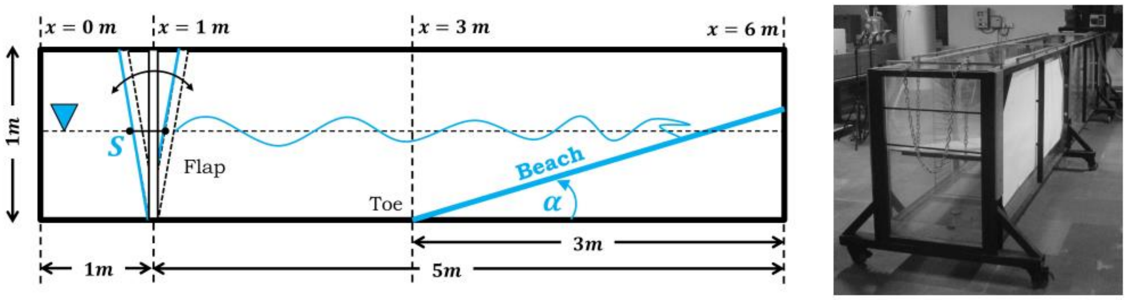


Figure 7 Illustration of Proposed design

The general system specification/system breakdown is brought about in *Figure 8*:

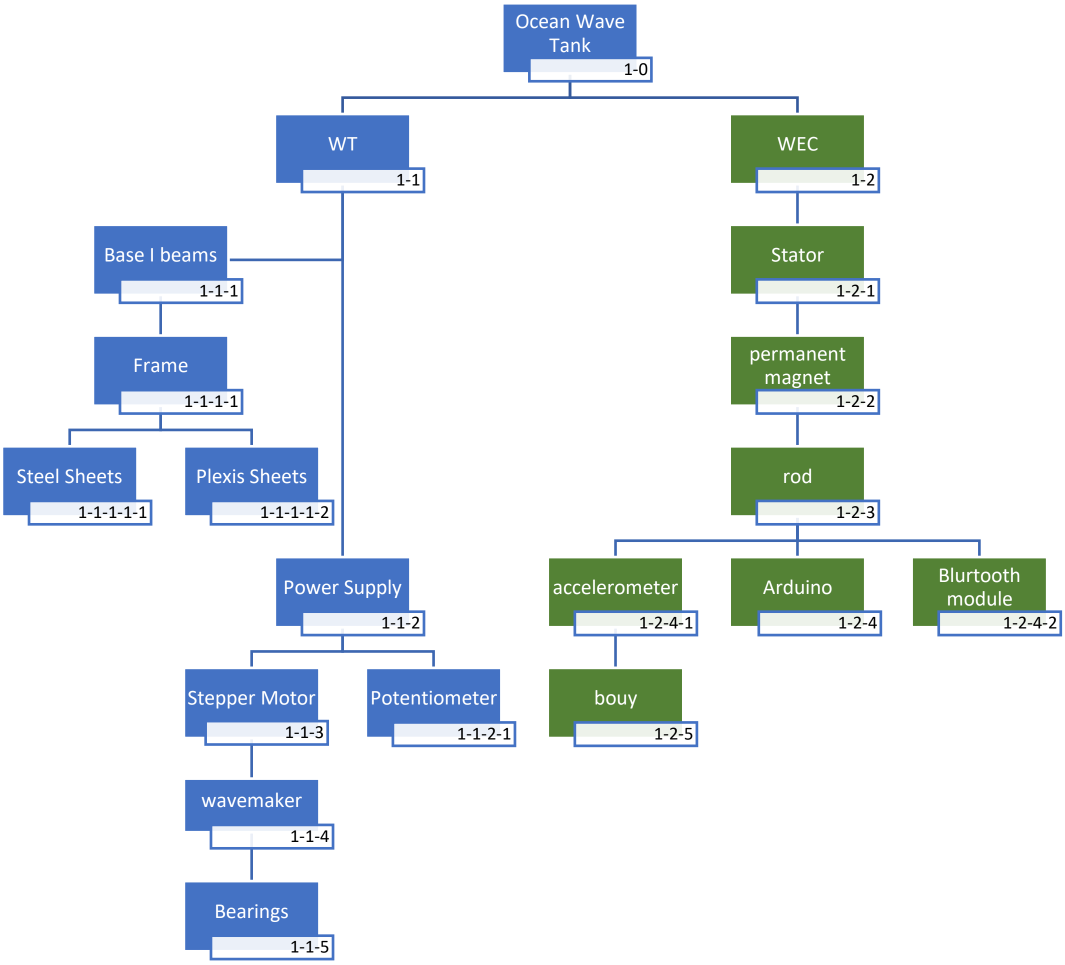


Figure 8 System breakdown

The main components that make up the Ocean Wave energy Tank are as follows:

- Mechanical Parts
- Physical Parts
- Electronic Parts

3.1.1. Mechanical Subsystem

3.1.1.1. Design Evolution:

Several stages and concepts were gone through before arriving at the ideal design. Research into earlier concepts that had participated in the wave tank design was conducted, along with a thorough study of how efficient and robust tanks are built and manufactured. The choice of tank design was settled upon based on a research paper (Saincher & Banerjeea, 2015) and an old capstone project from their university.

The approved design was then drafted using the computer-aided design (CAD) application SolidWorks and was later completed while considering all efficiency and safety considerations. However, limitations were encountered due to material availability and the available manufacturing techniques. The main objective of designing a tank using the minimum number of components was pursued in order to simplify the assembly procedure and reduce ordering and manufacturing costs.

3.1.1.2 Tank Design Aims:

1. A wave tank that can hold the given amount of water without leakage.
2. A wave tank that produces variety of waves according to considerable scaling factor
3. A transparent side tank to visualize the waves motion and the working of the WEC that will be tested in it.
4. The tank should be easy to move and maintain.

3.1.1.2.1 Design Configuration 1:

In the earliest stages of our design, we agreed on the material of our tank which is made up of galvanized steel sheets with dimensions calculated according to (Saincher & Banerjeea, 2015).

The use of galvanized steel sheet ensures structural stability and durability, providing a robust framework for the tank. Galvanized steel is known for its corrosion resistance, making it suitable for prolonged exposure to water. The transparent plexiglass on the front side allows for clear observation and visualization of the waves and fluid behaviour inside the tank. Plexiglass provides optical clarity like glass while being lighter and less prone to shattering, making it a practical choice for wave tank applications. The combination of galvanized steel and transparent plexiglass creates a sturdy and visually accessible wave tank design as shown in *Figure 9*, facilitating detailed analysis and experimentation in the field of fluid dynamics and wave studies.

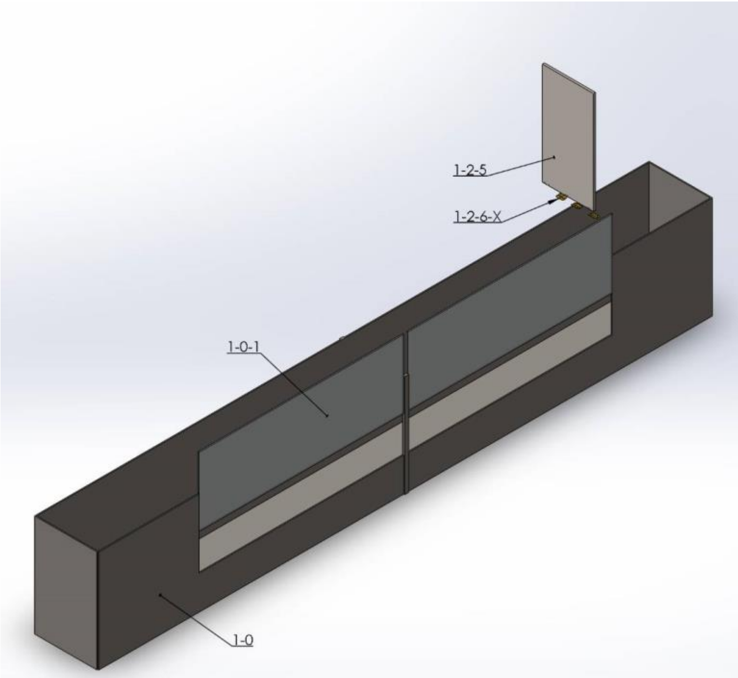


Figure 9 Tank Configuration 1

3.1.1.2.2. Design Configuration 2:

In addition to the galvanized steel sheet and transparent plexiglass, incorporating steel frames within the wave tank design provides essential reinforcement and structural stability. Steel frames serve as a supportive framework that enhances the overall strength and rigidity of the tank structure *Figure 10*. The inherent strength of steel makes it an ideal material for withstanding the forces exerted by the water inside the tank and any external impacts. By strategically placing steel frames throughout the tank, the overall integrity of the tank is improved, minimizing the risk of deformation or failure under varying hydraulic conditions. The steel frames ensure that the tank maintains its shape and structural integrity, even when subjected to the dynamic forces generated by the waves. This reinforcement is crucial for maintaining accurate and reliable wave propagation characteristics within the tank and allows for repeatable experiments and consistent results. Therefore, incorporating steel frames within the wave tank design provides the necessary reinforcement to support the galvanized steel sheet and transparent plexiglass components, ensuring the tank's durability and stability during experimental studies.

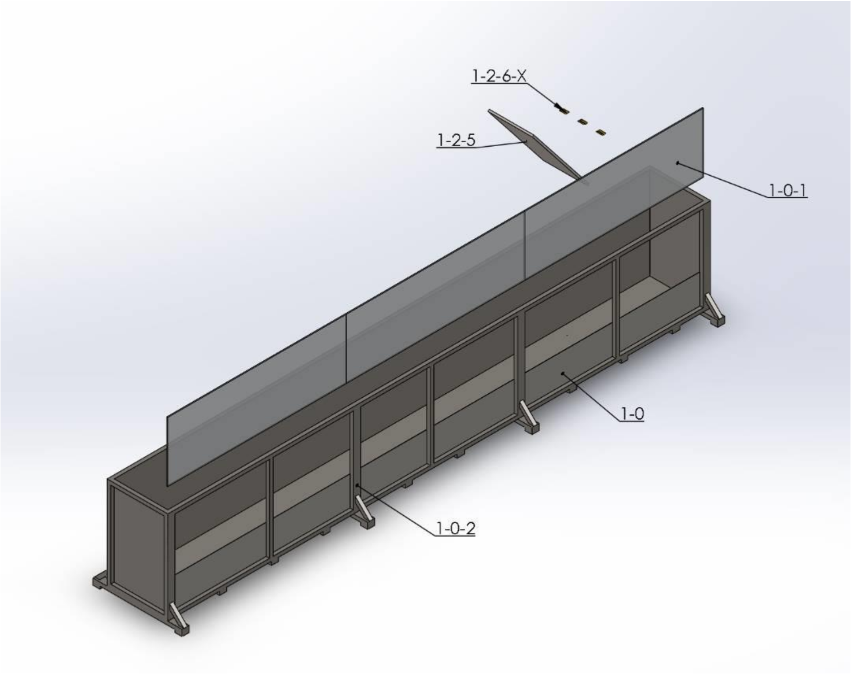


Figure 10 Tank Configuration 2

3.1.1.2.3 Design Configuration 3:

To enhance the mobility and manoeuvrability of the wave tank, incorporating six wheels into the design is a practical solution, especially for a tank with a length of six meters *Figure 11*. The wheels can be strategically positioned along the bottom of the tank to evenly distribute the weight and provide ease of movement. With the addition of wheels, the tank can be easily transported or repositioned within a laboratory or research facility, enabling flexibility in experimental setups, or facilitating the tank's storage when not in use.

The wave tank design incorporates galvanized steel sheet panels, steel frames, and six wheels to create a versatile and robust system for studying fluid dynamics and wave propagation. The galvanized steel sheet panels provide structural stability and durability, while the steel frames offer reinforcement and support, ensuring the tank maintains its shape and integrity under varying hydraulic conditions. The addition of six wheels enhances mobility, allowing for easy transportation and repositioning of the tank within a laboratory or research facility. This combination of materials and features provides a reliable and flexible wave tank solution that enables accurate observations, repeatable experiments, and convenient storage when not in use.

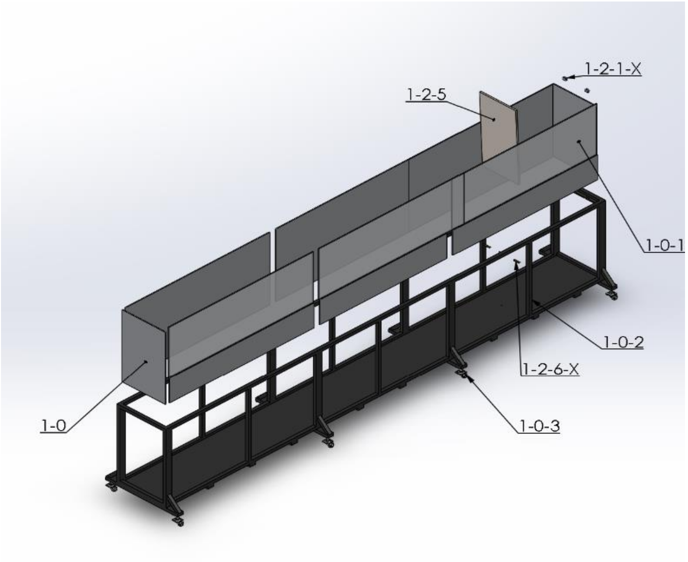


Figure 11 Tank Configuration 3

3.1.1.2.3 Design Configuration 4:

The tank is constructed with three segments, each segment being 2 meters in length *Figure 12*. These segments are firmly assembled to form a unified tank unit, a steel frame serves as the fundamental support structure, ensuring the tank's overall stability and strength. To provide clear visibility of the tank's contents, transparent plexiglass sheets are utilized for both sides of the tank. These plexiglass panels offer an unobstructed view of the interior. For added durability and protection against rust and corrosion, the tank's base and width sides are reinforced with galvanized sheets.

Supporting the tank at the bottom is a reliable I-beam framework. This I-beam support system evenly distributes the weight of the tank and its contents, ensuring optimal load-bearing capacity and stability.

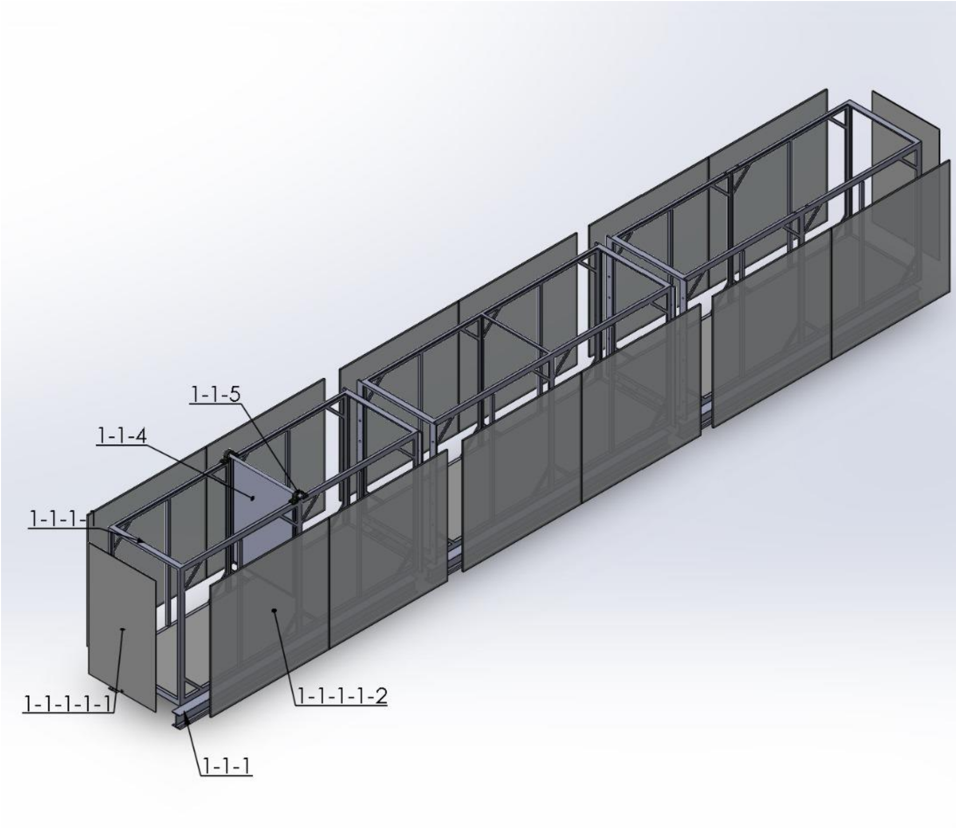


Figure 12: Design Configuration 4

Table 4 Tank design configurations comparison

Configuration	Design Configuration 1	Design Configuration 2	Design Configuration 3	Design Configuration 4
Stability	Moderate	Enhanced	Enhanced	Enhanced
Manoeuvrability	Not applicable	Not applicable	Improved (With the addition of wheels)	Not Applicable
Cost	Lowest	High	High	Highest
Ease of Assembly	Easy	Moderate	Moderate	Moderate
Flexibility	Limited	Moderate	High (With mobility provided by wheels)	Moderate
Scalability	Limited	Moderate	Moderate	Enhanced

Environmental	Environmentally friendly			
Friendliness	(Use of recyclable materials, energy-efficient design, etc.)			
Safety	Standard safety measures	Enhanced safety measures (e.g., reinforced frames)	Enhanced safety measures (e.g., reinforced frames, safety features for wheels)	Enhanced safety measures
Manufacturability	Standard	Moderate	Moderate	Moderate
Power Performance	Standard	Standard	Standard	Standard

In *Table 4* "Low" represents a lower level or extent of meeting the objective, "Moderate" indicates a moderate level of meeting the objective, and "High" signifies a higher level or extent of meeting the objective. Please note that the scale is relative to the other configurations listed in the table and may not represent absolute values.

3.1.1.3. Wave Creator Design Configuration:

3.1.1.3.1. Design configuration 1 (Piston Type Wave Maker):

For wave creation we looked at different wave creators with various mechanism, (Beneduce, 2019) & (Streng et al.). The first design configuration was a wave creator utilizing a piston mechanism The piston mechanism consists of a piston that moves back and forth, creating oscillatory motion in the water within the wave tank. As the piston moves forward, it displaces the water, resulting in the formation of a wave. The piston's movement can be controlled and adjusted to achieve different wave characteristics, such as wave height, frequency, and wavelength. This mechanism offers precise control over wave generation, allowing researchers to study and analyse specific wave behaviours and their interactions with different structures or objects. The piston-based wave creator is versatile and adaptable, making it suitable for a wide range of applications in fields such as fluid dynamics, coastal engineering, and wave energy research shown in Figure 13 Wave creator Configuration 1.

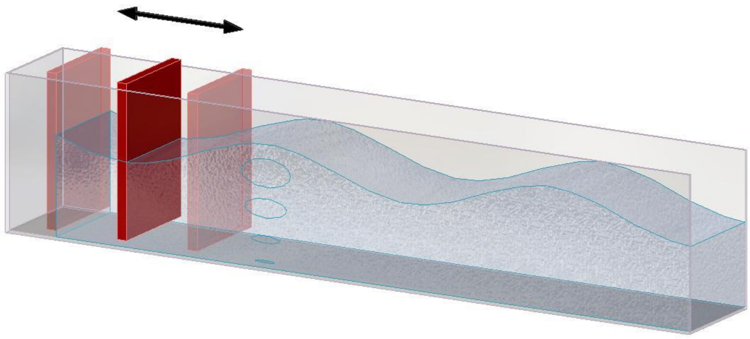


Figure 13 Wave creator Configuration 1

When testing for deep water waves in a small scaled 6m tank, the choice between motorized piston actuation *Figure 14* and hydraulic actuation becomes even more critical. Deep water waves have distinct characteristics compared to shallow water waves, necessitating an appropriate wave generation method.

Motorized piston actuation, with its precise control over wave frequency and amplitude, can be utilized to simulate deep water waves with relative accuracy. By adjusting the motor's speed and direction, researchers can replicate the dispersion relationship and the phase velocity of deep-water waves. However, generating large-amplitude deep water waves with motorized pistons might be limited by the available power and the physical size of the piston.

On the other hand, hydraulic actuation, with its capacity to generate larger waves, may better replicate the wave behaviour observed in deep waters. Hydraulic systems can produce substantial forces, enabling the creation of deep-water waves with significant amplitudes and wavelengths. While hydraulic actuation may lack the precise control of motorized pistons, its ability to generate larger waves can be advantageous for deep water wave testing.

Figure 14 Piston wave maker [15]

3.1.1.3.2. Design configuration 2 (Flap wave maker):

Another design for wave creation involves the implementation of a flapper mechanism *Figure 15*. The flapper mechanism consists of a hinged panel or flap that oscillates back and forth in the water, generating waves through its motion. As the flapper swings forward and backward, it pushes and displaces the water, resulting in the formation of waves. The amplitude and frequency of the waves can be adjusted by controlling the flapper's movement speed and angle of oscillation. The flapper mechanism offers a different approach to wave generation, providing a unique wave pattern and behaviour compared to the piston mechanism. It allows for the study of wave interactions, wave-structure interactions, and the analysis of wave energy transmission.

The flapper mechanism for wave generation can be enhanced by integrating a servo motor, Arduino Uno, and potentiometer. The servo motor serves as the actuator, controlled by the

Arduino Uno microcontroller, which receives input from the potentiometer. This setup enables precise control over the flapper mechanism's movement, allowing for adjustable angles and speeds. Researchers can program the Arduino Uno to generate customizable wave patterns by regulating the servo motor's motion. This integration offers an automated and versatile wave generation system suitable for a wide range of scientific and engineering applications shown below in Figure 15 Wave creator Configuration 2

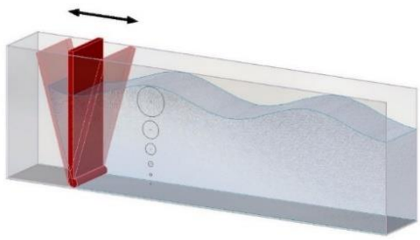


Figure 15 Wave creator Configuration 2

The flapper mechanism is a fascinating and versatile method for generating ocean waves in various research and experimental setups. It involves a horizontal plate or "flapper" that is mounted at one end of a water tank *Figure 16*. This flapper oscillates up and down in a controlled manner, creating waves as it moves through the water. The motion of the flapper generates a disturbance at the water's surface, leading to the formation of waves that propagate through the tank. The flapper mechanism can be actuated using different methods, such as motor-driven cams, crankshafts, or even manual actuation, providing flexibility and adaptability to different experimental needs.

One of the significant advantages of the flapper mechanism is its simplicity in design and construction, making it accessible for researchers and students exploring wave phenomena. It does not require complex hydraulic systems or precise motor control, contributing to its cost-effectiveness. Moreover, the flapper mechanism's versatility allows for adjustments in the flapper's oscillation frequency and amplitude, enabling the generation of various wave patterns. This adaptability is beneficial for simulating different types of waves, such as deep-water waves or specific wave profiles observed in real-world conditions.

While the flapper mechanism offers several benefits, there are also some considerations to bear in mind. Achieving precise control over the wave characteristics might be more challenging compared to methods like motorized pistons or hydraulic systems. The flapper's size and oscillation mechanism might limit the generation of very large-amplitude waves, which could be a concern for certain experiments. Additionally, the energy efficiency of the flapper mechanism depends on the actuation method used, and researchers should be mindful of optimizing its operation to minimize energy consumption.

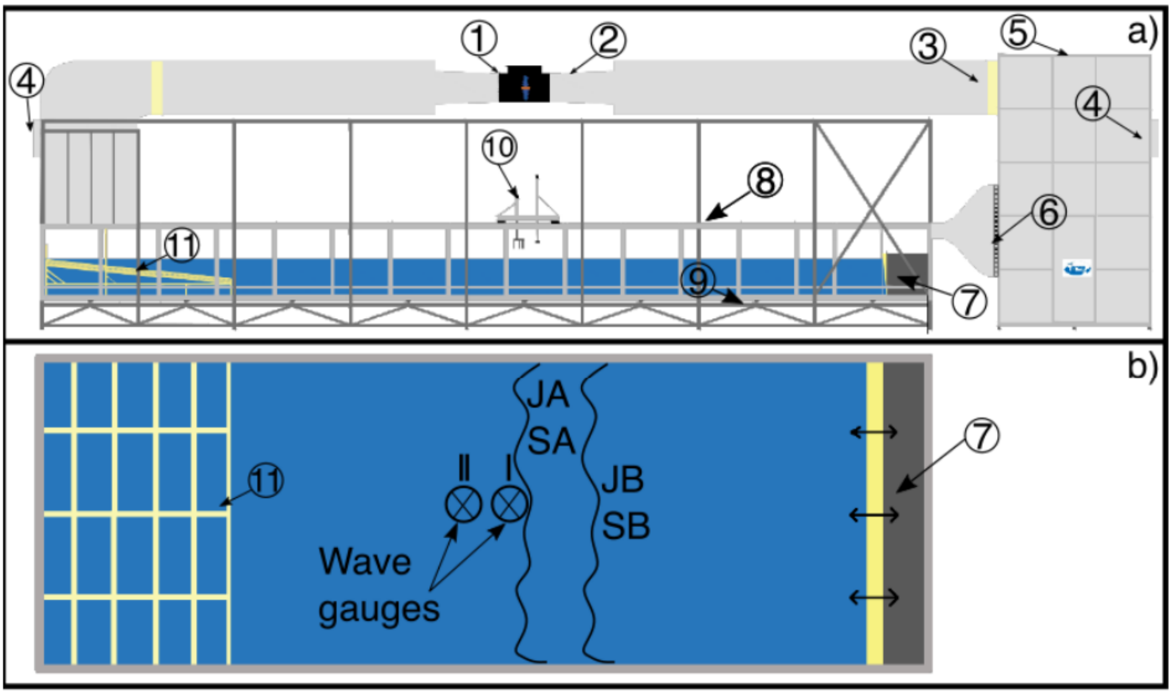


Figure 16: 12 flap wave makers [16]

3.1.1.4. Selected Configuration:

Our selected tank design *Figure 17* consists of 3 segments, each segment features galvanized steel sheet walls reinforced with steel frames and I beam at the base for durability and stability.

The front side of the tank incorporates a transparent plexiglass sheet, providing visibility and transparency during wave experiments. The tank also includes a flapper mechanism with a shaft and steel plate for wave creation, driven by a stepper motor controlled by an Arduino Uno. The angle and speed of the flapper mechanism can be adjusted using a potentiometer. This design allows for precise control over wave generation, easy transportation of the tank, and clear observation of wave behaviour through the plexiglass sheet. It provides researchers with a comprehensive solution for studying and analysing waves in various scientific and engineering applications.

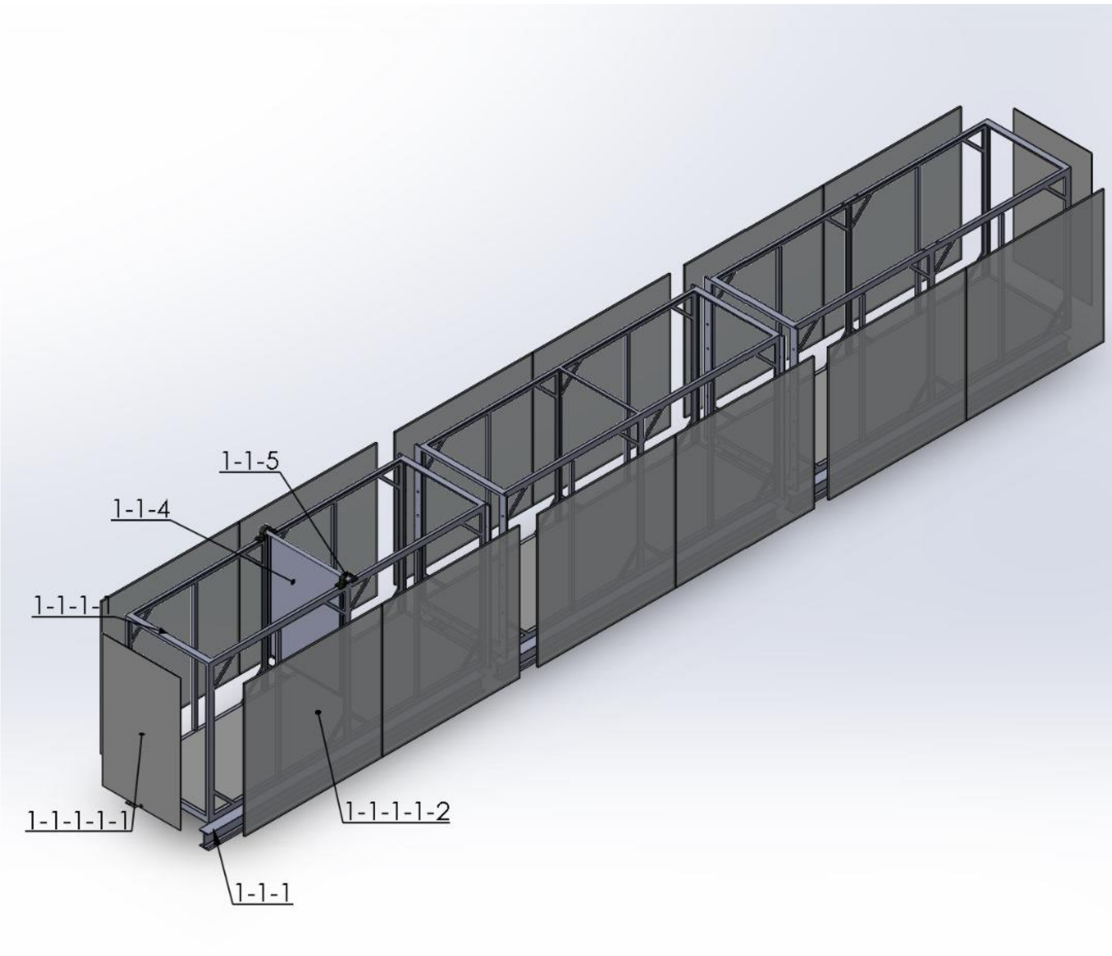


Figure 17 Selected tank design

3.1.2. Physical Subsystem

Wave Creator and Bearings: The wave creator flap *Figure 18* is an essential component of the tank's wave generation mechanism. It is attached to the tank using bearings *Figure 19*, allowing it to oscillate back and forth. The flap is typically made of galvanised steel sheet, and is designed to displace water as it moves. When the flap swings forward, it pushes the water in front of it, creating a wave crest. As it swings backward, it pulls water behind it, generating a wave trough. This back-and-forth motion of the flap results in the formation of waves within the tank. The bearings provide the necessary flexibility and smooth movement for the flap, ensuring that it can oscillate freely and generate waves effectively. Operators can control the oscillation angle and speed of the flap, allowing for adjustable wave patterns and frequencies. The shaft plays a crucial role in facilitating the wave creation process and are integral to the overall functioning of the tank's wave generation system.

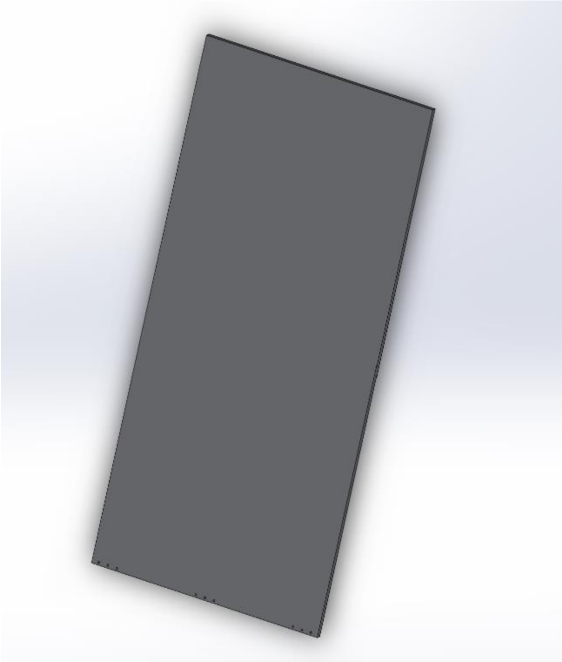


Figure 18 wave creator flap (1-1-4)

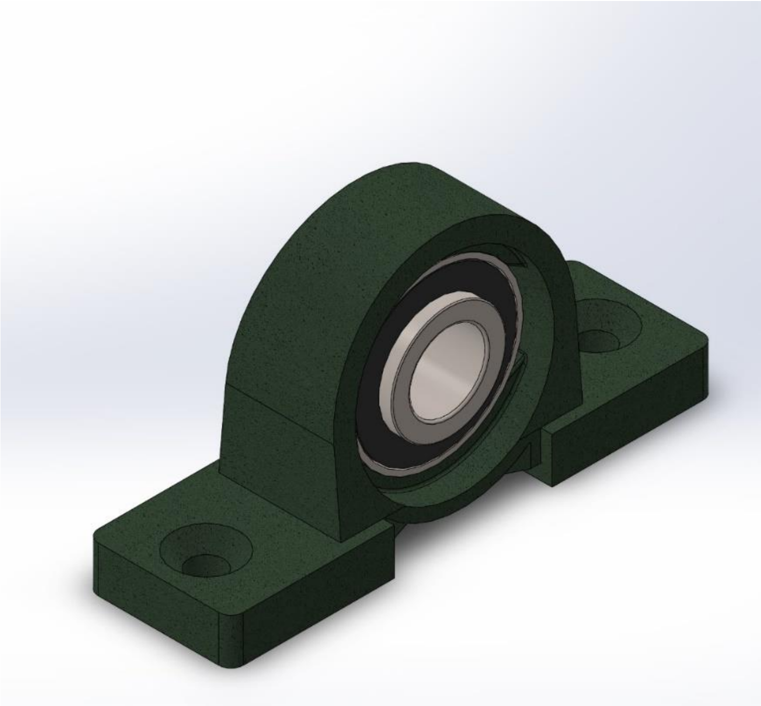


Figure 19 Bearings (1-1-5)

Floating Buoy (1-2-5): The floating buoy is a key component of this design. Its primary function is to convert the kinetic energy of the waves into electrical energy, which can be used to power homes and businesses. The buoy moves because the wave travels while connecting to a crank mechanism and is meant to supply high torque while maintaining the generated power with a low speed.

We looked at five different versions of the floating buoy, all of which had the same dimensions. The models have been made up so that they may be utilized in the wave tank; however, it was found that this might not produce enough energy, thus there are committees working on deciding whether the buoy will be used instead. To guarantee that the 5 models have accurate measurements and a sound conceptual design as shown in *Figure 20*, a 3D model has been created for each of them using the SolidWorks program. After that, the 3D printing method is used to transform these models into actual prototypes so that the produced components may be guaranteed to be exact. However, making the buoy out of plastic would not have been an effective use of resources since the same geometries would have been required. At last, the buoys are constructed such that they may float on the surface of the water as required.

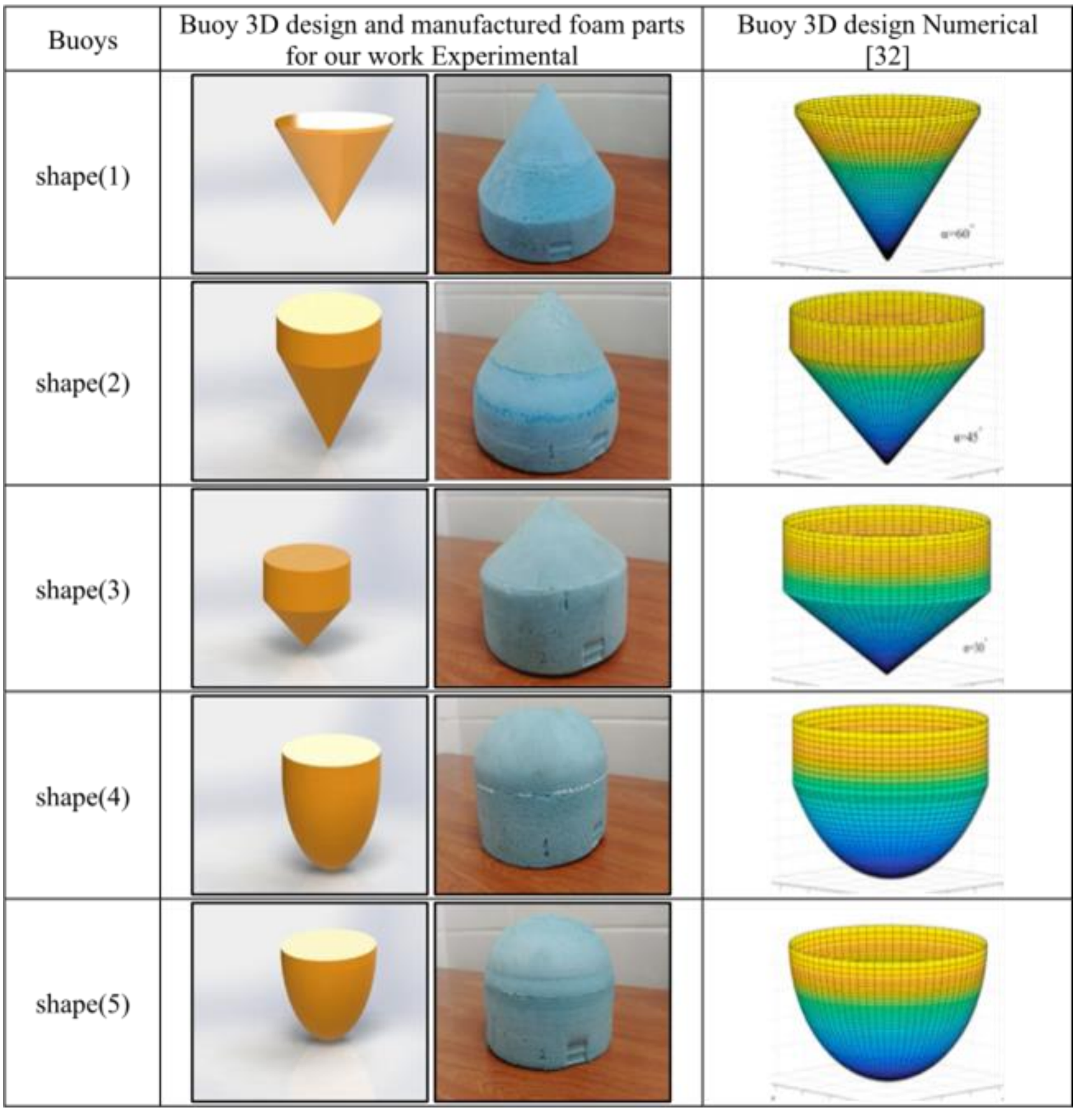


Figure 20 Buoy comparison

Table 5: buoy selection matrix

Concept Criterion Scale (1=worst) (10=Best)	Weight	Shape 1	Shape 2	Shape 3	Shape 4	Shape 5
Power Performance	5	6	7	7	9	10
Sustainability	4	6	6	4	7	10
Efficiency	4	6	6	8	7	9
Maintenance	3	7	6	7	8	10
Manufacturability	3	8	8	6	9	9
Economic	3	7	7	7	9	10
Score		144	146	143	179	213

After the selection matrix shown in *Table 5*, Shape 5 was chosen for the design of the buoy for having low density, low cost and being easy to maintain, in a linear generator point absorber, a spherical buoy plays a crucial role in converting the mechanical energy of ocean waves into electrical energy. The buoy is typically attached to a linear generator, which is a device that converts linear motion into electrical power. here's how the spherical buoy functions within the linear generator point:

- **Wave Absorption**: The spherical buoy is designed to float on the surface of the ocean and is exposed to the incoming waves. As the waves pass by, they cause the buoy to rise and fall with the wave motion. The buoyancy of the spherical buoy allows it to move up and down in response to the wave action.

- **Linear Motion**: The vertical movement of the spherical buoy is converted into linear motion. Typically, the buoy is connected to a linear generator system through a mechanical linkage, such as a piston or a hydraulic system. The up and down motion of the buoy is translated into linear motion in the generator.
- **Electrical Generation**: The linear motion of the buoy drives the linear generator, which consists of coils and magnets. The magnets are fixed, while the coils move relative to them. As the coils move through the magnetic field, an electrical current is induced in the coils due to electromagnetic induction. This generated electrical energy can then be harvested and utilized for various purposes.by capturing the energy from the vertical motion of ocean waves, the spherical buoy in a linear generator point absorber enables the conversion of wave energy into usable electrical power.

3.1.4 Electronic parts

3.1.4.1 Arduino Uno (1-2-4):

An Arduino Uno microcontroller and a stepper motor can play important roles in creating an automated wave generator in a small scaled wave tank.

The Arduino Uno microcontroller is a programmable microcontroller board that can be used to control various electronic components. It can read inputs from sensors, process data, and send output signals to control other electronic components, such as the stepper motor.

3.1.4.2 Stepper Motor (1-1-3):

Figure 21:Stepper motor with driver

The stepper motor *Figure 21* is a type of motor that moves in discrete steps, making it suitable for precise positioning tasks. It is commonly used in robotic applications and can be controlled by an Arduino Uno microcontroller.

In an automated wave generator, the stepper motor can be used to control the movement of a wave paddle that creates waves in the tank. By attaching the wave paddle to the stepper motor, the microcontroller can control the timing and amplitude of the waves by sending signals to the stepper motor.

For example, the microcontroller could be programmed to create a wave every few seconds with a specific amplitude and duration. The microcontroller could also be programmed to adjust the wave amplitude and duration based on input from sensors that measure water level, temperature, or other parameters.

Overall, the combination of an Arduino Uno microcontroller and a stepper motor *Figure 22* can provide a flexible and customizable platform for creating an automated wave generator in a small scaled wave tank.

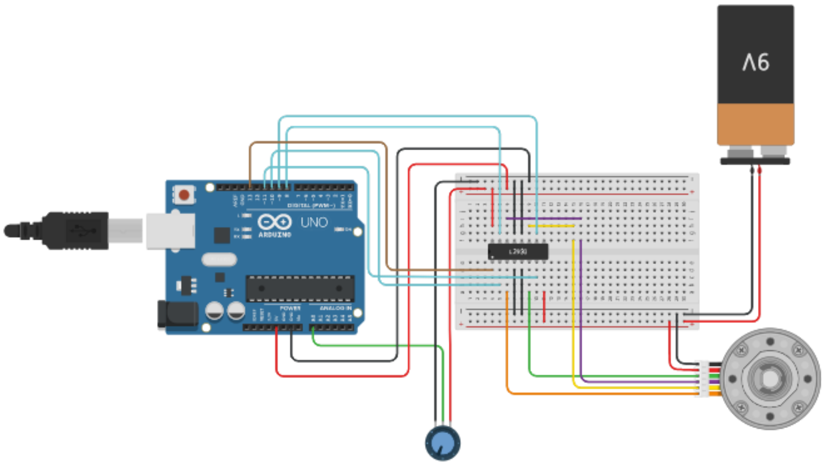


Figure 22 Tinker cad schematic of stepper motor and Arduino interface with potentiometer

The design above is the connection of the Arduino to the stepper, motor driver and potentiometer. The Arduino reads the potentiometer reading which allows speed change of the stepper motor. The Arduino that will be used the Arduino uno in the *Figure 23* below as is

provided an average processing speed that won't affect the stepper movement.

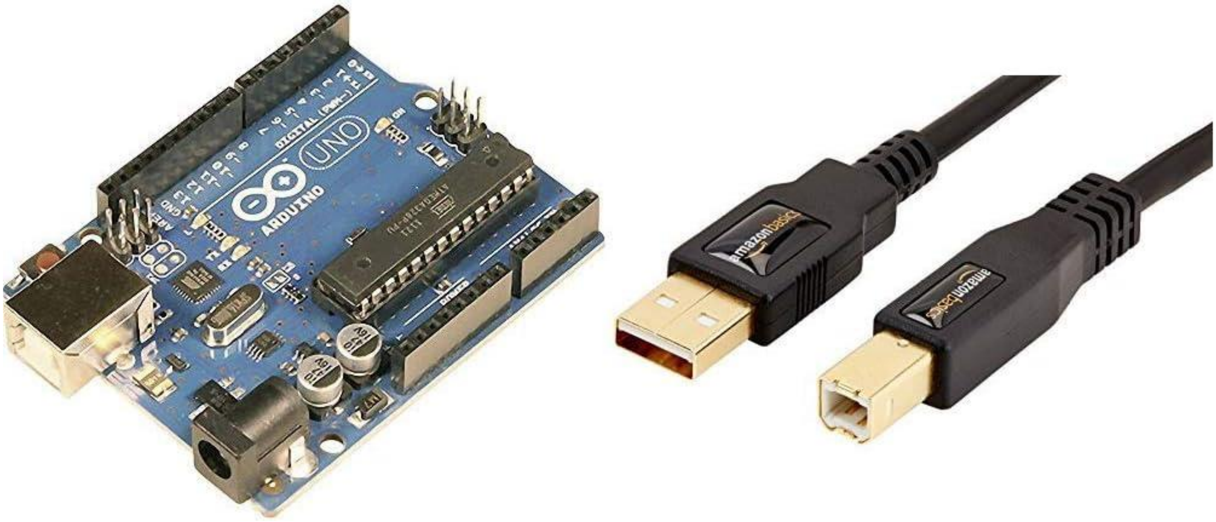


Figure 23 Arduino uno [17]

3.1.4.3. Stator (1-2-1):

The stator of a point absorber is the stationary part of the device that contains the magnetic field. It is typically made of a series of magnetically conductive plates or laminations, stacked together, and arranged around a central core.

The cable windings of a linear generator are the coils of wire that are attached to the moving element (such as a cable) *Figure 24*. As the moving element moves back and forth within the magnetic field of the stator, it causes the cable windings to move within the magnetic field as well. This motion generates an electrical current in the cable windings, which can be captured and used to generate electricity. The specification of the stator can be found in APPENDIX F: Engineering Drawings.

Figure 24: generator stator (1-2-1)

The stator is made up of a series of magnetically conductive plates or laminations, stacked together and arranged around a central core. These plates or laminations are typically made of a material such as steel, which can conduct magnetism. As the translator moves back and forth within the magnetic field of the stator, it generates an electrical current in the cable windings.

3.1.4.4. Permanent magnet (1-2-2):

Permanent magnets *Figure 27* are employed in linear generators because they can generate a powerful magnetic field while being lightweight and small, making them suited for usage in maritime settings. Furthermore, they do not require any maintenance or an external power source to operate, making them a dependable and effective alternative for use in wave energy conversion systems.

As the inner component of the LPMG, the translator can move vertically *Figure 25*, and its movement is proportional to the Buoy's motion. The use of permanent magnets is simpler and more mechanically stable. In this design, the magnets are made of Neodymium-Iron Boron (NdFeB) material of N40 type. They are arranged axially as shown in Figure *26* below, in which two adjacent magnets have opposite magnetic orientations.

Figure 25:magnets and translator shape[18]

Figure 26 *Axial magnet (1-1-4)* [18]

Figure 27：selected Neodymium magnets (1-1-4) [18]

Table 6:Magnet comparison

Criteria	Rectangular	Circular	Triangular
Length	9	3	6
Width	6	9	3
Efficiency	7	9	6
Manufacturability	5	8	6
Assembly	5	8	6

In the above matrix *Table 6*, the circular magnets are the overall best option because they score the most points. Circular magnets were chosen in our design because of their efficiency, ease of manufacturing, and assembly.

3.1.4.5. Translator:

A solid cylindrical magnet can function as a translator in a permanent magnet system by interacting with magnetic fields and exhibiting magnetic properties.

When a solid cylindrical magnet is placed in the vicinity of other permanent magnets or magnetic fields, it experiences magnetic forces due to the magnetic interactions. These forces can cause the cylindrical magnet to move or translate along a particular direction.

The translation of the cylindrical magnet is primarily governed by the principles of magnetic attraction and repulsion. Like poles of magnets repel each other, while opposite poles attract. By strategically positioning the cylindrical magnet with respect to other magnets or magnetic fields, it can be made to move in a controlled manner.

The translation of the cylindrical magnet can be utilized in various applications, such as magnetic conveyors, linear actuators, or magnetic levitation systems. By manipulating the magnetic field arrangements and controlling the positioning of the cylindrical magnet, precise translational movements can be achieved in these systems.

3.1.4.6. Control System

The control system of the design is responsible for regulating the operation of the device and ensuring that it operates efficiently and reliably. The control system typically consists of the following components:

Sensors: Sensors are used to measure various parameters, such as the position and velocity of the floating platform, the output power of the generator, and the environmental conditions. These sensors provide input to the control system, which uses this information to adjust the operation of the device.

3.1.4.7. Accelerometer (1-2-4-1)

An accelerometer is a device that measures acceleration, which can be used to measure the movement and vibration of a point absorber ocean wave energy converter. The converter moves in response to the waves, and this motion can be measured by the accelerometer.

To measure the various amplitudes and frequencies of the point absorber ocean wave energy converter, the accelerometer is typically mounted at a specific location on the device where it can detect the movement in one or more directions. The accelerometer then generates an electrical signal that represents the acceleration, which can be analysed to determine the amplitude and frequency of the motion.

The amplitude of the motion is the maximum displacement of the device from its resting position, and it can be measured by analysing the peak-to-peak voltage of the electrical signal generated by the accelerometer. The frequency of the motion is the number of times per second that the device moves back and forth, and it can be determined by analysing the frequency spectrum of the electrical signal.

3.1.4.7. Bluetooth Module (1-2-4-2)

For transferring accelerometer data, we needed to integrate an accelerometer sensor *Figure 29* into our hardware and wire it to a microcontroller. Then, we connected the Bluetooth module (HC-06) *Figure 28* to the microcontroller. When both the accelerometer and Bluetooth module are powered on, it was initiated pairing on our receiving device (smartphone) and select the Bluetooth module from the available devices list. Once paired, the firmware was developed on the microcontroller to read accelerometer data and transmit it to the connected Bluetooth module. On the receiving device, an application was used that can receive and interpret the accelerometer data sent over the Bluetooth connection. This way, we can wirelessly transfer accelerometer data from your hardware to the paired device.

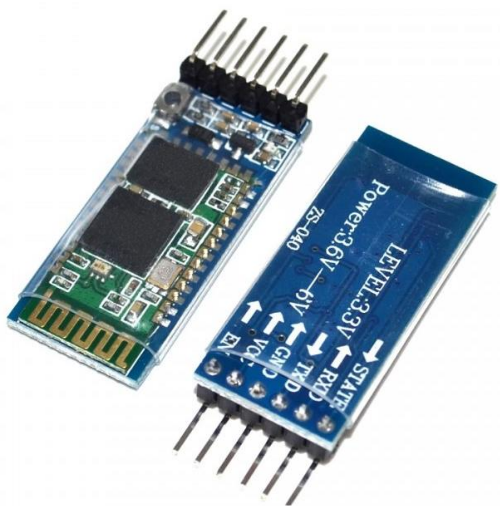


Figure 28:Bluetooth Module HC-06

In a point absorber ocean wave energy converter, the device is designed to absorb energy from the waves as it moves, so the amplitude and frequency of the motion will vary depending on the characteristics of the waves. By measuring the amplitude and frequency of the motion with an accelerometer, engineers can optimize the design of the device to maximize its energy absorption efficiency and ensure that it operates safely and reliably in a wide range of ocean conditions.

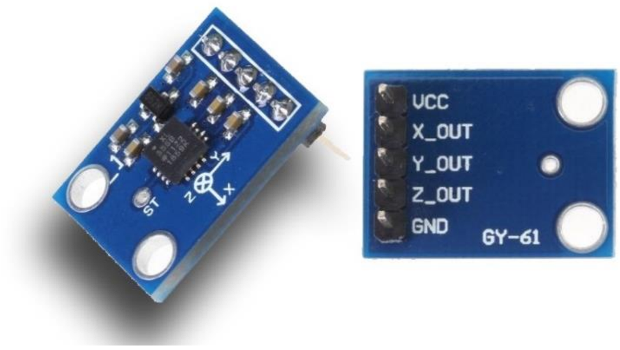


Figure 29 Accelerometer (1-2-4-1) [19]

3.2. Engineering standards

There are several engineering standards and codes that apply to point absorber wave energy converters, which are devices that use the movement of ocean waves to generate electricity. These standards and codes ensure the safety and reliability of the point absorber, as well as its compliance with regulatory requirements. Some of the key engineering standards and codes for point absorber wave energy converters are discussed below.

- ISO 19906:2010: provides guidelines for the design, testing, and operation of wave energy converters, including point absorbers. It covers topics such as materials, structural design, loadings, and reliability.

- IEC 61400-3:2014: covers the design, testing, and operation of wind turbines, including those used in offshore wave energy conversion systems. It includes requirements for structural design, fatigue, and reliability.

- DNV GL RP-A203: provides guidance on the design, testing, and operation of wave energy converters, including point absorbers. It covers topics such as materials, structural design, loadings, and reliability.

- ASME BPVC: covers the design, fabrication, and inspection of pressure vessels, including those used in wave energy conversion systems. It includes requirements for materials, fabrication, and testing.

- ISO 19902: It includes requirements for the structural, mechanical, and electrical systems of the point absorber, as well as the environmental conditions in which it will be used.

- International Organization for Standardization (ISO) Standard 14001: it covers the management of environmental impacts of wave energy converters. It includes requirements for the assessment and reduction of the environmental impacts of the point absorber.

- ABS Rules for Classification and Construction of Marine Structures: it covers the design, construction, and operation of marine structures, including those used in wave energy conversion systems. It includes requirements for materials, structural design, and loadings.

- ISO 19901-1:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 1: General requirements

- ISO 19901-2:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 2: Materials and fabrication

- ISO 19901-3:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 3: Structural design

- ISO 19901-4:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 4: Foundations

- ISO 19901-5:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 5: Loads and load combinations.

- ISO 19901-6:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 6: Structural analysis

- ISO 19901-1:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 1: General requirements

- ISO 19901-2:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 2: Materials and fabrication
- ISO 19901-3:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 3: Structural design
- ISO 19901-4:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 4: Foundations
- ISO 19901-5:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 5: Loads and load combinations.
- ISO 19901-6:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 6: Structural analysis

3.3. Design calculations

3.3.1 Scaling

When scaling a tiny WEC, the small-scale version must have the same properties as the full scaled version. The physics that work for the full scaled version must also work for the scaled-down version. Several techniques to creating such a form can be discussed. Modelling a PTO can be difficult and unsuitable for implementation. As a result, a special scaling law can be used to solve such problems. Dimensionless quantities such as the Froude number (Fr), Reynolds number (Re), Mech's (Mn), and Weber's (Wn) can be used to calculate the consistency between the laboratory model and the full-scaled model. Among these, the Froude and Reynolds scaling is one of the best options for the PTO. And the Froude scaling approach is applied throughout this investigation.

The Froude and Reynolds figures are in relation to the full-scaled prototype and the model-scaled version, respectively. This parameter should be as stable as feasible. However, keeping the numbers steady is impractical because it implies that fluid does not exist. As a result, it is unsuitable for practice testing. As a result, 14 a specific approach for practically scaling a WEC should be created. The Froude scaling and Reynolds numbers are defined as:

$$\mathrm{Fr} = \frac{\mathrm{U}}{\sqrt{\mathrm{gL}}} \tag{1}$$

[20]

$$= \frac{\mathrm{pUL}}{\alpha} \tag{2}$$

Here:

the U represents the velocity of the fluid, L represents the device's length,

g is gravity's acceleration,

the ρ represent the fluid density,

and α denotes the dynamic viscosity of the fluids.

The Froude number Fr indicates that the inertial force is proportional to gravity. And the Reynolds number Re indicated the inertial force is relative to the viscous force. However, in wave tank studies, the Reynolds numbers cannot be too low since a low Reynolds number induces viscosity in the device. As a result, the parameters are applied appropriately based on the investigation. Froude scaling is an appropriate parameter for wave tank testing since gravity force is greater than viscous force[21], as shown in *Table 7*.

Table 7: Froude's scaling factors [21]

Quantity	Scalingfactor
Linear displacement	μ
Angular displacement	1
Translational velocity	$\mu^{0.5}$
Angular velocity	$\mu^{-0.5}$
Translational acceleration	1
Angular acceleration	μ^{-1}
Mass	μ^{3}
Force	μ^{3}
Torque	μ^{4}
Power	$\mu^{3.5}$
Linear stiffness	μ^{2}
Angular stiffness	μ^{4}
Linear damping	$\mu^{2.5}$
Angular damping	$\mu^{4.5}$
Wave height and length	μ
Wave period	$\mu^{0.5}$
Wave frequency	$\mu^{-0.5}$

Power density	$\mu^{2.5}$

The scaling factor is represented by in Table *7*, For example, if the power is 3.5, the full-scale value of the power will be split by the scaled factor to the power 3.5 for tank testing. As a result, if the scaling factor is 20, the model power will be:

$$\mathrm{PPm} = 20^{3.5}$$

Here Pm is the model power, and P is the full-scale power value.

3.3.2. Tank Design Calculations:

One of the important criteria for the wave energy converter is the sea state. As a result, the Mediterranean Sea will be considered for this investigation. The specific sea has a diverse geography, and the Mediterranean wave environment has a longer duration of swells. A wind sea exists in the sea, where waves of varying heights, durations, and directions combine to produce unpredictable conditions. As a result, a point absorber is an ideal wave energy solution for such sea states. Various key factors for marine conditions exist all around the world. Significant wave height and period are two of them. The significant wave height is traditionally defined as the mean wave height (peak and trough) of the third highest wave; in this case, the subscript "1/3" is used. However, significant wave height is currently defined as four times the standard deviation of the surface elevation, or four times the square root of the zeroth-order moment of the wave spectrum. "mo" is the subscript used in this definition. As a result, the significant wave height is known as "Hmo" or "Hs." The difference between the two definitions is negligible. The peak wave period "Tp" is the one with the most energy in the spectrum.

According to Zahra Shahroozi's extreme wave investigation for point absorbers, the 1:30 scaled version of the WEC is used for calculating force for various sea states and conditions of motion. In this study, the parameters in table 8 serve as the extreme wave reference. The figures aid in the approximation of forces when compared to the Mediterranean Sea state. [22]shows the wave heights and peak durations, a comparison to the Mediterranean Sea wave value simplifies the selection of the essential force values. Only the forces induced by normal conditions are addressed in this paper's scaling simulation. As a result, the estimated numbers can be used in comparison to the Mediterranean Sea state.

Table 8 wave parameters full scale and with scale (Shahroozi et al., 2022)

scaling factor 1:30			Full scaled		
Wave (Hs)(m)	Peak Wave Period (Ts) (s)	Forces [N]	Wave Height (Hs)(m)	Peak Wave Period (Tp)(m)	Forces [kN]
0.18	1.64	200	5.4	8.9	5400
0.12	1.64	100	3.6	8.9	2700
0.07	1.64	40	2.1	8.9	1080
0.22	2.10	150	6.6	11.50	4050
0.18	2.56	110	5.4	14.02	2970
0.12	3.30	125	3.6	18.07	3375
0.07	4.29	75	2.1	23.49	2025

Table 9 full scaled parameters (Shahroozi et al., 2022)

Full scaled		
Significant Wave Height (Hs) [m]	Peak Wave Period (Tp)[s]	Forces [kN]
5	9	300
3.5	9	250
2.5	10	108
5.5	12	270

Based on this research, the approximate values for the buoy's forces have been derived. The full-scaled values of the forces utilized in this simulation are listed in Table 9

The Table Below shows the dimensions of the wave tank and point absorber at scales of 1:1 and 1:35.

Table 10 Tank parameters after scaling

Full Scale		
Water Depth	**Wave Period**	**Wavelength**
40	**7**	**76.5**
Scaled to 1:80		
0.5	**0.78**	**0.96**

The tank dimensions can be calculated according to [23] formulas:

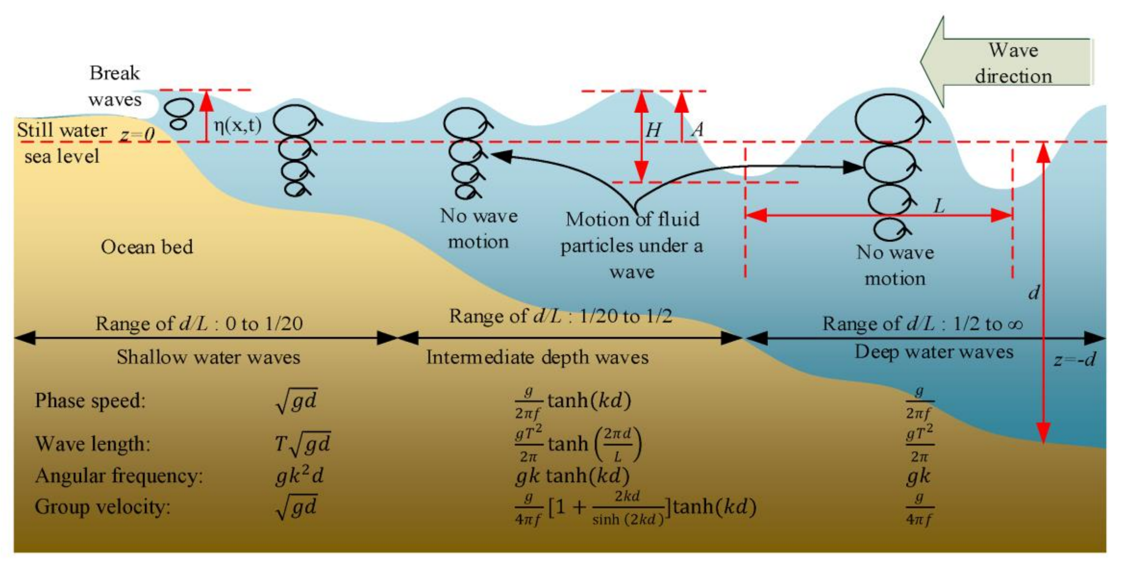


Figure 30:Sketch of ocean waves representing the prominent wave parameters in the varying depths of water.[24]

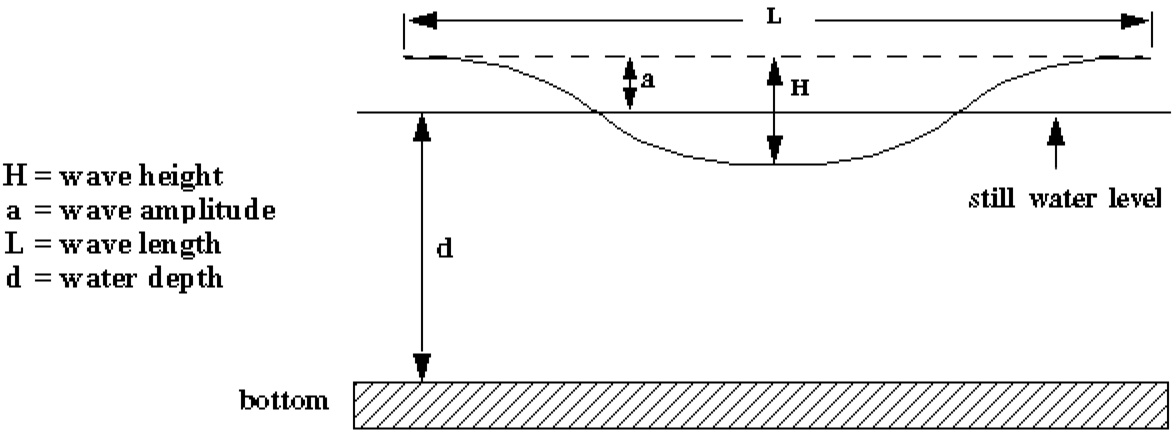


Figure 31 Water Wave Celerity [25]

$$\lambda = \frac{gT^2}{2\pi} \tag{3}$$

$$= \frac{(9.81)(7)^2}{2\pi} = 76.5\text{m}$$

$$\frac{D}{\lambda} \tag{4}$$

$$\frac{D}{\lambda} = \frac{40}{76.5} = 0.522 > \frac{1}{2}$$

Table 11 Unscaled wave parameters

Wave height (m)	Period(s)	Frequency (Hz)	Wavelength(m)	Water depth(m)
0.075	0.76	1.2	0.96	0.75
Wave height (m)	Period(s)	Frequency (Hz)	Wavelength(m)	Water depth(m)
4	7	0.14	76.5	40

$$\mathrm{D}' = 40 \times \left(\frac{1}{53}\right) = 0.75\mathrm{m}$$

$$\mathrm{T}' = 7 \times \left(\frac{1}{53}\right)^{0.5} = 0.96\mathrm{s}$$

$$\mathrm{H}' = \frac{4}{53} = 0.075\mathrm{m} = 2\mathrm{A}' = \mathrm{A}' = 0.038\mathrm{m}$$

$$\lambda = \frac{76.5}{53} = 1.44\mathrm{m}$$

$$M_w = D' + A' \tag{5}$$

$$M_w = 0.75 + 0.05 = 0.08\mathrm{m}$$

$$c = \frac{\lambda}{T} \tag{6}$$

$$= \frac{76.5}{7} = 10.9\mathrm{m/s}$$

$$\mathrm{c} = \frac{\lambda}{\mathrm{T}} = \frac{0.96}{0.78} = 1.23\mathrm{m/s}$$

Using the obtained wavelength, we can determine the length of the tank since we need to obtain a minimum of two times the wavelength.

Wave maker equations for stroke required (Berends, 2021).

Wave height H = 0.075m

Period T= 0.76s

Frequency = 1.2Hz

Wavelength = 0.96m

Water depth = 0.75m

$$c = \frac{g}{\omega}\tanh(kd) = \sqrt{\frac{g}{k}\tanh(kd)} \tag{7}$$

3.3.3. Wave maker calculation:

$c = \sqrt{\frac{g}{k}} = \frac{g}{\omega} = \frac{g}{2\pi}T = 1.56T\left[\frac{m}{s^2}, s\right].$

$c = \sqrt{\mathrm{gd}}$

c = 2.71m/s

$c = \frac{g}{\omega} = \omega = \frac{g}{c} = \frac{9.81}{2.71} = 3.62$

$\alpha = \frac{\omega^2 d}{g}$ and $\beta = \alpha(\tanh(\alpha))^{-\frac{1}{2}}$

$\alpha = \frac{\omega^2 d}{g} = \frac{3.62^2 x 0.75}{9.81} = 1.001$

$\beta = 1.001(\tanh(1.001))^{-\frac{1}{2}} = 3.89$

Substituting alpha and beta into the equation below.

$$kd \approx \frac{\alpha + \beta^2(\cosh(\beta))^{-2}}{\tanh(\beta) + \beta(\cosh(\beta))^{-2}} \tag{8}$$

$kd \approx 3.62$

$$\left[\frac{H}{S}\right]_{\text{llap}} = 4\left(\frac{\sinh(kh)}{kh}\right)\left(\frac{kh\sinh(kh) - \cosh(kh) + 1}{\sinh(2kh) + 2kh}\right) \tag{9}$$

$$\left[\frac{H}{S}\right]_{\text{llap}} = 1.46cm$$

At a wave height of 5 cm the Stroke require S

= 5/1.46 = 3.42cm

3.3.4. Shaft design calculations:

The shaft of length 0.7m from bearing A to bearing B will be added with a reinforced plate of galvanised steel at the centre distanced 0.05m from the bearings on both ends. To design the shaft 3 moments acting on the shaft calculated below.

$$\sum M_A = 0$$

$$L1 \times F1 + L2 \times F2 + B \times L3 = \sum M_A \tag{10}$$

F1 and F2 are force caused by the plate made of galvanised steel which has a weight of 96 N considering reinforcements a factor of safety of 2 = 192N

$$0.05m \times 192N + 0.55 \times 192N + B \times 0.6m = \sum M_A$$

$$B = 192N$$

$$M_A = 192N \times 0.6m = 115.2Nm$$

The forces are in equilibrium, so A and B are equal.

The dynamic force obtained from equation (equation number) is 2400N multiplied by 0.63 the result is 1512Nm and the holding torque provided by the motor equalling 10 Nm.

$$\tau = \sqrt{M_A + M_B + T_M} \qquad (11)$$

$$\tau = \sqrt{115.2 + 1512 + 10} = 40.4Nm$$

$$\frac{\tau}{\tau_{all}} = \frac{J}{c} = \frac{40.4}{250MPa} = 1.616 \times 10^{-7}$$

$$\frac{J}{c} = \frac{\pi}{2}c^3 = \sqrt[3]{\frac{2 \times 1.616 \times 10^{-7}}{\pi}} = c = 4.6 \times 10^{-4} \approx 0.005m$$

$$d = 0.01m$$

With a factor of safety of 1.3 d = 0.13m

3.4. Load calculations:

Hydrostatic Force: For calculating pressure acting at the centre of the end sheet:

$$F = P_{ave} \text{ x } A \qquad (12)$$

$$F = \frac{1}{2}\rho gh \times h \times w \qquad (13)$$

$$\therefore F = \frac{1}{2}(100 \times 9.81 \times 0.75)(0.75 \times 0.65) = 1793N$$

Stress and deflection Analysis for Galvanized Steel sheets and Plexi glass [26]

	Simply Supported		Fixed-Fixed	
	Stress (Pa)	Deflection(m)	Stress (Pa)	Deflection(m)
Plexis of 0.01m thickness a= 1	$5x10^6$	-0.031	$5.5x10^6$	0.012
Plexis of 0.01m thickness a=2	$5x10^6$	-0.5	$8.9x10^6$	0.3
Plexis of 0.02m thickness a=1	$2.7x10^6$	-0.009	$1.3\ x10^6$	0.0015
Plexis of 0.02m thickness a= 2	$2.7x10^6$	-0.15	$2.2\ x10^6$	0.049
Galvanised steel of 0.003m thickness a = 1	$95.8\ x10^6$	-0.024	$101.5\ x10^6$	-0.007
Galvanised steel of 0.003m thickness a = 2	$203.4\ x10^6$	-0.123	$165.8\ x10^6$	-0.031

From the table above we can evaluate that it would is recommended to fix the sheets on all ends instead of leaving them simply supported as the deflection expressed in the fixed-fixed state is significantly lower than the simply supported.

- For choosing the sheets thickness it would be possible to choose either 20mm or 10mm thickness.
- The 20mm can used with minimal supporting frames and stringers.
- The 10mm thickness sheet can used with more supporting stringers per sheet to reduce its deflection.
- A10mm thickness will be considered with supports throughout the design and development of the project.

The load calculations performed to select an economical beam that can support the weight of the tank. (Wang, 2003)

$$mass\ of\ water + mass\ of\ tank = Mass\ total$$

The mass of the flapper and the frame beams could be neglected in comparison with the mass of water and the galvanize steel sheets mass because the load will be distributed in the beams of the frame.

❖ **For the galvanized steel sheets mass** (3mm thickness)**:**

$\mathbf{3}\ sheets\ at\ side\ walls, \mathbf{2}\ at\ end\ walls\ and\ \mathbf{3}\ at\ the\ base$

Total mass:

side wall: $3 \times density \times volume\ of\ single\ sheet = 3 \times 7800 \times 6 \times 10^{-3} = 140.4kg$

For the base: $3 \times density \times volume\ of\ single\ sheet = 3 \times 7800 \times 3.6 \times 10^{-3} = 84.24kg$

For the walls: $2\times\ density \times volume\ of\ single\ sheet = 2 \times 7800 \times 1.8 \times 10^{-3} = 28.08kg$

❖ **For plexi glass sheets mass** (10mm thickness):

3 sheets at side walls

$$plexi\ glass\ mass = 3 \times density \times volume\ of\ single\ sheet = 3 \times 1190 \times 0.02$$
$$= 71.4\ kg$$

$\boldsymbol{Total\ mass\ of\ all\ the\ sides} = 140.4 + 83.24 + 28.08 + 71.4 = 323.1kg$

water weight at 0.75m depth $= 2.7\text{m}^3 \times 998\text{kg/m}^3$= 2694.6N

Total Weight = 2694.6+323.1=3020N

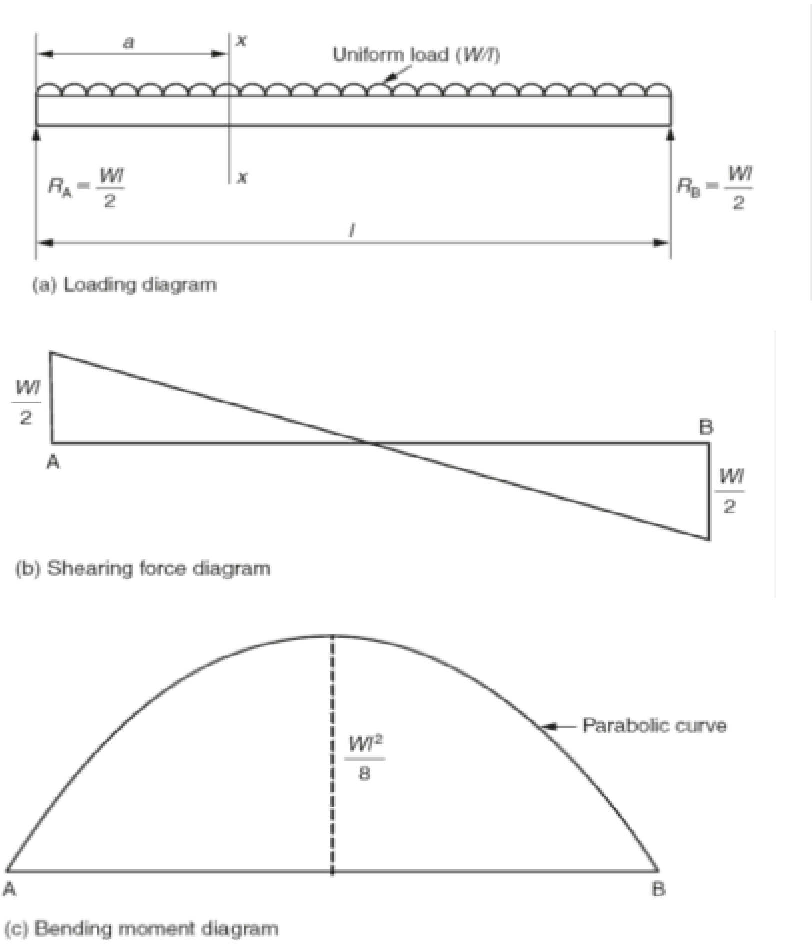


Figure 32 Calculation for Uniformly Distributed load

[27]

Assuming a distributed load of 2000 N acting on the beam of a 2m segment. (Beer, 2011)

The Force q = 2000 ×10m/s^2

=20000N

Uniform Load = $q \times L$ = 20000N/m 2m = 40kN

Each support load = ½ ×40kN = 20kN each side

Moment at max = (40kN×2)/8

Moment at max = 10000N.m

Assuming Structural steel for the material if the wide flange to act as the base of the tank. It has an ultimate tensile strength of 250MPa.

$$S = \frac{I}{c}, \sigma = \frac{Mc}{I}, \quad S_{\text{req}} = \frac{M_{max}}{\sigma_{\text{allow}}} \tag{14}$$

From appendix C-A19 of the mechanics of materials, we can design for a beam that provides us with a factor of safety of two.

The Ultimate strength is 250MPa.

$$S_{\text{req}} = \frac{10 \times 1000 \times 1000 N.mm}{250\text{N}/mm^2}$$

$$S_{\text{req}} = 40 * 10\text{^}3$$

From the appendices the wide flanges come close to the section modulus which are the W100x19.3 with a section modulus of 89.1.

$$S_{\text{req}} = \frac{89.1}{40}$$

$$\text{F.O.S} = 2.24$$

It satisfies the factor of safety requirements so this beam can as the base of the project.

3.5. hydrodynamic pressure calculations

3.5.1. Impulsive hydrodynamic pressure:

- On the wall p_{iW}:

$$\boldsymbol{p_{iW} = Q_{iW}(y)(A_h)_i \rho g h} \tag{15}$$

$$\boldsymbol{Q_{iW}(y) = 0.866\left[1 - \left(\frac{y}{h}\right)^2\right] \tanh\left(0.866\frac{L}{h}\right)} \tag{16}$$

$$\boldsymbol{A_{hi} = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}} \tag{17}$$

$A_{hi} = \frac{0.18}{2}\frac{1}{2.5}1.5 = 0.054$

$Q_{iW}(y) = 0.866\left[1 - \left(\frac{0.7}{1}\right)^2\right]\tanh\left(0.866\frac{6}{1}\right) = 0.437$

$p_{iW} = 0.437 \times 0.054 \times 997 \times 9.81 \times 1 = \boldsymbol{230.801\ N}$

- On the base p_{ib}

$$\boldsymbol{p_{ib} = Q_{ib}(x)(A_h)_i\rho g h} \tag{18}$$

$$\boldsymbol{Q_{ib}(x) = \frac{\sinh\left(1.732\frac{x}{h}\right)}{\cosh\left(0.866\frac{L}{h}\right)}} \tag{19}$$

$Q_{ib}(x) = \frac{\sinh\left(1.732\frac{2.5}{1}\right)}{\cosh\left(0.866\frac{6}{1}\right)} = \frac{37.965}{90.277} = 0.421$

$p_{ib} = 0.421 \times 0.054 \times 997 \times 9.81 \times 1 = \boldsymbol{222.351\ N}$

3.5.2 Convective Hydrodynamic Pressure:

- **On the wall**

$$\boldsymbol{p_{cW} = Q_{cW}(y)(A_h)_c\rho g h} \tag{20}$$

$$\boldsymbol{Q_{CW}(y) = 0.4165 \frac{\cosh\left(3.162\frac{y}{L}\right)}{\cosh\left(3.162\frac{h}{L}\right)}} \tag{21}$$

$$A_{hc} = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g} = \frac{0.18}{2}\frac{1}{2.5}\ 1.75 = 0.63$$

$$Q_{CW}(y) = 0.4165\frac{\cosh\left(3.162\frac{0.7}{6}\right)}{\cosh\left(3.162\frac{1}{6}\right)} = 0.4165 \times \frac{1.068}{1.142} = 0.389$$

$$p_{cW} = 0.389 \times 0.63 \times 997 \times 9.81 \times 1 = \mathbf{2396.92\ N}$$

- **On the base:**

$$\boldsymbol{p_{cb} = Q_{cb}(x)(A_h)_c \rho g h} \tag{22}$$

$$\boldsymbol{Q_{Cb}(x) = 1.25\left[\frac{x}{L} - \frac{4}{3}\left(\frac{x}{L}\right)^3\right]\mathrm{sech}\left(3.162\frac{h}{L}\right)} \tag{23}$$

$$Q_{Cb}(x) = 1.25\left[\frac{2.5}{6} - \frac{4}{3}\left(\frac{2.5}{6}\right)^3\right]\mathrm{sech}\left(3.162\frac{1}{6}\right) = 0.415$$

$$p_{cb} = 0.415 \times 0.63 \times 997 \times 9.81 \times 1 = \mathbf{2557.13\ N}$$

The impulsive hydrodynamic pressure will be used.

Note: All the parameters are shown in *Figure 33*.

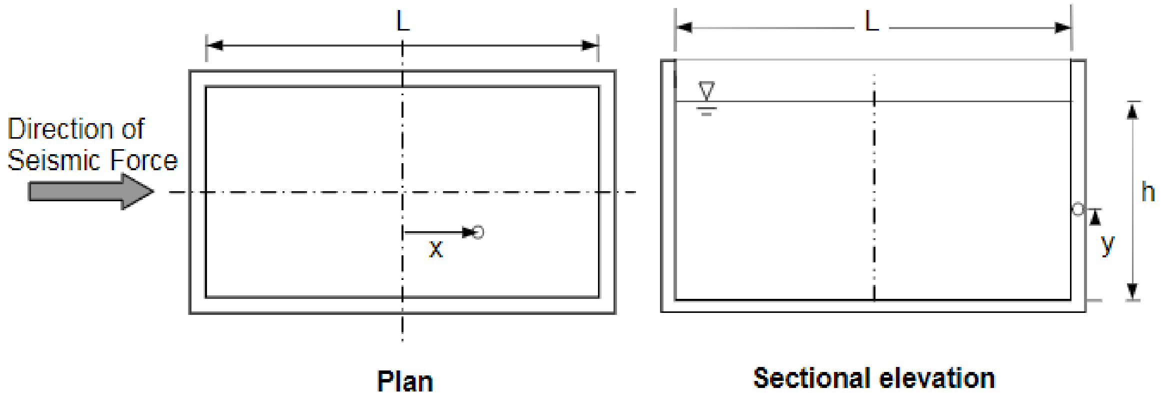


Figure 33 Seismic parameters

3.6. Power, Force & Torque Calculations:

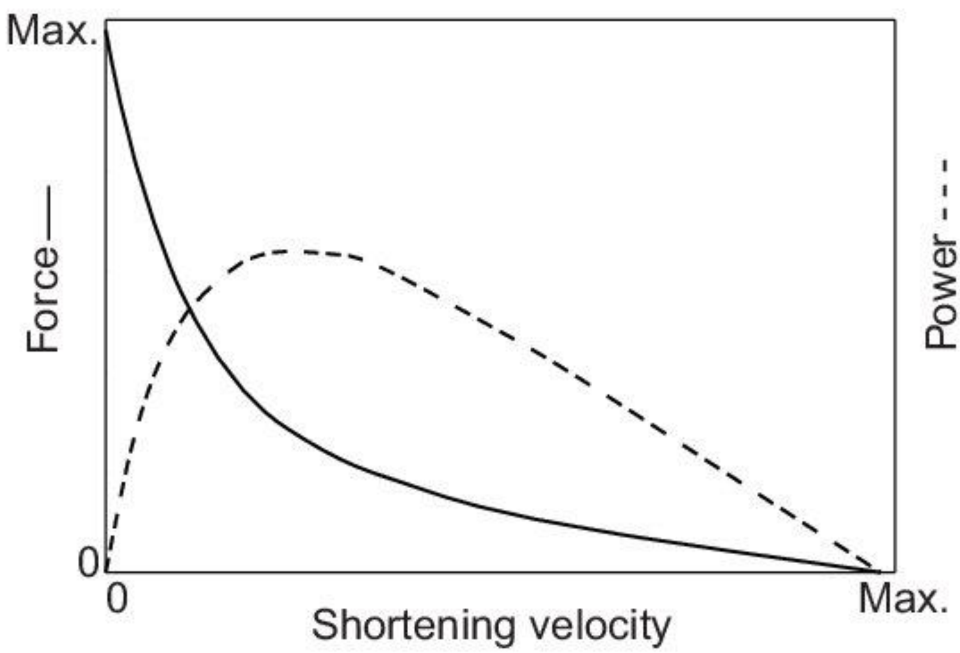


Figure 34:. Hill's pioneering experiments provided the force-velocity curve shown here. Because power is the product of force and velocity, these two measurements yield one more variable. Adapted from Hill (1950).

Power = Force X Wave Velocity

The basic relationship for Wave Velocity is given in Equation (24) (Wang, 2003)

$$v = d / t = \frac{\lambda}{t} \tag{24}$$

From equation(13) the force can be determined:

$$F = \frac{1}{2}\rho g h \times h \times w$$

$$F = \frac{1}{2}(1000 \times 10)(0.75)^2(0.65) = 1768\ N$$

$P_{avg=}$ (1/2) (1000) (10) (0.8) =2.5KPa

Power with FOS= 2600N X $\frac{0.96}{0.78}$ = 3.2 KW

For wave Power calculations we will use equation (28) (Wang, 2003)

$$\mathrm{P} = \frac{\rho g^2}{64\pi} \mathrm{H}_{m0}^2 \mathrm{T} \approx \left(131.53 \frac{\mathrm{W}}{\mathrm{m}^3 \cdot \mathrm{s}}\right) \tag{25}$$

Where:

P: is the wave energy flux per unit of wave-crest length,

Hm0: the significant wave height,

T: the wave period,

ρ: the water density

g: the acceleration by gravity

3.7. Buoy Design Calculations:

3.7.1. The buoy diameter design

The actual diameter of the buoy is 22m with reference to “optimal design of wave flume in **Error! Reference source not found.**, We scaled it to:

$$\mathrm{D_{buoy}} = {}^{1}/_{80} \times \mathrm{D_{actual}} \tag{26}$$

$$= 0.0125 \times 22 = 0.275\mathrm{m}$$

3.8. Motor Torque Calculations:

$$A = L \times W \tag{27}$$

$$= 1 \times 0.6 = 0.6\mathrm{m}^2$$

$$P = 0.5 \times \rho \times g \times h \tag{28}$$

$$= 997 \times 9.81 \times 0.5 \times 0.5 = 2396\mathrm{N/m}^2$$

$$F = P \times A \tag{29}$$

$$= 2396 \times 0.6 = 1435.2\ \mathrm{N}$$

To calculate the torque using equation (30) [28]:

$$T = F \times D \tag{30}$$

$= 1435.2 \times 0.5 \times \tan\left(\frac{22\pi}{180}\right) = 4.81\text{Nm}$

4.8 Nm * 10 kg.cm/Nm = 48 kg.cm

That is the max torque required to move the hinged flap when submerged a set of motors with a 20kgcm rating can be used as actuators.

3.9. Voltage Output Estimation:

In the linear generator, the magnetic flux is generated by the permanent magnets on the translator can be calculated by equation (34) [29]:

$$\phi = \phi_0 sin\,(kx + \theta) \tag{31}$$

ϕ_0 =1.0

$\mathrm{k} = \frac{2\pi}{\lambda} = \frac{2\pi}{0.95} = 6.61$

$\mathrm{x} = 0.215$
$\theta = 180°$

$\phi = 1\sin\big((6.61 \times 0.215) + 180\big) = -0.025$

If the magnetic flux is time dependent on the x-axis, the flux can be derived with respect to time [29]:

$$\frac{d\phi}{dt} = k\phi_0 cos\,(kx + \theta) \cdot \frac{dx}{dt} \tag{32}$$

$$\frac{d\phi}{dt} = 6.61(1.0)\cos\left((6.61 \times 0.215) + 180\right) \times 0.287 = -1.90$$

According to Faraday's Law, when the magnetic flux is induced and flows through the path of magnet circuit, the voltage is also generated according to the change of magnetic flux over time. The induced open-circuit voltage is expressed as shown in equation (33) [29]:

$$\varepsilon = -N\frac{d\phi}{dt} \tag{33}$$

where N is the number of turns of the coils. Inserting (32) into the right-hand side of (33), then (37) is obtained:

$$\varepsilon = -Nk\phi_0 cos\,(kx + \theta) \cdot \frac{dx}{dt} \tag{34}$$

$$\epsilon = -490 \times -1.9 = 931\text{mV}$$

3.10. Efficiency of the Point Absorber

The efficiency of the point absorber of WECs can be calculated by the equation (35) below:

$$\text{Efficiency } (\eta) = \frac{\text{Power Absorbed}}{\text{Power available within the waves}} \tag{35}$$

The power absorbed being the output power of the point absorber and the possible power absorption from the waves. This will allow a proper estimate of how much power the point absorber can contain with wave power being (25):

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T \approx \left(131.53 \frac{W}{m^3 \cdot s}\right) H_{m0}^2 T$$

Where:

P: is the wave energy flux per unit of wave-crest length,

Hm0: the significant wave height,

T: the wave period,

ρ: the water density

g: the acceleration by gravity

3.11 Cost Effectiveness:

The cost efficiency of a point absorber wave energy converter can be determined by calculating the levelized cost of energy (LCOE), which represents the cost of generating one unit of energy kWh (kilowatt-hour) over the lifetime of the device.[30]

To calculate the LCOE for a point absorber, the following parameters Capital costs, Operational costs, Energy output and Lifetime of the device should be considered (36) [30].

$$\text{LCOE} = (\text{Capital costs} + \text{Operational costs}) \div (\text{Energy output} \times \text{Lifetime of the device}) \tag{36}$$

$$\text{Performance Index }(PI) = \frac{\text{Device Cost }[k€]}{\text{Net Productivity }\left[\frac{MWh}{\text{year}}\right]} \tag{37}$$

3.12 Linear Generator Dimensions:

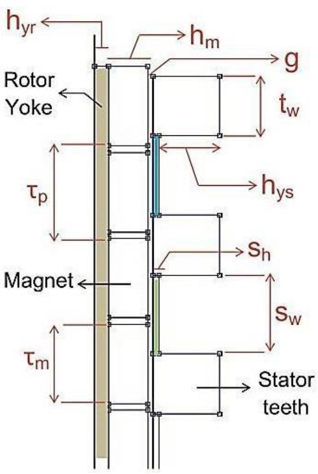


Figure 35 dimensions names [30]

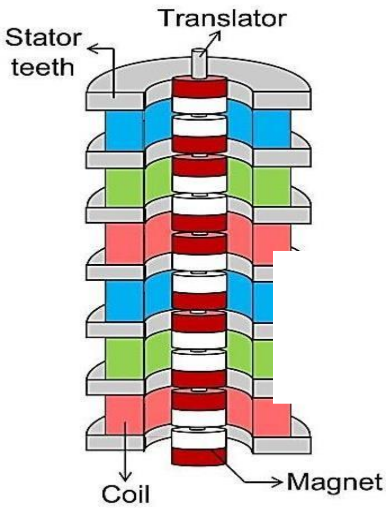


Figure 36 generator over all shape [30]

Table 12 stator parts

Part, Symbol	Value	Unit
Pole pitch, τ_p	15	mm
Magnet length, τ_m	10	mm
Magnet thickness, h_m	30	mm
Translator yoke thickness, h_{yr}	10	mm
air gap, g	5	mm
Tooth width, t_w	7.5	mm
Slot width, s_w	10	mm

Slot height, s_h	3.5	mm
Stator yoke thickness, h_{ys}	10	mm
Number of the magnet, 2p	10	units
Translator total length, L_t	108	mm
Number of the slot, n_{sl}	10	units
Stator total length, L_s	105	mm
Number of turn/slots, N_s	490	turns

The iron-cored model has ferromagnetic materials filling the whole stator body *Figure 35.* The teeth are radially inward extensions of the stator yoke. The dimensions of the stator parts shown in *Table 12* are determined based on the expected output, and the use of a stator with coils mounted to it is also a consideration.

3.15 Cost analysis:

The Bill of Materials is shown in *table 14* and the Cost analysis chart is shown in Figure 37 shown in the next pages.

Part No.	Item	Description	Details	Qty	Unit Price ($)	Total Price(£)	Total Price (€)	Total Price ($)	Reference
1-1-1-1-2	**Plexi Glass Sheets**	**Plexiglas is a transparent material that allows for clear observation of the water and wave behaviour within the tank. This transparency is beneficial for studying wave patterns, flow dynamics, and the behaviour of objects or structures submerged in the water.**	**3 Sheets with Dimensions:** **187,5cm x 103,5 cm** **190,5cm x 104cm** **196cm x 103,5cm**	**3**	**400**	**961.62**	**1118.50**	**1200**	**Pem Reklam & Pazarlama Ltd.** **10. Sokak, No: 53, Organize Sanayi Bölgesi, Lefkoşa-Kıbrıs**
1-1-1-1-1	**Galvanized Steel Sheets**	**Galvanized steel can be used in the construction of a wave tank to provide structural support and resistance to corrosion.**	**5 Sheets with dimensions :2mX1mX0.002m 2x1x0.003**	**5**	**39**	**151.52**	**175.13**	**195.00**	**GUNES-Gazimagusa Sanayi Bolgesi**
1-1-1-1	**Steel Frame**	**For reinforcing the tank**				**524.60**	**611.37**	**660**	**GUNES-Gazimagusa Sanayi Bolgesi**
1-1-4	**Wave Maker (Flap) Stainless steel**	**A flapper mechanism is a common device used in wave tanks to generate waves or simulate wave motion.**	**1 sheet with dimensions:** **1mX0.6mX0.002m**	**1**	**55**	**42.74**	**49.40**	**55.00**	**GUNES-Gazimagusa Sanayi Bolgesi**
1-1-5	**Bearings**	**Bearings are commonly used to attach the flap or barrier to the pivot point, allowing it to rotate back and forth.**	**2 Bearings with dimensions 0.02mX0.06mX0.023m**	**2**	**25.00**	**39.74**	**46.32**	**50**	**https://www.trendyol.com/senel-yapi-market/12-cm-celik-cerman-yonsuz-mentese-kutu-26-adet-p-277292568**

1-1-3	Stepper Motor	When creating waves in a wave tank using a flapper mechanism, a Stepper motor can be used to drive the movement of the flap	Max.displacement: Up to 397 cc/rev Max.torque: 61 daNm (Cont. operation) Max.output power: 15kW Max.pressure drop: 175 bar (Cont. operation) Max.oil flow: 75 liter/min Min.speed: 10 rpm	1	87.99	69.94	81.51	87.99	https://www.robotistan.com/mg995-12-kg-servo-motor-en
1-1-2	Microcontroller	The Arduino Uno can interface with a servo motor that drives the movement of the flap in the wave tank. By connecting the servo motor to one of the digital pins on the Arduino Uno, you can use the Arduino's built-in servo library to control the motor's position and speed.	2 Boards	2	7.00	10.88	12.57	14.00	https://www.robotistan.com/orjiginal-arduino-uno-r3-new-version
1-1-2	Power Supply	Ac-Dc converter Power Supply	24V 150W	1	50.00	40.07	46.62	50.00	IZMIR ELECTRIC

1-2-4-1	**Accelerometer**	**An accelerometer is a device that measures acceleration, which can be used to measure the movement and vibration of a point absorber ocean wave energy converter. The converter moves in response to the waves, and this motion can be measured by the accelerometer**	**1 ADXL345 3-Axis Accelerometer - Triple Axis Accelerometer Breakout -**	**2**	**8.00**	**6.36**	**7.41**	**16.00**	**https://www.robotistan.com/adxl345-3-eksen-ivme-olcer-triple-axis-accelerometer-breakout-adxl345**
1-2-4-2	**Bluetooth Module**	**To send signals from the accelerometer to the PC**	**1 HC06 Bluetooth-Serial Module Board**		**5.00**	**3.89**	**4.49**	**5.00**	**https://www.robotistan.com/kablolu-hc06-bluetooth-serial-modul-karti-hc06-bluetooth-to-serial-port-m**
Manufacturing Cost & Adhesives (Cutting, Milling, Coating , Drilling & Welding)						**1033.31**	**1204.21**	**1300**	
Shipping, Customs and Transportation Cost						**64.02**	**74.48**	**80.00**	
						3365.59	**3917.89**	**4,207.99**	

Table 13 Cost analysis

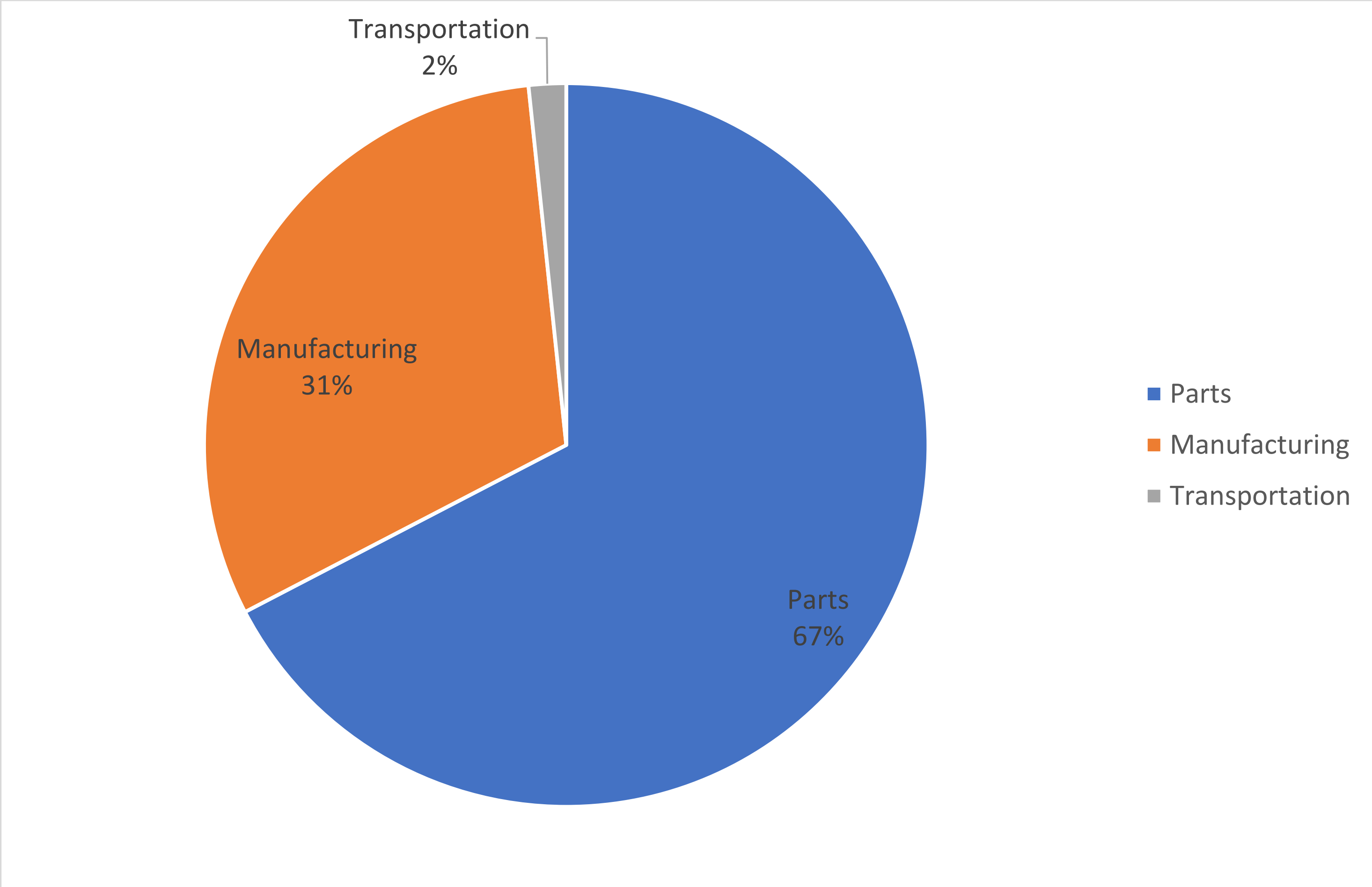


Figure 37 Pie chart showing percentage of each component cost out of total

CHAPTER 4 – MANUFACTURING

4.1. Manufacturing process selection

4.1.1 Tank Manufacturing selection:

For the tank design it is comprised of 3 parts namely the frame and bolts, the galvanised steel sheets and finally the plexi glass sheets. For the manufacturing of the tank and installation of the sheets it has 2 options which were self-made or external manufacturing. The Pugh's matrix below shows the benefits and drawbacks of each method, *ranking policy: [10 is highest and 0 is lowest].*

Table 14 Selection of manufacturing method

Criteria 1-lowest 10- highest	Methods	
	Self-Manufactured	External Manufacture
Cost	8	10
Reliability	6	9
Speed	7	8
Durability	6	9
Material usage	9	6
Accuracy	6	8
Total	42	50

The objective of this manufacturing plan of the tank is to outline the steps involved in creating a water wave testing tank. The tank will consist of one transparent side and the other sides is not transparent, a frame for support, the tank's shape should be strong, and highly resistant to corrosion, which is particularly important for tanks exposed to saltwater or other corrosive substances. And the material of the tank must be easy to cut drilled and shaped into a wide shape of the designs and configurations.

4.1.2. Frame support:

There are a few things to consider when choosing the appropriate material for a frame that can hold a water wave testing tank, including strength, corrosion resistance, weight, and cost. For tank frames, the following materials are frequently used, *ranking policy: [10 is highest and 0 is lowest].*

Table 15 Selection of frame support material

Criteria 1-lowest 10-highest	Materials		
	Steel	Aluminium	Concrete
Cost	10	5	5
Manufacturability	9	5	3
Strength	9	7	6
Weight	6	9	2
Water Resistibility	4	9	7
Ductility	10	7	4
Total	48	42	27

Steel: Due to their excellent strength and longevity, steel frames are employed extensively. Steel is a great material for sustaining huge water wave testing tanks because of its strong load-bearing capability and structural integrity. The water proofing for steel can be rectified by painting it and coatings to reduce corrosion and improve on its heat resistance.

Aluminium: Aluminium frames are easy to fabricate, have an excellent strength-to-weight ratio, and are resistant to corrosion. They work well for portable or smaller tanks since they are lighter than steel frames. Although aluminium frames are more costly than steel, they offer higher corrosion resistance for applications involving water. Aluminium falls short as it is difficult to perform a welding process on it and it is significantly more expensive than steel even though it has a better weight to strength ratio.

Concrete: Concrete frames are a possibility for temporary or smaller-scale water wave testing tanks. The concrete would be sturdy enough to withstand the dynamic motion within the tank, but its high weight would bring it down as well as its ductility it would require steel reinforcements within it which is redundant.

As per the matrix a **steel frame** is most suited for the tank.

4.1.3 Transparent side:

The Table 16**Error! Reference source not found.** below material selection matrix for the transparent side of the testing tank, *ranking policy: [10 is highest and 0 is lowest].*

Table 16 selection of transparent side material

Criteria	**Plexi-Glass**	**Acrylic Sheets**	**Glass**	**Micah-glass**
Cost	(9)	(6)	(6)	(7)
Transparency	(9)	(6)	(10)	(4)
Strength	(6)	(6)	(7)	(5)
ductility	8	7	5	5
Weight	(8)	(7)	(5)	(9)
Manufacturability	(9)	(9)	(3)	(9)
Score	(49)	(44)	(36)	(39)

Based on the above matrix **Plexi-Glass** appear to be the best choice for the testing tank transparent side material.

Other sides of the tank: the material of the other sides is selected to be **galvanize steel sheets** due to its availability, strength and it is eased to be assemble.

4.1.4 Wave flap**:**

The wave flap will be made of a material that is capable of corrosion resistance and can withstand the dynamic force generated in the tank without deflecting. It must be light and easy to add to the design the material selection for the flap is given below in Table 17, *ranking policy: [10 is highest and 0 is lowest].*

Table 17 Selection of wave flap material

Criteria	Galvanized Steel	Aluminium	Plexiglass
Weight	(5)	(6)	(8)
Strength	(9)	(6)	(3)
Corrosion resistance	(7)	(8)	(8)
Weldability	10	0	0
Total	31	20	19

Based on the above matrix the best material for the flap would have to be a **galvanized steel sheet**.

4.1.5 Permanent magnets:

Mainly the translator consists of rectilinear translating permanent magnets so mainly our focus is on the material of the magnet that gives high magnetic field to rise the efficiency of power output and it should have high strength to holdup to the up and down motion and unexpected actions of the sea state.

There are several types of permanent magnets that can be used in a linear generator. Some common materials used to make permanent magnets include:

- Neodymium magnets: These magnets are made of an alloy of neodymium, iron, and boron and are known for their strong magnetic field. They are commonly used in a variety of applications, including linear generators.

- Samarium cobalt magnets: These magnets are made of an alloy of samarium and cobalt and are known for their high temperature resistance and strong magnetic field. They are commonly used in applications where high temperatures are encountered, such as in the aerospace industry.

- Alnico magnets: These magnets are made of an alloy of aluminium, nickel, and cobalt and are known for their high magnetic field strength and resistance to corrosion. They are commonly used in a variety of applications, including linear generators.

- Ferrite magnets: These magnets are made of a composite of iron oxide and ceramic materials and are known for their low cost and high resistance to corrosion. They are commonly used in a variety of applications, including linear generators.

The Table 18 below shows a material selection matrix between the types of the permanent magnets, *ranking policy: [10 is highest and 0 is lowest].*

Table 18 selection of permanent magnets material

Criteria	**Samarium cobalt Magnets**	**Neodymium magnets**	**Alnico magnets**	**Ferrite magnets**
Magnetic field	9	10	6	3
Temperature resistance	9	5	7	6
Cost	4	7	6	9
Corrosion resistance	6	7	9	9
Score	28	29	28	27

The matrix shows that the neodymium magnets show a high magnetic field but low resistance to the temperature, the temperature is not a main concern in our design because the sea temperature varies between 0˚ C to 30˚C so this material will be selected as the best option.

4.2. Detailed manufacturing process

4.2.1 WT Manufacturing Process

1. Measuring tape
2. Circular saw or table saw.
3. Drill and drill bits
4. Screwdriver or power drill
5. Custom welding equipment for galvanize steel sheets.
6. Angle grinder
7. other tools used for insulation process.
8. Tools used for coating process.
9. Clamps, Safety equipment (gloves, goggles, etc.).

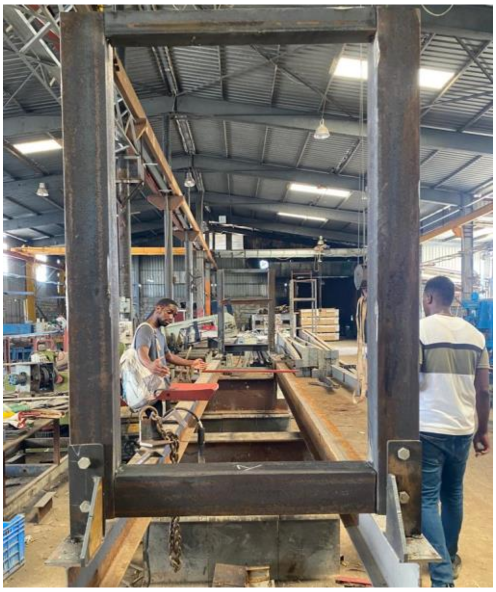


Figure 38 Base frame welded and bolted

The first step in the manufacturing of the tank was creating the base frame as shown in the figure with two end frames that account for the overall tank length.

Figure 39 Frame faces welded on two 6m I beams

The frame is fixed on 2 I beam by welding the outer frame face and then bolting the inner frame to the outer face.

Figure 40 Segment faces

The faces of the segments were made separately using angle iron and joined into the shape by welding.

Figure 41 Full 6m tank before segments are made

The next step is to add the tank segment faces to the frame, this allowed us to see a general or possible error that may be cause during manufacturing as one of the segments was a bit shorter which created an angle.

Figure 42 Welding of galvanised sheets to frame segment

The segments were then sawed off of the base and the galvanised steel sheets were joined to each segment by welding them to the angle iron frame to ensure no leakage.

Figure 43 Assembly of the 3 segments using bolts and washers

The segments were rejoined using nuts and bolts and silicone sealing to prevent leakage.

The three segments were missing the attachment section for the plexi glass so the holes needed to be drilled on the open face each hole was drilled manually with a spacing of 20cm between each hole in which the bolts will be added to attach the glass to the frame.

The plexi glass was cut and provided as well as attached by professionals in order to reduce the risk of poor attachment and or breaking the plexi glass sheets. Silicon and rubber were added to reduce the risk of leakage as well as ensure the plexi isn’t in contact with the steel as it may result in a crack forming.

4.2.2 Wave Maker:

Figure 44 Cutting the shaft with shearing machine

During the manufacturing of the shaft a 20 mm diameter rod was cut to allow machining processes to proceed

Figure 45 Turning of the shaft

Shaft undergoing turning.

the shaft underwent turning and surface turning to prepare it for attachment to the bearings.

The wave maker is made of a 1 m galvanised steel sheet which is welded to a shaft and reinforced with a frame.

The wave maker is attached at 1m from the end of the tank, four holes were made for attaching the bearings.

The shaft is then inserted into the bearings and the motor is attached directly to the shaft and controlled with a stepper motor driver with the speed adjusted with a potentiometer.

4.2.4 Buoy manufacturing:

The manufacturing process of this innovative buoy began with the careful dissection of an older model, skilfully executed to extract its core structure. Inside, a precision-engineered accelerometer was delicately installed, seamlessly integrating modern technology with the buoy's sturdy foundation. To ensure a durable and water-resistant seal, a specialized Copolymer adhesive was meticulously applied, creating an unyielding bond. A final layer of silicon was meticulously applied, providing an additional barrier against the elements, guaranteeing longevity and reliability in even the harshest marine environments. Once the buoy was meticulously assembled, it was expertly attached to its designated tank, poised to embark on its mission as a beacon of safety and data collection.

Figure 46 Sensor buoy with accelerometer installed.

Figure 47 Buoy attached to the wave tank third segment.

Figure 48:Final Tank Assembly

4.2.5 WEC Manufacturing:

1. First the stator should be installed into the generator housing and make sure the stator secondary isolation is perfectly done.

2. The magnets should be in a form of a translator inside the stator it will be linked to the rod which connects to the buoy.

3. After completing all these steps, the buoy is connected to the translator and placed in the tank 1m away from the wave flap.

4. The flap will be connected at 0.5m from the wall of the tank and will be fixed at the bottom with hinges.

Electrical components and motors

- The motors will be selected based on calculated torque; the motors will mostly push the flap from the above segment so the overall required torque decreases.

- The motors will be placed at the same level as the wave flap and connected in a perpendicular manner with a servo rod.

- The motors will be connected to a power supply from the breadboard, which is connected to the Arduino and potentiometer.

The Bluetooth module will also be connected to the Arduino board to collect data from the accelerometer wirelessly.

We will use the Zinc Yellow epoxy stainless steel aluminium paint epoxy for coating the steel frame and galvanized steel to act as a water barrier to protect from rusting. Even though galvanized steel has its own waterproof properties it will be and additive safety measure. Moreover, Plastic dip will be used for coating and waterproofing the servo motors as the liquid isn’t conductive hence it won’t cause damage to the motors.

Figure 49:Coating spray for galvanized steel [31]

4.2.3 Quality Assurance:

Conduct thorough inspections of all components, including plexiglass sides, galvanized steel sheets, and frame, to ensure they meet the required specifications, perform a water leak test to confirm that the tank is completely watertight, test the mobility and stability of the tank on various surfaces to ensure safe transportation.

CHAPTER 5 - PRODUCT TESTING

Testing the actual product is a necessary step in ensuring that the technical standards established for the design have been fulfilled. It is also essential for the future evolution of the design. Finding test conditions, test cases, and test data is the goal of a test design technique. Any of the strategies may be employed depending on the developer's, testers, and user's experience.

5.1. Verification plan of the objectives of the project

Our energy generation system is made up of two distinct systems the wave generator and the energy harvester. For testing we will have our wave generator produce waves at different amplitudes and frequencies, to determine their effect on the point absorber energy generation. The testing procedure will go as follows:

- An accelerometer sensor on a buoy to record wave heights and period.
- Test magnet and coil if they can generate energy output.
- Measure power output at a calm water level before introducing waves.
- Servo motor performance for wave generation at different speed and sustained speeds
- Introduce the waves in the tank for a given time and record the results.
- Use the obtained results to adjust the actuators in the system to obtain desired results.
- Perform testing at boundary regions of servo motor speed and record the effect on wave propagation.
- Energy output will be measured with a voltmeter to ensure that we have an energy output from the point absorber.

The wave maker will be tested initially at the recommended water level to ensure performance. The wave generator will be implemented and tested in the tank with waves obtained from the wave maker.

5.2. FAILURE MODES AND EFFECT ANALYSIS (FMEA) PROCESS:

A method for evaluating the consequences of assemblies, components, and subsystems' potential failure modes is called failure modes and effect analysis (FMEA). Finding failure modes that can adversely affect the overall system reliability is a dependability method. All potential failure modes and their related processes are to be identified, then limited or avoided. A team of designers and maintenance workers will typically execute an FMEA, and their expertise and opinions will be considered as elements to be weighed in the analysis. They will then produce a functional summary of all possible modes of failure along with their level of perceived risk this analysis will be made for both the wave energy converter and the testing tank as well.

Table 19 FMEA Table for the wave energy converter

Part Name & Number	Function	Failure Mode	Effects	(S)	(O)	Root of Failure	Controls	(D)	RPN	Recommended Action
Buoy (1-2-5)	Give movement in heave motion	Does not give anticipated movement & force	Power at low voltage or no power being regenerated	4	3	Defective of design or weak wave energy	Inspect the design of the buoy and wave energy accurately	7	84	A rigid trial in the laboratory before placing buoy
Permanent Magnets (1-2-2)	transmit	The magnetic field become weak	Reduce the efficiency of power output	2	5	Motion of translator with the wave motion	Motion control and degree of freedom	6	60	Make short period between Preventive maintenances
Stator (1-2-1)	Generate power through actions of motion of translator across lines of flux of an electromagnet	Loss of electric power generation.	reduced efficiency and eventual total shut down failure	2	4	Generator is defective - open circuit at winding, an abnormal connection in the stator windings	Design shape and components position and isolating	8	64	Design of the coils and material of the stator, shape of stator
Base (1-2)	Mooring/ Support system	Mooring line fracture	WEC point absorber shutdown	4	4	1. Extreme marine environment	Control the mooring and stability of the system	3	48	The type of concrete should be improved to contain all marine environment situations
					6	2. Fatigue damage		8	72	
					3	3. Improper anchor design		3	36	
					4	4. Improper anchor installation		2	32	
					4	5. Collision		2	32	

5.3. Tank Testing:

Tank testing can be carried out at any stage of a WEC's development, from the early proof of concept stage up to getting ready for the following serial production unit. Thus, depending on the project, the goals and testing methods of a tank testing campaign can vary. All testing should be run on a generic basis prior to knowing the actual site of a commercial device's installation. This will allow for more detailed investigations to be done later with the exact environmental circumstances and these are the procedures to be done in the testing stage for the tank:

5.3.1 Leakage Test:

Fill the tank with water and monitor for any signs of leakage, visually inspect the tank's joints, seams, and connections for water seepage, apply pressure to the tank by increasing water level and observe for any sudden drops.

5.3.2 Electronic Components Test:

Verify the proper connections of all electronic components including the motor, stepper motor drive, potentiometer, and accelerometer, check for any loose wires, damaged connectors, or faulty components, Test the control interface to ensure accurate frequency control.

5.3.3 Motor Test:

Run the motor at different frequencies and observe its performance, Check for unusual noises, vibrations, or overheating during motor operation, Test the emergency stop functionality to ensure the motor halts immediately.

5.3.4 Water Motion Testing:

Activate the wave generation mechanism and observe the water waves, use the accelerometer to measure the wave heights at different frequencies, compare the measured wave heights with the expected values based on simulation or theoretical calculations.

5.4. Numerical model:

5.4.1 Numerical model for wave energy converter:

To model the highly non-linear interaction of extreme wave events with the floating point-absorber WEC, numerical simulations will be done using an advanced methodology.

Using a Volume of Fluid (VoF) interface capturing scheme, the Reynolds-Averaged Navier Stokes (RANS) equations are solved for two incompressible fluids using a finite volume approach. A k SST turbulence model and y+ wall treatment is used to account for the influence of turbulence. The numerical simulations were performed using OpenFOAM v.4.1, an open source CFD program. The CFD code's six DoF Rigid Body Motion utility is used to implement the fluid-structure interaction, and the wave DyMFoam solver, which supports dynamic mesh motion, is used to solve the problem.

Note: the simulation should be done with two types of waves the first on is regular waves and the second one for the focused waves and may also be done for the extreme wave events (storms), then the results should be compared with the tank test results to see if the results are similar and gives the same conclusion for the point absorber WEC.

5.4.2 Numerical model for the wave tank:

Set up a simulation software to model the tank's geometry and the water motion inside, validate the simulation's accuracy by comparing its predictions with the real tank's behaviour, adjust simulation parameters to match the real tank's experimental results.

5.5 FMEA of the testing tank:

Please note that the ratings for severity (S), occurrence (O), and detection (D) are assigned based on hypothetical scenarios and should be determined through a thorough risk assessment process specific to your setup. The recommended actions are also provided as guidelines and should be customized based on your actual observations and assessments.

Part Name & Number	**Function**	**Failure Mode**	**Effects**	**(S)**	**(O)**	**Root of Failure**	**Root of Failure**	**Controls**	**(D)**	**RPN**	**Recommended Action**
Tank Frame (1-1-1-1)	Provide structural support	Corrosion, structural failure	Tank instability or collapse	5	3	Corrosion due to environmental exposure	Corrosion due to environmental exposure	Regular inspection and maintenance	5	75	Apply protective coatings, monitor corrosion
Galvanized Steel Sheets (1-1-1-1-1)	Enclose the tank	Corrosion, physical damage	Compromised tank integrity	6	3	Corrosion due to environmental exposure	Corrosion due to environmental exposure	Regular inspection and maintenance	5	90	Apply protective coatings, monitor corrosion
Plexiglass Side (1-1-1-1-2)	Provide transparency for observation	Scratches, cracks	Reduced visibility, potential water leakage	3	2	Physical impact or stress	Physical impact or stress	Handle with care, regular inspection	7	42	Prevent physical impact, monitor for damage
Flapper Mechanism (1-1-4)	Generate waves in the tank	Malfunction, mechanical failure	Inaccurate wave generation, hindered testing process	4	3	Mechanical wear and tear, misalignment	Mechanical wear and tear, misalignment	Regular maintenance, calibration	5	60	Implement routine maintenance schedule
Stepper Motor (1-1-3)	Drive the flapper mechanism	Overheating, electrical failure	Flapper motion disruption, testing interruption	5	3	Electrical component failure	Electrical component failure	Regular maintenance, thermal monitoring	6	90	Implement thermal management, regular checks

Potentiometer (1-1-2-1)	Control wave frequency	Inaccurate control, signal loss	Frequency mismatch, inaccurate testing control	4	2	Electronic component failure	Electronic component failure	Regular calibration, backup control mechanism	7	56	Implement redundant control, calibration
Accelerometer (1-2-4-1)	Measure wave height	Calibration error, sensor malfunction	Inaccurate wave height measurement	4	3	Sensor malfunction, calibration error	Sensor malfunction, calibration error	Regular calibration, backup sensors	6	72	Implement redundant sensors, calibration

5.6 Verification plan of the applied engineering standards

ISO/IEC/IEEE 29119-1:2022: Software testing standard

IEC TC 114: Marine energy- marine energy converters

ASTM A-34: Testing Magnetic Materials

ASTM A-340: Standard Terminology of Symbols and Definitions Relating to Magnetic Testing 16

ASTM A-341: Standard Test Method for Direct-Current Magnetic Properties of Materials International Electrotechnical Commission, IEC Std. 404-5

ISO 17771:2010: This standard provides guidelines for the design, testing, and performance evaluation of wave energy converters. It covers a wide range of topics, including system design, materials, safety, and environmental impacts.

ISO 9001: Quality Management Systems: This standard provides a framework for quality management and can be applied to the design, development, testing, and production processes of the testing tank and its components.

ISO 14001: Environmental Management Systems: If your testing involves potentially hazardous materials or waste generation, adhering to this standard will help ensure environmental responsibility.

ISO 45001: Occupational Health and Safety Management Systems: Safety should be a top priority during testing. Following this standard will help you establish a systematic approach to managing health and safety risks.

IEC 61010: Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use: This standard outline safety requirements for electrical equipment used for measurement and control. It covers aspects such as electrical insulation, grounding, and protection against electric shock.

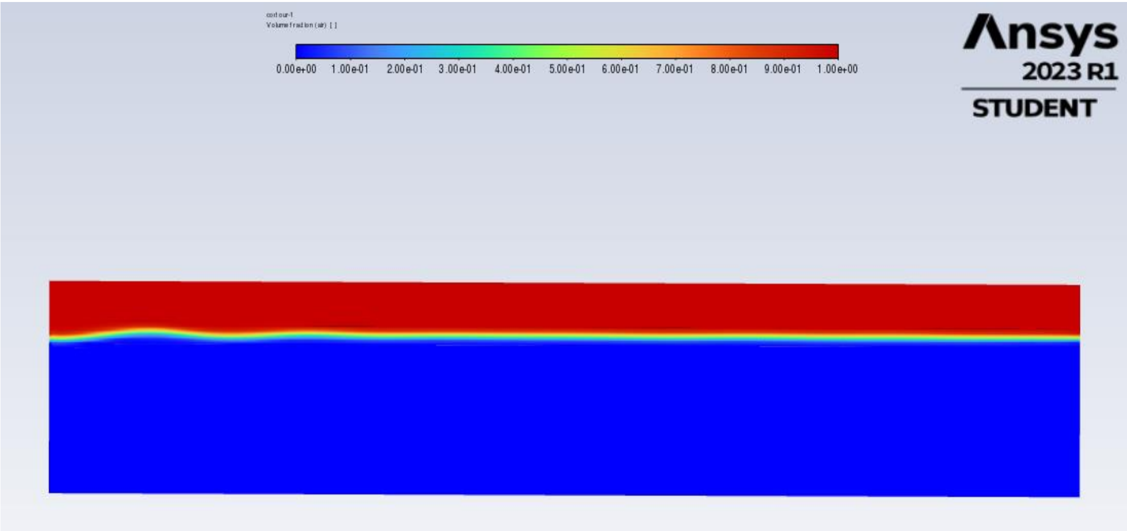
ISO 12100: Safety of Machinery - General Principles for Design: Relevant for designing and testing machinery, this standard provides guidance on risk assessment and reduction to ensure machinery safety.

CHAPTER 6 - RESULTS and DISCUSSIONS

The team had a lot of difficulties producing the parts and locating the required electrical parts for the following project. The parts have to be handled carefully and cautiously because the current location has very low component availability.

6.1. The results

An Ansys fluent CFD simulation was performed according to the numerical parameters provided in (section 3.3.2). The simulation shows a general expression of how the waves would be generated in the tank at a water level of 0.75m with a wavelength of 0.9m.



The starting point of the waves is at 1 m and the waves travel for about 3.5m after generation further this is a reasonable range to obtain 2 given wavelengths from the tank.

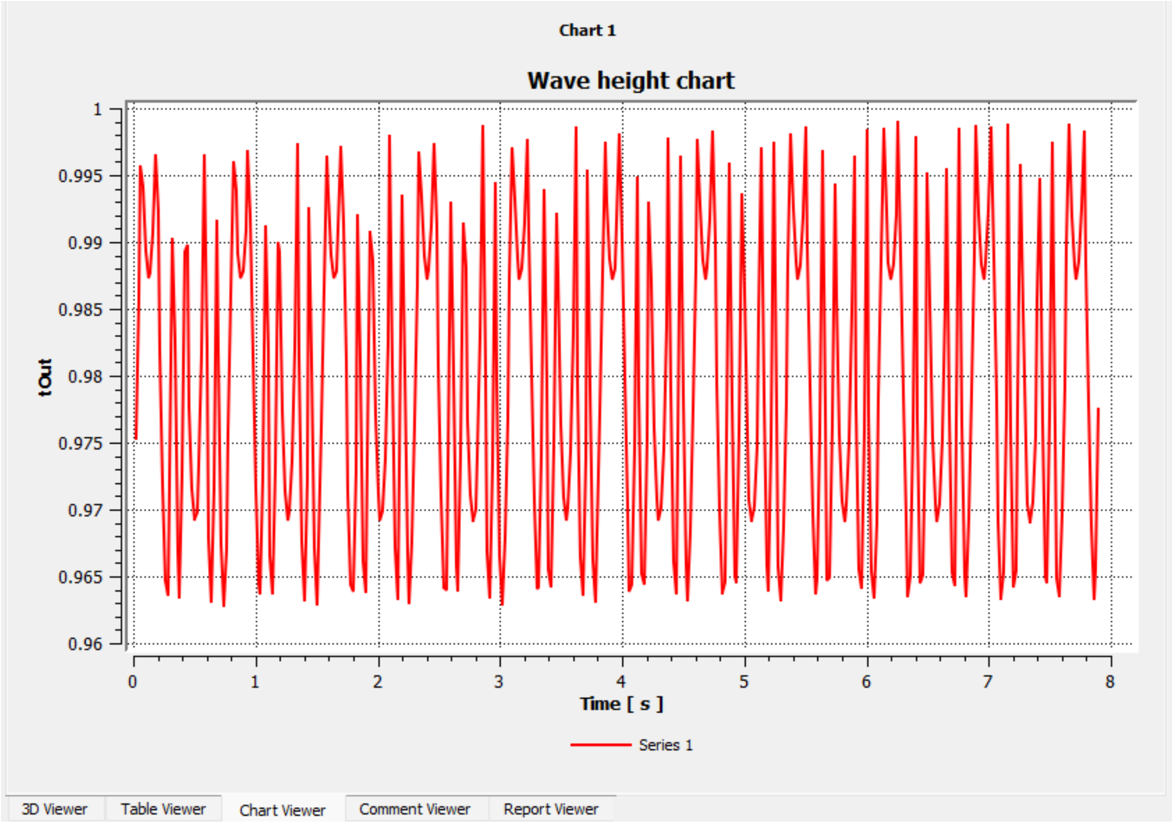


Figure 50:Wave Height

A shown in the figure above the resulting wave height is approximately 0.02m which further coincides with the mathematical evaluation done in chapter 3.2.2. The simulation results are obtained using Tout (Volume fraction of water) against time in seconds.

A time-domain wave-to-wire numerical model, the Wave Energy Converter Simulator (WEC-Sim), was developed for modelling WEC devices. The model is an open-source numerical tool that uses the MATLAB SimMechanics package to calculate multibody dynamics and computes wave interactions using the hydrodynamic coefficients derived from frequency-domain boundary-element methods. WEC-Sim can model these devices, which are comprised of rigid bodies, power take-off systems, and simple mooring systems using user-specified mooring stiffness and damping matrices. To model realistic mooring designs for floating WECs, WEC-Sim was coupled with a lumped-mass based mooring model, MoorDyn. MoorDyn accounts for the submerged weight, inertia, and axial elasticity of each mooring line, as well as hydrodynamic added mass, drag forces, and vertical spring-damper forces from contact with the seabed. It has been successfully validated with semisubmersible offshore wind platform model test data.

The simulated model was based on the one developed in the U.S. Department of Energy's Reference Model Project. It contains a float and a spar/plate that is connected to a central column, and it converts energy from the relative motion between the float and the spar/plate induced by ocean waves. The relative motion is in the axial direction of the device and is predominantly in heave (vertical direction).

Hydrodynamic data for each RM3 body must be parsed into a HDF5 file using BEMIO. BEMIO converts hydrodynamic data from WAMIT, NEMOH, Aqwa, or Capytaine into a HDF5 file, *.h5 that is then read by WEC-Sim. BEMIO code is found in Appendix J

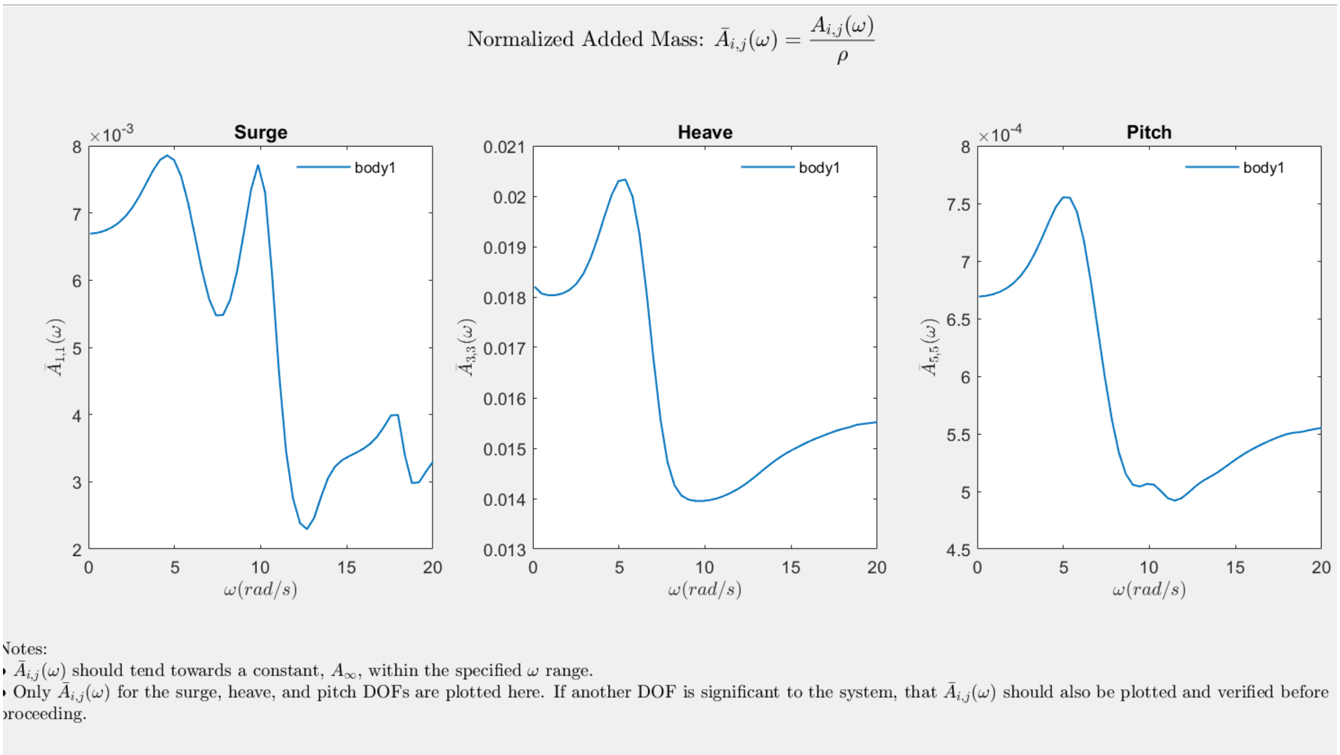


Figure 51: Normalized Added Mass

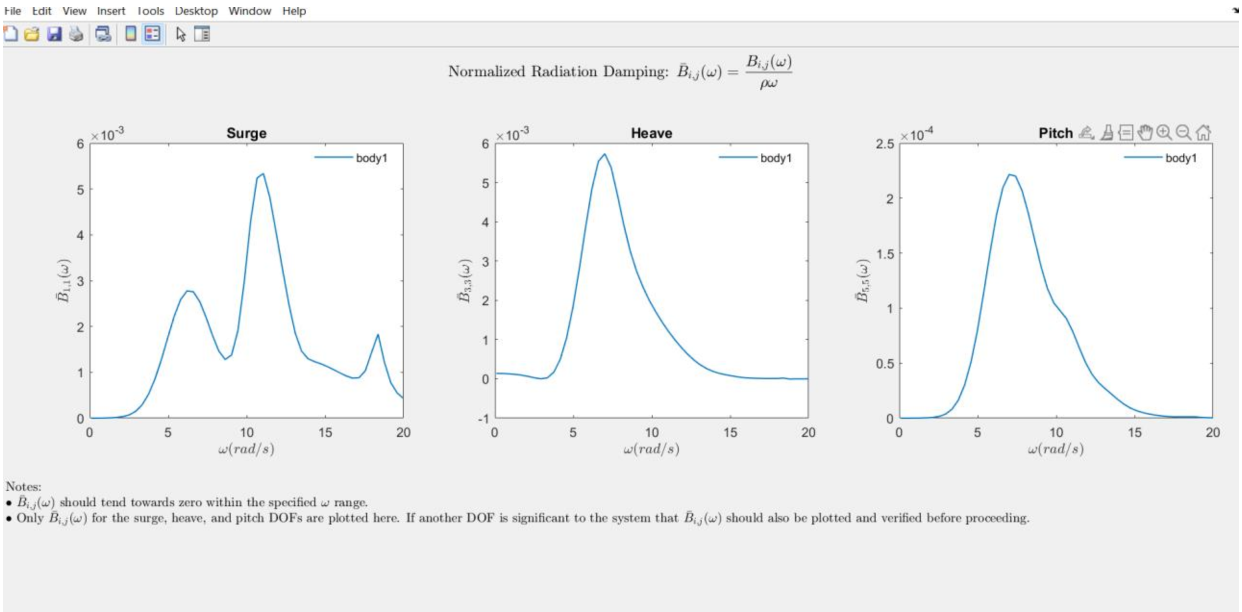


Figure 52:Normalized Radiation Damping

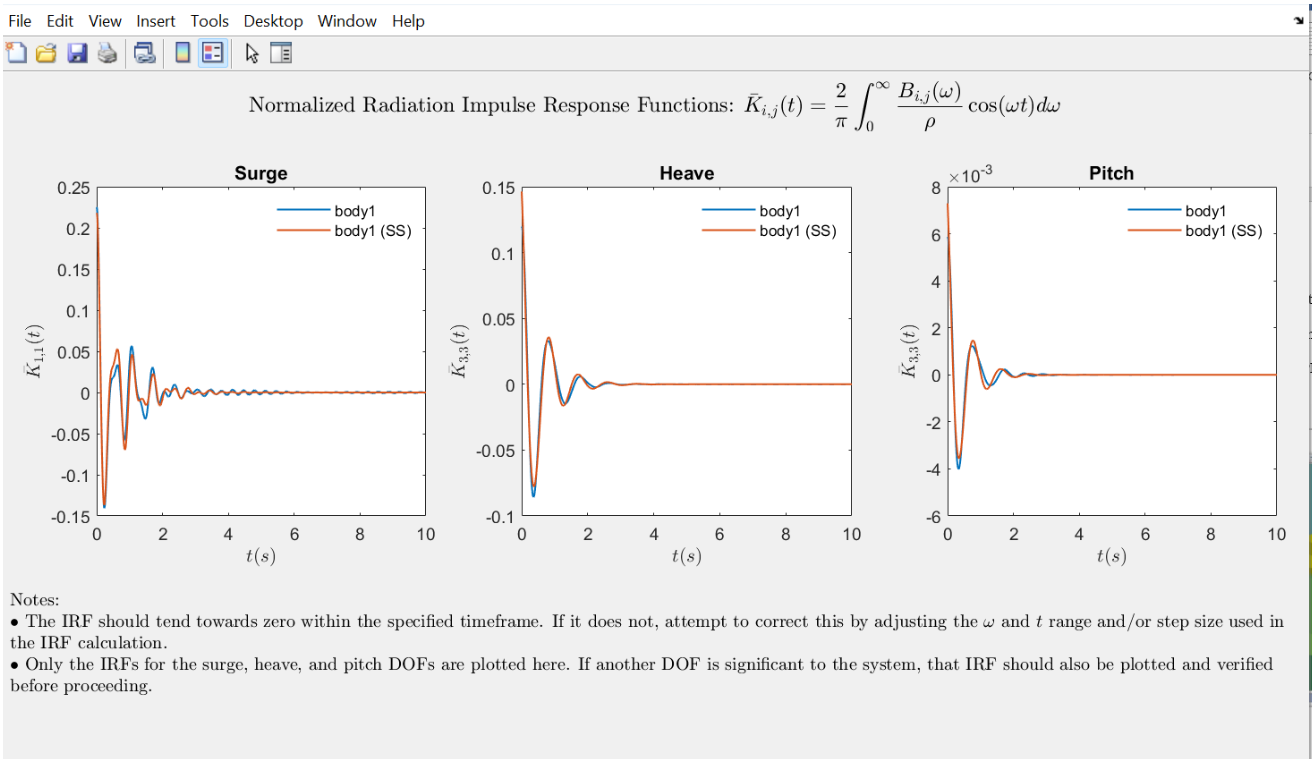


Figure 53:Normalized Radiation Impulse Response Functions

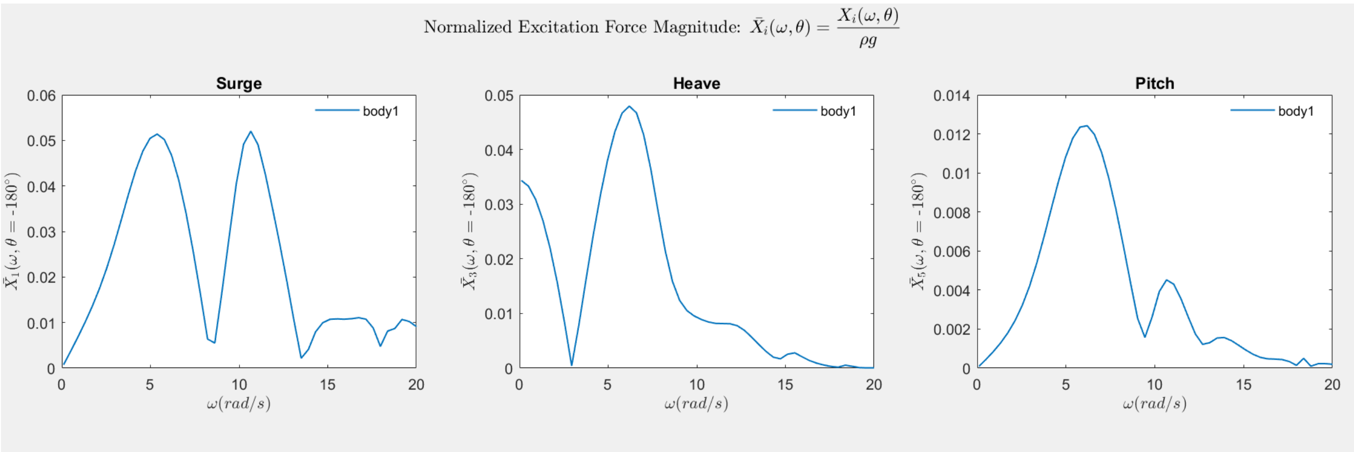


Figure 54: Normalized Excitation Force Magnitude

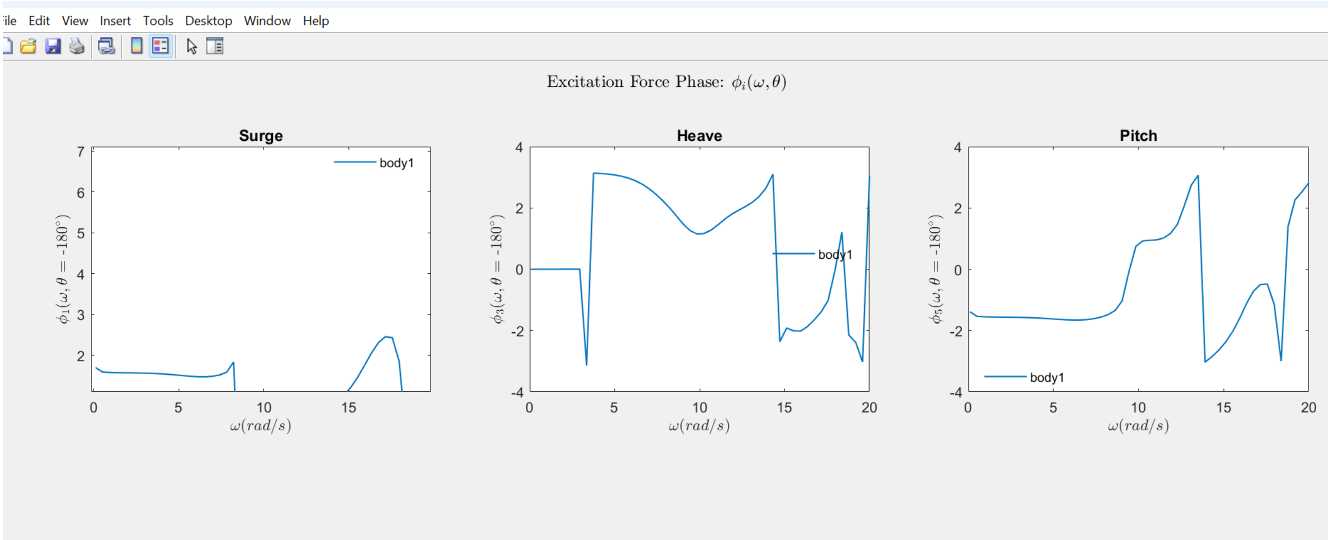


Figure 55:Excitation Force Phase

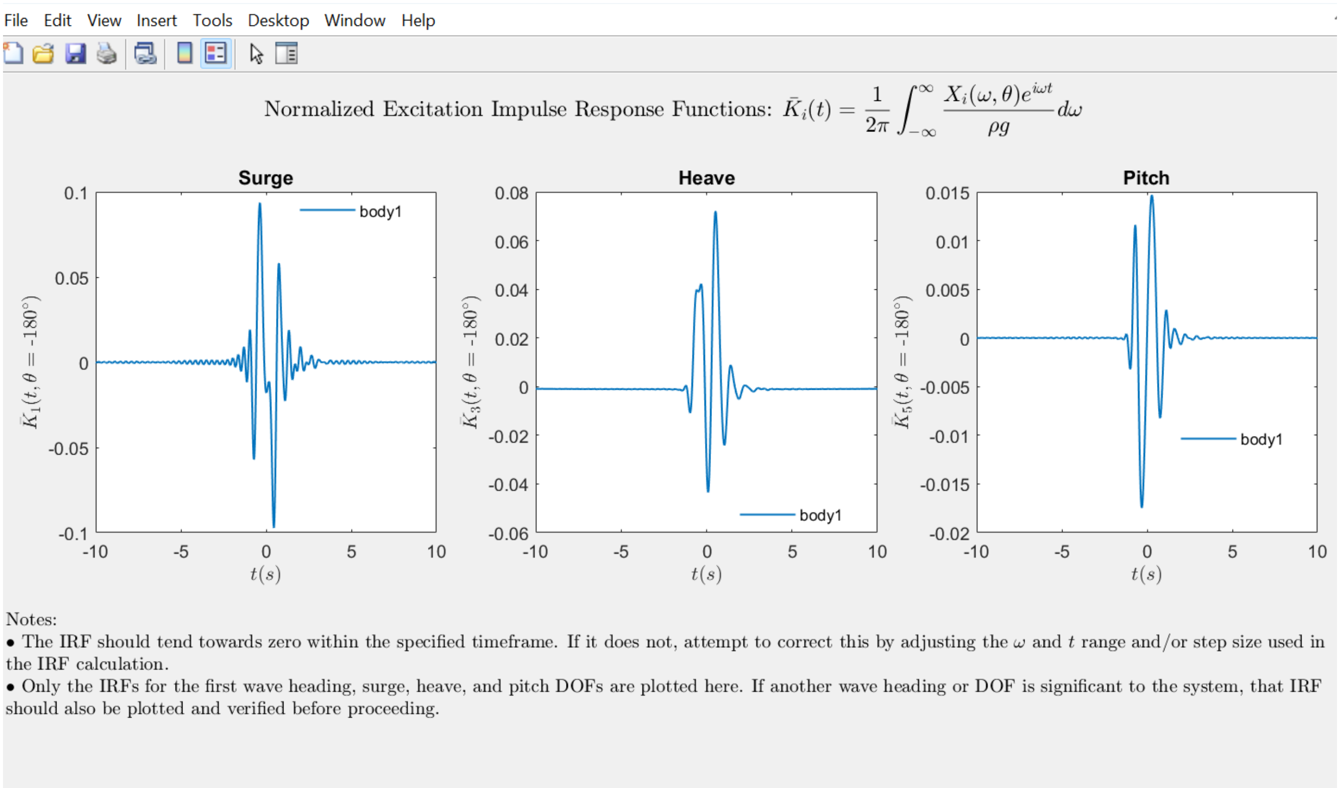


Figure 56:Normalized Excitation Impulse Response Functions

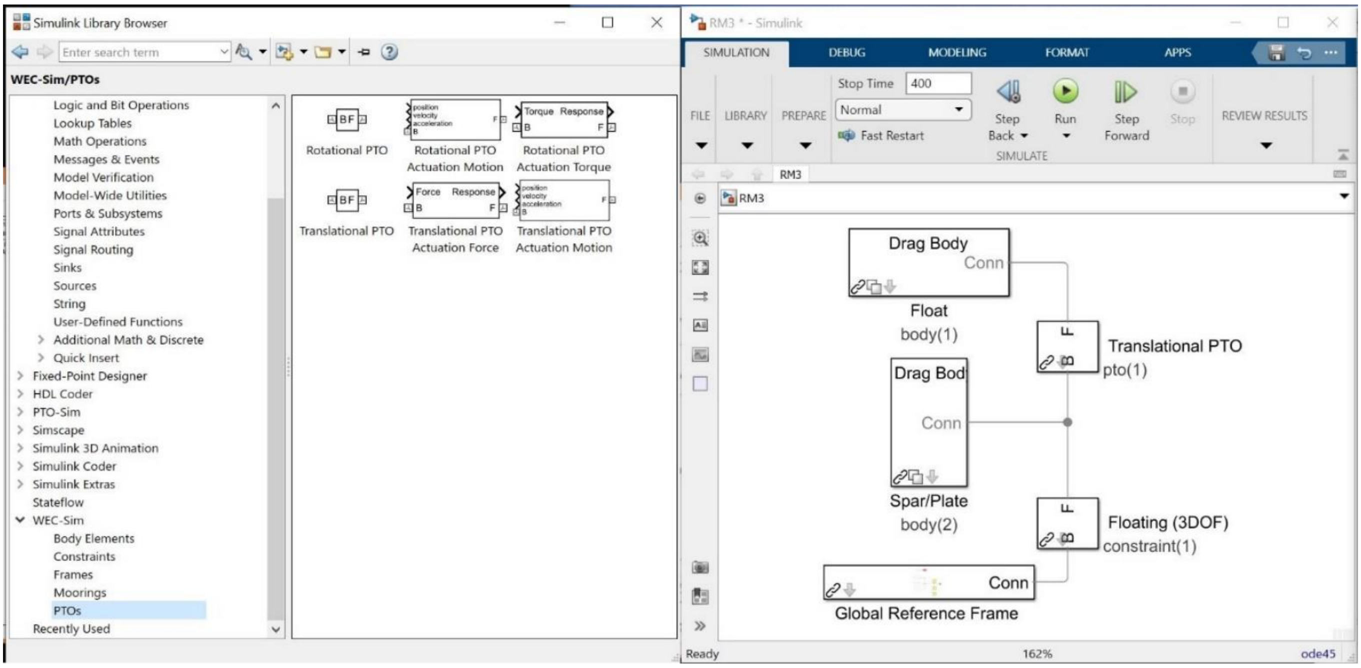


Figure 57: Simulink model

After the Simulink model was set and all bodies are defined, PTOs and constraints present in the Simulink file. There are distinct classes for bodies, PTOs and constraints that contain different properties and function differently. Bodies are hydrodynamic and contain mass and geometry properties. Initialize bodies by calling the body Class and the path to the relevant h5 file. The path is set to the geometry file, and the body's mass properties are defined. PTOs and constraints are simpler and contain forces and power dissipation (in the constraint) that limit the WEC's motion. The codes for this application are found in APPENDIX J

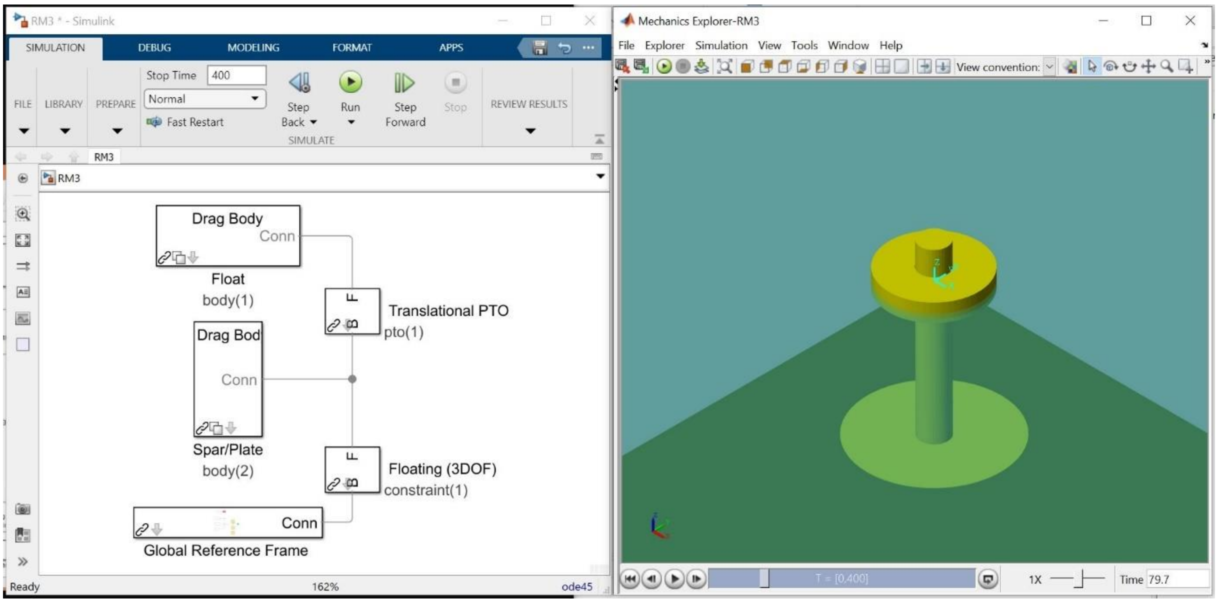


Figure 58:Simulink Result

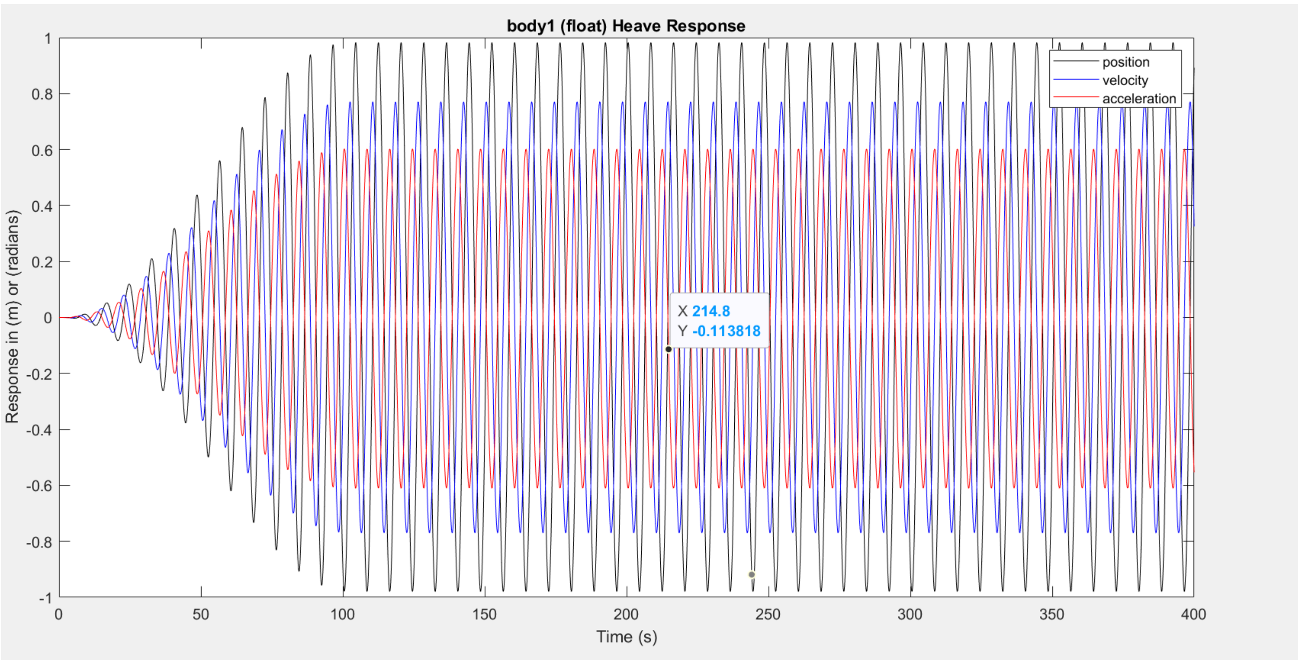


Figure 59:Buoy Heave Response

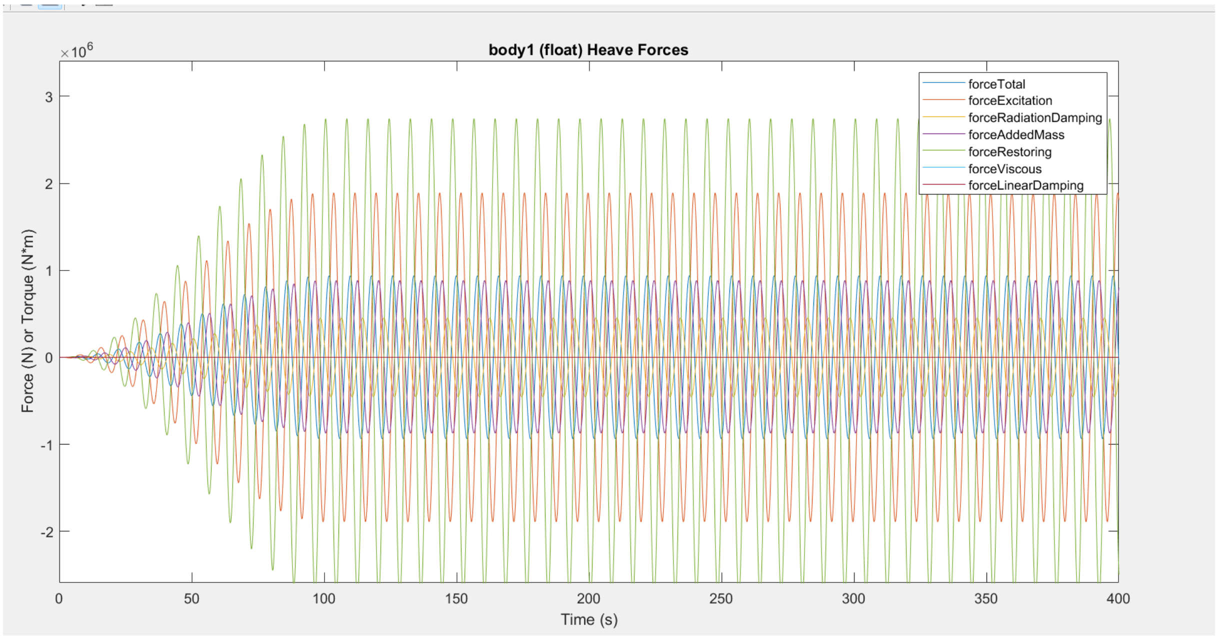


Figure 60: Buoy Heave Force

Comparison of results

The table compares the results provided by the wave parameters in table () using different approaches.

Table 20 Table of Results

	Un-Scaled Wave parameters	Scaled Wave Parameters	ANSYS(Fluent)
Wave-height	4	0.075	0.037
Period	7	0.76	
Frequency	0.14	1.2	
Depth	40	0.75	0.75
Wavelength	76.5	0.96	0.96

CHAPTER 7- FUTURE WORK

7.1 Wave Generation Enhancement:

To strengthen the control and accuracy of wave production, it is crucial to optimize the wave creation mechanisms within the tank. In order to do this, the system that creates waves within the tank must be specifically improved. Instead of using the standard flapper mechanism, it would be wise to install more advanced control algorithms that are able to simulate a wider variety of wave patterns and unique sea conditions with a level of authenticity that exceeds that of the basic flapper mechanism. This ambitious project may be made a reality by recalibrating the flapper's motion in response to real-time data from a variety of sensors that have been painstakingly calibrated to measure wave properties including heights, frequencies, and other essential elements. The goal of this extensive improvement is to enable the creation of testing scenarios that are accurate and, as a result, enable the modelling of a wide range of sea conditions.

7.2 Enhancing Realism with Wave Absorption:

The development of a powerful wave absorption system is necessary to provide an experimental setting that accurately represents actual marine conditions. The system's dual goals are to reduce interference caused by undesired wave reflections off of the tank walls and to provide a testing habitat that closely resembles real-world sea conditions. It is possible to achieve a balance between experimental control and reproducibility by skilful wave absorption. In order to provide results that may be generalized to real-world scenarios with a higher degree of accuracy, this equilibrium is essential. As a result, the cogent design and integration of a wave absorption system have the potential to revolutionize research with wave energy converters.

7.3 Scaling Considerations and Boundary Effects:

Conducting wave energy converter studies in a scaled tank requires careful consideration of scale effects, which are the intricate changes in wave dynamics and converter performance brought on by the scale change. To create a knowledge of the interplay between the scaled waves and the reduced-size converters, both of which are endowed with distinct behaviours needing careful investigation, an in-depth analysis of these impacts is essential. Furthermore, it is crucial to describe the intricate details of wave absorption, reflection, and diffraction at this scaled level with exactitude. Researchers may extend findings from a scaled context to a larger, unadulterated realm of application thanks to this project's achievement of results that reflect the reality of deep-sea settings.

7.4 Standardized Integration and Comprehensive Data Collection:

A critical step toward the realization of a smooth procedure for the installation and subsequent testing of various variations of wave energy converter devices within the tank is the clarification of a standardized integration framework. The key aspect of this is the creation of an infrastructure with flexible mounting methods, well-placed connection points, and well-thought-out power supply interfaces, all choreographed to support a wide range of converter prototypes. Additionally, the incorporation of a cutting-edge instrumentation framework with a complex array of sensors that can precisely measure a variety of wave attributes, converter efficiency metrics, energy output levels, and a variety of other crucial parameters beckons. The obtaining, collation, and storage of these diverse data types is the basis of a thorough data collection architecture. Such a knowledge base sets the way for a thorough examination and iterative improvement of converter designs, while also encouraging a comprehensive understanding of their behaviour across a wide range of various wave conditions.

This analysis of research concerns grows as additional dimensions are added, which will raise the bar for testing wave energy converters even higher. By including a multi-directional wave creation component, for example, the tank may be able to produce waves coming from several directions, providing new insights regarding the converter's adaptability to various wave approaches. Collaboration among academics, engineers, and industry stakeholders starts the process of building a collaborative environment that makes it easier to create testing standards that are widely recognized. Additionally, a thoughtful consideration of the ecological effects of such experiments emerges via the lens of an environmental impact assessment. This paper, which meticulously outlines the possible effects of experimenting on aquatic ecosystems, strengthens the ethical foundation of your research endeavours. The optimization of tank materials can enhance realism by simulating the unique properties of water in deep-sea conditions, while a step into the field of numerical simulations and computer models offers the prospect of predictive insights into wave behaviour and converter performance. As a result, the combination of these approaches creates a thorough roadmap for the progress of wave energy converter testing that is supported by accuracy, authenticity, and unrelenting innovation.

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permanent magnet linear generator for small-scale wave energy converter. AIP Adv 2017;7. https://doi.org/10.1063/1.4974496/1021280.

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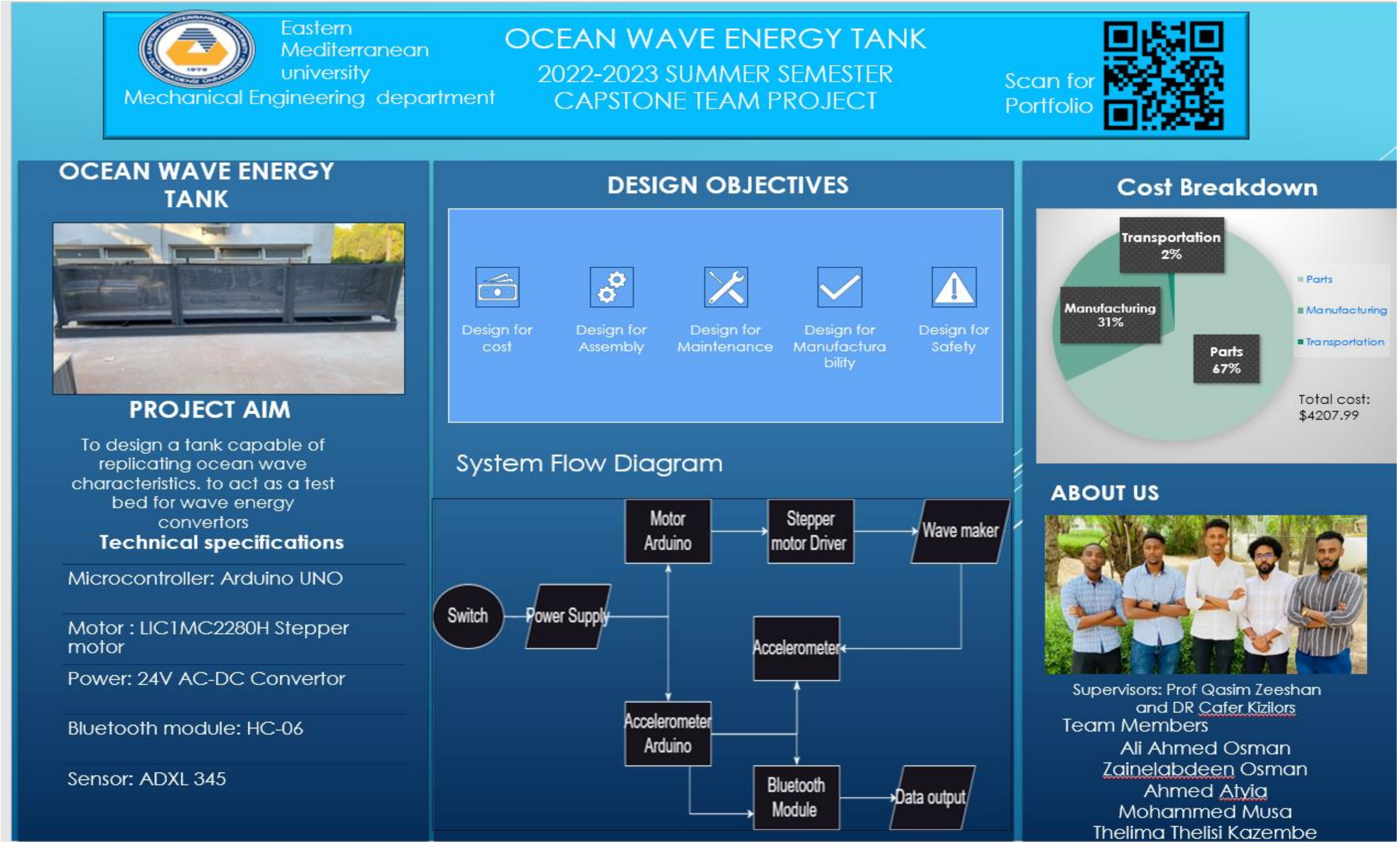
APPENDIX A: Electronic Media

Here's The Link To our Portfolio: https://thelimakt.editorx.io/oeta.


Eastern Mediterranean university
Mechanical Engineering department
OCEAN WAVE ENERGY TANK
2022-2023 SUMMER SEMESTER
CAPSTONE TEAM PROJECT
Scan for Portfolio
OCEAN WAVE ENERGY TANK
PROJECT AIM
To design a tank capable of replicating ocean wave characteristics. to act as a test bed for wave energy convertors
Technical specifications
Microcontroller: Arduino UNO
Motor : LIC1MC2280H Stepper motor
Power: 24V AC-DC Convertor
Bluetooth module: HC-06
Sensor: ADXL 345
DESIGN OBJECTIVES
Design for cost
Design for Assembly
Design for Maintenance
Design for Manufactura bility
Design for Safety
System Flow Diagram
Motor Arduino
Stepper motor Driver
Wave maker
Switch
Power Supply
Accelerometer
Accelerometer Arduino
Bluetooth Module
Data output
Cost Breakdown
Transportation 2%
Manufacturing 31%
Parts 67%
Parts
Manufacturing
Transportation
Total cost: $4207.99
ABOUT US
Supervisors: Prof Qasim Zeeshan and DR Cafer Kizilors
Team Members
Ali Ahmed Osman
Zainelabdeen Osman
Ahmed Atyia
Mohammed Musa
Thelima Thelisi Kazembe

APPENDIX B: Ocean Wave Tank Standards

- ISO 19906:2010: provides guidelines for the design, testing, and operation of wave energy converters, including point absorbers. It covers topics such as materials, structural design, loadings, and reliability. "ISO 19906:2010 - Petroleum and natural gas industries — Arctic offshore ...." https://www.iso.org/standard/33690.html.

- IEC 61400-3:2014: covers the design, testing, and operation of wind turbines, including those used in offshore wave energy conversion systems. It includes requirements for structural design, fatigue, and reliability. This was not applied as it is meant for wind turbines which is applied in oscillating water columns but not point absorbers. "IEC 61400-3 - Wind turbines – Part 3: Design requirements for offshore ...." 01 Feb. 2009, https://standards.globalspec.com/std/1160984/IEC%2061400-3.

- DNV GL RP-A203: provides guidance on the design, testing, and operation of wave energy converters, including point absorbers. It covers topics such as materials, structural design, loadings, and reliability. Followed when designing the point absorber."DNV-RP-A203 Technology qualification - DNV." https://www.dnv.com/oilgas/download/dnv-rp-a203-technology-qualification.html.

- ISO 19902: It includes requirements for the structural, mechanical, and electrical systems of the point absorber, as well as the environmental conditions in which it will be used. "ISO 19902:2020 - Petroleum and natural gas industries — Fixed steel ...." https://www.iso.org/standard/65688.html.

- (ISO) Standard 14001: it covers the management of environmental impacts of wave energy converters. It includes requirements for the assessment and reduction of the environmental impacts of the point absorber. "ISO - ISO 14001 and related standards — Environmental management." https://www.iso.org/iso-14001-environmental-management.html.

- ABS Rules for Classification and Construction of Marine Structures: it covers the design, construction, and operation of marine structures, including those used in wave energy conversion systems. It includes requirements for materials, structural design, and loadings. ABS: rules for building and classing offshore installations." 21 Feb. 2023, https://www.marineregulations.news/rules-for-building-and-classing-of-offshore-installations-issued-by-abs/.

- ISO 19901-1:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 1: General requirements "ISO 19901-1:2005 - Petroleum and natural gas industries — Specific ...." https://www.iso.org/standard/34586.html.

- ISO 19901-2:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 2: Materials and fabrication "SIST EN ISO 19901-2:2005 - Petroleum and natural gas industries ...." 31 Mar. 2005, https://standards.iteh.ai/catalog/standards/sist/96b6a3cb-df38-4c33-b15f-bfd3fabeb1c6/sist-en-iso-19901-2-2005.

- ISO 19901-3:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 3: Structural design "ISO 19901-1:2005 - Petroleum and natural gas industries — Specific ...." 15 Nov. 2005, https://standards.iteh.ai/catalog/standards/iso/1f99e7d9-a79c-4597-8a96-d4375d0da6ad/iso-19901-1-2005.

- ISO 19901-4:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 4: Foundations "ISO - ISO 19901-4:2003 - Petroleum and natural gas industries ...." https://www.iso.org/standard/34589.html.

- ISO 19901-5:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 5: Loads and load combinations "ISO - ISO 19901-5:2021 - Petroleum and natural gas industries ...." https://www.iso.org/standard/73039.html.

- ISO 19901-6:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 6: Structural analysis "INTERNATIONAL ISO STANDARD 19901-6." https://cdn.standards.iteh.ai/samples/34591/1992978603c6427b9a9c3ee2dd5521da/ISO-19901-6-2009.pdf.

- ISO 19901-1:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 1: General requirements "ISO 19901-1:2005 - Petroleum and natural gas industries — Specific ...." https://www.iso.org/standard/34586.html.

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- ISO 19901-5:2005 - Petroleum and natural gas industries - Fixed steel offshore structures - Part 5: Loads and load combinations "ISO - ISO 19901-5:2021 - Petroleum and natural gas industries ...." https://www.iso.org/standard/73039.html.

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ISO 19901 was not applied for an offshore model but instead a down scaled version suitable for a tank.

- ISO 8887-1:2017Technical product documentation — Design for manufacturing, assembling, disassembling and end-of-life processing. "ISO 8887-1:2017 - Technical product documentation — Design for ...." https://www.iso.org/standard/62047.html.
- ISO/TC 205, Building environment design "ISO/TC 205 - Building environment design." https://www.iso.org/committee/54740.html.
- ISO/TC 184, Automation systems and integration "ISO/TC 184 - Automation systems and integration." https://www.iso.org/committee/54110.html.
- ISO/TC 301, Energy management and energy savings "ISO/TC 301 - Energy management and energy savings." 29 Sept. 2022, https://www.iso.org/committee/6077221.html.

Components Standards:

1. Neodymium Magnets (1-2-2):

Grade	Remanence (BR) mT (KGS)	Coercive Force (Hcb) kA/m (kOe)	Intrinisc Coercive Force (Hcj) kA/m (kOe)	Max. Energy Product (BH)max	Max. Operating Temp TW
N35	1170-1220 (11.7- 2.2)	868 (10.9)	955 12	263-287 (33-36)	80
N38	1220-1250 (12.2-12.5)	899 (11.3)	955 (12)	287-310 (36-39)	80
N40	1250-1280 (12.5-12.8)	907 (11.4)	955 (12)	302-326 (38-41)	80
N42	1280-1320 (12.8-13.2)	915 (11.5)	955 (12)	318-342 (40-43)	80
N45	1320-1380 (13.2-13.8)	923 (11.6)	955 (12)	342-366 (434-46)	80
N48	1380-1420 (13.8-14.2)	923 (11.6)	955 (12)	366-390 (46-49)	80
N50	1400-1450 (14-14.5)	796 (10)	876 (11)	382-406 (48-51)	80
N52	1430-1480 (14.3-14.80)	796 (10)	876 (11)	398-422 (50-53)	80

2. Plexi Glass (1-1-1-1-2):

- ASTM D4802: This standard from ASTM International provides specifications for the physical properties of plexiglass sheets, including dimensions, flatness, thickness, colour, and visual defects. "ASTM International - ASTM D4802-16 - Standard Specification for Poly ...." 01 May. 2016, https://standards.globalspec.com/std/3861238/ASTM%20D4802-16.

- ASTM D543: This standard specifies the methods for evaluating the resistance of plexiglass to various types of chemical reagents. It helps determine the material's resistance to chemicals, solvents, and other substances it may come into contact with during use. "ASTM International - ASTM D543-20 - Standard Practices for Evaluating ...." 01 Feb. 2020, https://standards.globalspec.com/std/14137369/ASTM%20D543-20.

- ASTM D638: This standard covers the tensile properties of plastic materials, including plexiglass. It provides guidelines for testing the tensile strength, elongation, and modulus of elasticity of the material. "Step by Step Guide to ASTM D638 Testing | Frank Bacon." 11 Jan. 2023, https://frankbacon.com/astm-specifications/step-by-step-guide-to-astm-d638-testing/.

- ASTM D790: This standard outlines the test methods for determining the flexural properties of rigid plastics, including plexiglass. It covers flexural strength, flexural modulus, and other related properties. "ASTM D790: Standard Test Methods for Flexural Properties of ...." https://www.academia.edu/86416925/ASTM_D790_Standard_Test_Methods_for_Flexural_Properties_of_Unreinforced_and_Reinforced_Plastics_and_Electrical_Insulating_Materials.

- ISO 7823-1: This ISO standard specifies the dimensions and properties of cast acrylic sheets. It provides information on dimensions, flatness, thickness tolerances, and mechanical properties for cast acrylic sheets. "ISO 7823-1:2003 - Plastics — Poly (methyl methacrylate) sheets — Types ...." https://www.iso.org/standard/33450.html.

- ISO 7823-2: This ISO standard specifies the dimensions and properties of extruded acrylic sheets. It covers dimensions, flatness, thickness tolerances, and mechanical properties for extruded acrylic sheets. "ISO 7823-2:2003 - Plastics — Poly (methyl methacrylate) sheets — Types ...." https://www.iso.org/standard/28757.html.

3. Stepper Motor (1-1-3):

- IEC 60034: This International Electrotechnical Commission (IEC) standard provides general specifications for rotating electrical machines, including induction motors, synchronous motors, and servo motors. It covers aspects such as performance, dimensions, electrical and mechanical requirements, and testing methods. "IEC 60034-1:2017 - Rotating electrical machines - Part 1: Rating and ...." https://standards.iteh.ai/catalog/standards/iec/d0fabb69-b122-4306-8a86-b35e2d2833c3/iec-60034-1-2017.

- IEC 61800: This series of standards, also known as the IEC 61800-x series, addresses adjustable speed electrical power drive systems. These standards cover various aspects of adjustable speed drives, including motor control, safety, performance, and electromagnetic compatibility (EMC). "IEC 61800-4 - Adjustable Speed Electrical Power Drive Systems - Part 4 ...." 01 Sept. 2002, https://standards.globalspec.com/std/322804/IEC%2061800-4.
- ISO 19438: This International Organization for Standardization (ISO) standard focuses on the rating and performance of electrical machines, including servo motors. It provides guidelines for determining the output power, efficiency, and temperature rise of electric motors. "ISO - ISO 19438:2023 - Diesel fuel and petrol filters for internal ...." https://www.iso.org/standard/82268.html.
- UL 1004-x: Underwriters Laboratories (UL) is a safety certification organization. The UL 1004-x series of standards covers electric motors, including servo motors. These standards focus on safety requirements and testing procedures to ensure the safe operation of electric motors. "UL 1004-1: UL Standard for Safety Rotating Electrical Machines ...." 19 Sept. 2012, https://global.ihs.com/doc_detail.cfm?item_s_key=00512225.
- ISO 13849: This ISO standard provides guidelines for the safety-related design of control systems, including those using servo motors. It addresses aspects such as safety functions, performance levels, and validation methods to ensure the safe operation of machinery and equipment. "ISO 13849-1:2015 - Safety of machinery — Safety-related parts of ...." https://www.iso.org/standard/69883.html.

4. Buoy (1-2-5):

- ISO 19901-7: This International Organization for Standardization (ISO) standard provides guidance for the design of floating structures, including buoys, used in offshore applications. It covers aspects such as design loads, stability, structural integrity, and safety considerations. "ISO 19901-7:2013 - Petroleum and natural gas industries — Specific ...." https://www.iso.org/standard/59298.html.

- API RP 2T: The American Petroleum Institute (API) Recommended Practice 2T offers guidelines for the planning, design, and installation of offshore platforms and structures. Although it primarily focuses on fixed platforms, it can provide valuable information for the design of mooring systems and floating buoys. "API RP 2T - Planning, Designing, and Constructing ... - Engineering360." 01 Jul. 2010, https://standards.globalspec.com/std/9958049/API%20RP%202T.

- IEC 61827: This International Electrotechnical Commission (IEC) standard addresses the design and operation of floating offshore structures, including buoys. It covers topics such as loads, materials, structural design, stability, and integrity. "IEC TS 61827:2004 - Electrical installations for lighting and beaconing ...." https://standards.iteh.ai/catalog/standards/iec/536fab62-a894-4be8-874d-0b683080a258/iec-ts-61827-2004.

- ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations: This guide by the American Bureau of Shipping (ABS) focuses on the design, construction, and classification of floating offshore wind turbine installations. Although it specifically targets wind turbines, it can be applicable to other floating buoy structures used in renewable energy applications. "ABS - 195 - GUIDE FOR BUILDING AND CLASSING FLOATING OFFSHORE WIND ...." 01 Jan. 2015, https://standards.globalspec.com/std/10015201/195.

- DNV GL-ST-0119: This standard by DNV GL provides guidelines for the design and certification of floating wind turbines and their support structures. While it focuses on wind turbines, Stator: "DNVGL-ST-0119 Edition July PDF Free Download - DocPlayer." https://docplayer.net/99173860-Dnvgl-st-0119-edition-july-2018.html.

- IEC 60034: This International Electrotechnical Commission (IEC) standard provides general specifications for rotating electrical machines, including electric motors and generators. It covers aspects such as dimensions, mechanical requirements, electrical performance, efficiency, temperature rise, and testing methods. "IEC 60034-1:2017 - Rotating electrical machines - Part 1: Rating and ...." https://standards.iteh.ai/catalog/standards/iec/d0fabb69-b122-4306-8a86-b35e2d2833c3/iec-60034-1-2017.
- NEMA MG 1: Published by the National Electrical Manufacturers Association (NEMA), this standard applies to motors and generators used in North America. It provides guidelines for motor and generator performance, dimensions, tolerances, and testing procedures, including specifications for stator winding insulation and temperature limits. "NEMA MG 1 Motor and Generators Standard Now Available for Free Digital ...." 12 Apr. 2021, https://www.nema.org/news-trends/view/nema-mg-1-motor-and-generators-standard-now-available-for-free-digital-download.
- IEEE 112: This standard from the Institute of Electrical and Electronics Engineers (IEEE) covers the test procedures for the evaluation of insulation systems used in rotating electrical machines, including stators. It specifies the electrical, thermal, and mechanical tests to assess the insulation system's performance and durability. "IEEE 112 - Standard Test Procedure for Polyphase Induction Motors and ...." 06 Dec. 2017, https://standards.globalspec.com/std/10273077/IEEE%20112.
- ISO 9001: While not specific to stators, ISO 9001 is a widely recognized quality management standard applicable to various industries. Many motor manufacturers adhere to ISO 9001 to ensure consistent quality in their manufacturing processes, which indirectly covers stator

production. "ISO - ISO 9001 and related standards — Quality management."

https://www.iso.org/iso-9001-quality-management.html.

APPENDIX C: Constraints

Constraints	HIGH	MEDIUM	LOW
Economic	**X**		
Sustainable	**X**		
Manufacturable	**X**		
Environmentally friendly	**X**		
Safety	**X**		
Overall, Power Performance		**X**	
Scalability		**X**	
Maintainability	**X**		

• Economic: In every engineering project, the design team must make every effort to spend the money effectively and produce a project that is economically feasible.

• Sustainability: Durability and dependability are essential characteristics of the finished product. Having a well-defined lifespan under common or standard operating circumstances is synonymous with sustainability.

• Manufacturability: Manufacturing operations are straightforward and cost and waste effective.

• Safety: Does not pose any harm to the user, whether from the electrical components or the products outside dimensions.

Some restrictions:

• Scalability: The wave energy tank should have the potential for scalability. It should be designed in a way that allows for easy expansion or modification to accommodate larger or different types of wave energy converter systems. Additionally, For the WEC to be a long-term, economically viable solution, the device must be scalable, which means it must be able to increase in size in the same manner as offshore wind turbines.

• Environmentally friendly: The wave energy tank should not have adverse effects on the surrounding marine environment. Measures should be taken to minimize disturbance to marine life, habitats, and ecosystems. The tank design should prevent leakage of harmful substances or chemicals into the water. Moreover, WECs are anticipated to have a substantial influence on the environment due to their usage of renewable energy. Nevertheless, this criterion also stipulates that WECs must be built using materials that do not pose a threat to marine life or the marine environment in general.

• Overall, Power Performance: The WEC must efficiently transform wave energy to useable power. In addition, the produced energy must be sufficiently smooth for use in the electrical system. Moreover, the WEC must have a high-capacity factor (the ratio between the unit's actual generation output and its maximum generation output maximum yield).

• Maintainability: The WEC should be readily accessible and permit examination of the most vital components if repairs are required. In addition, it would be preferable if maintenance could be performed in situ (out at sea) rather than bringing the WEC back to dry ground.

APPENDIX D: Logbook

Report writing	Written by	
	Name, Surname	Student Number
Report format	AHMED ATYIA	21903404
Report editing	ZAINELABDEEN OSMAN	21904977
Abstract	MOHAMED ABDELKARIM	21905008
Chapter 1	ALI ABUELGASIM	19700655
Chapter 2	AHMED ATYIA	21903404
Chapter 3 (section 3.1, 3.2, 3.3, 3.4)	THELIMA KAZEMBE	19701154
Chapter 3 (section 3.3.1, 3.5, 3.12)	AHMED ATYIA	21903404
Chapter 3 (section 3.9, 3.10, 3.11)	ZAINELABDEEN OSMAN	21904977
Chapter 3 (section 3.6, 3.7, 3.8, 3.14)	ALI ABUELGASIM	19700655
Chapter 4	ZAINELABDEEN OSMAN	21904977
Chapter 4	AHMED ATYIA	21903404
Chapter 5	THELIMA KAZEMBE	19701154

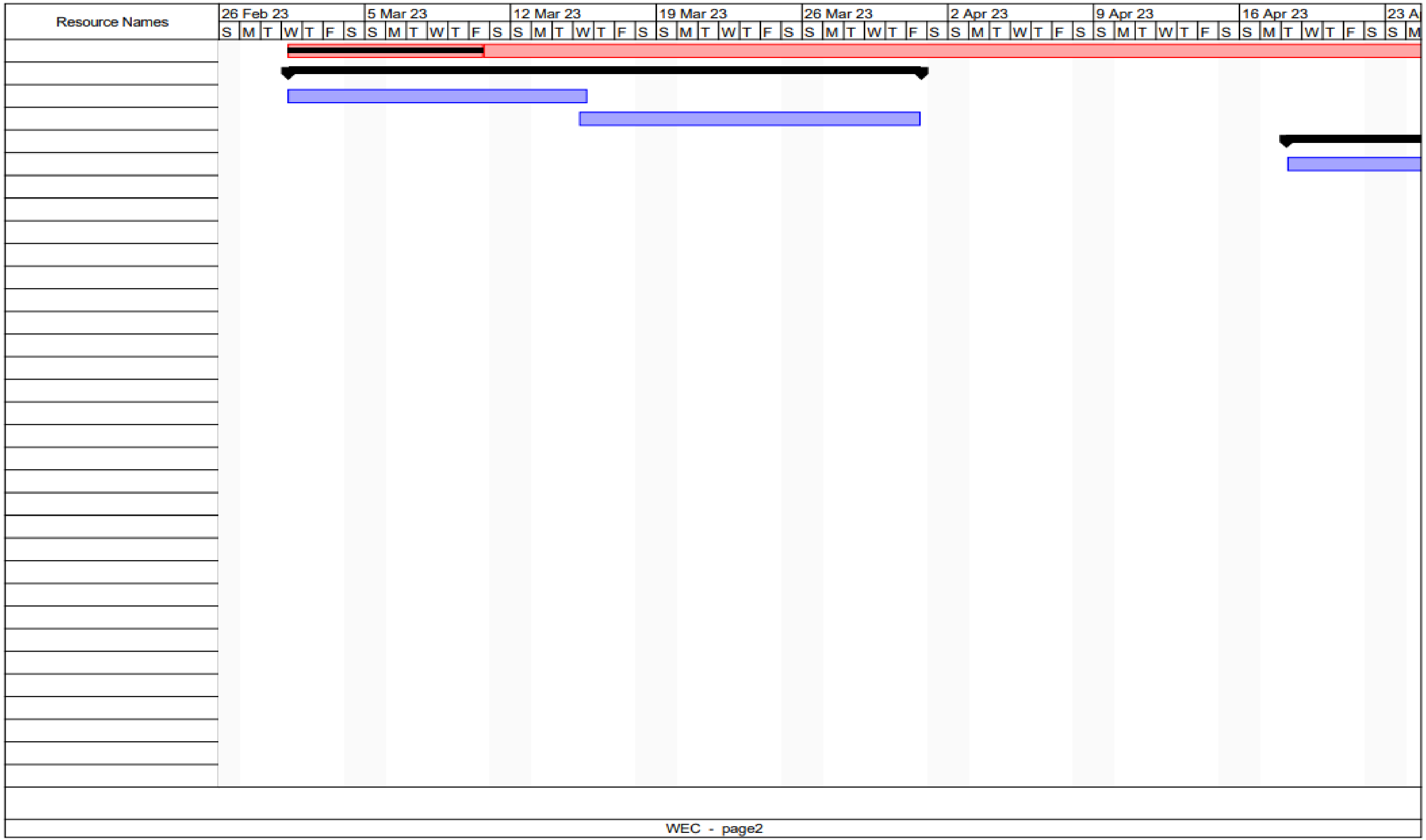
Chapter 6	ALI ABUELGASIM	19700655
References	AHMED ATYIA	21903404
Appendix A	MOHAMED ABDELKARIM	21905008
Appendix B	THELIMA KAZEMBE	19701154
Appendix C	MOHAMED ABDELKARIM	21905008
Appendix D	ZAINELABDEEN OSMAN	21904977
Appendix E	MOHAMED ABDELKARIM	21905008
Appendix F	ALI ABUELGASIM	19700655
Appendix G	ALI ABUELGASIM	19700655
Appendix H	THELIMA KAZEMBE	19701154
Appendix I	AHMED ATYIA	21903404
Appendix J	ZAINELABDEEN OSMAN	21904977
Appendix K	ALI ABUELGASIM	19700655
Appendix L	THELIMA KAZEMBE	19701154

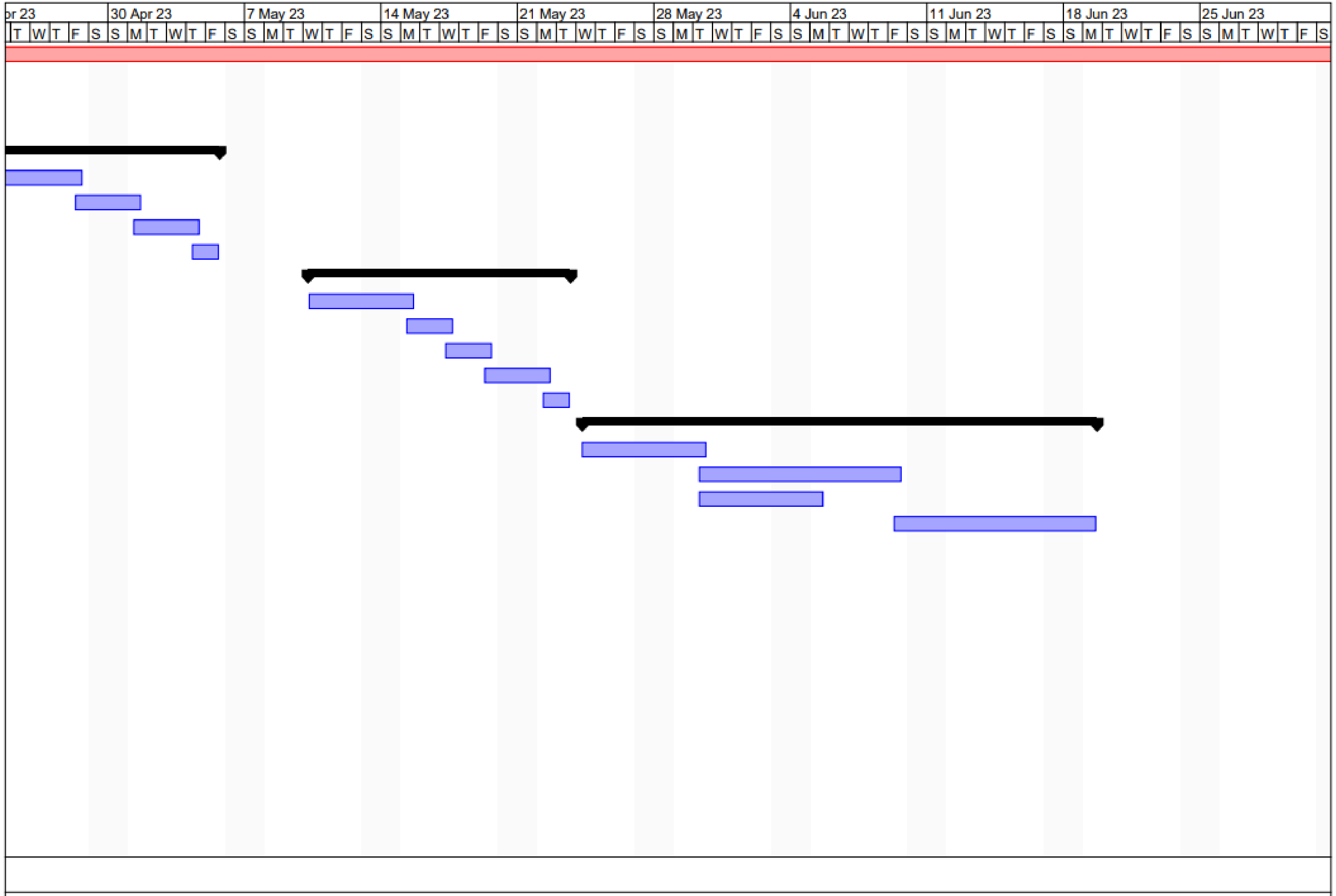
Appendix M	MOHAMED ABDELKARIM	21905008

APPENDIX E: Project Plan

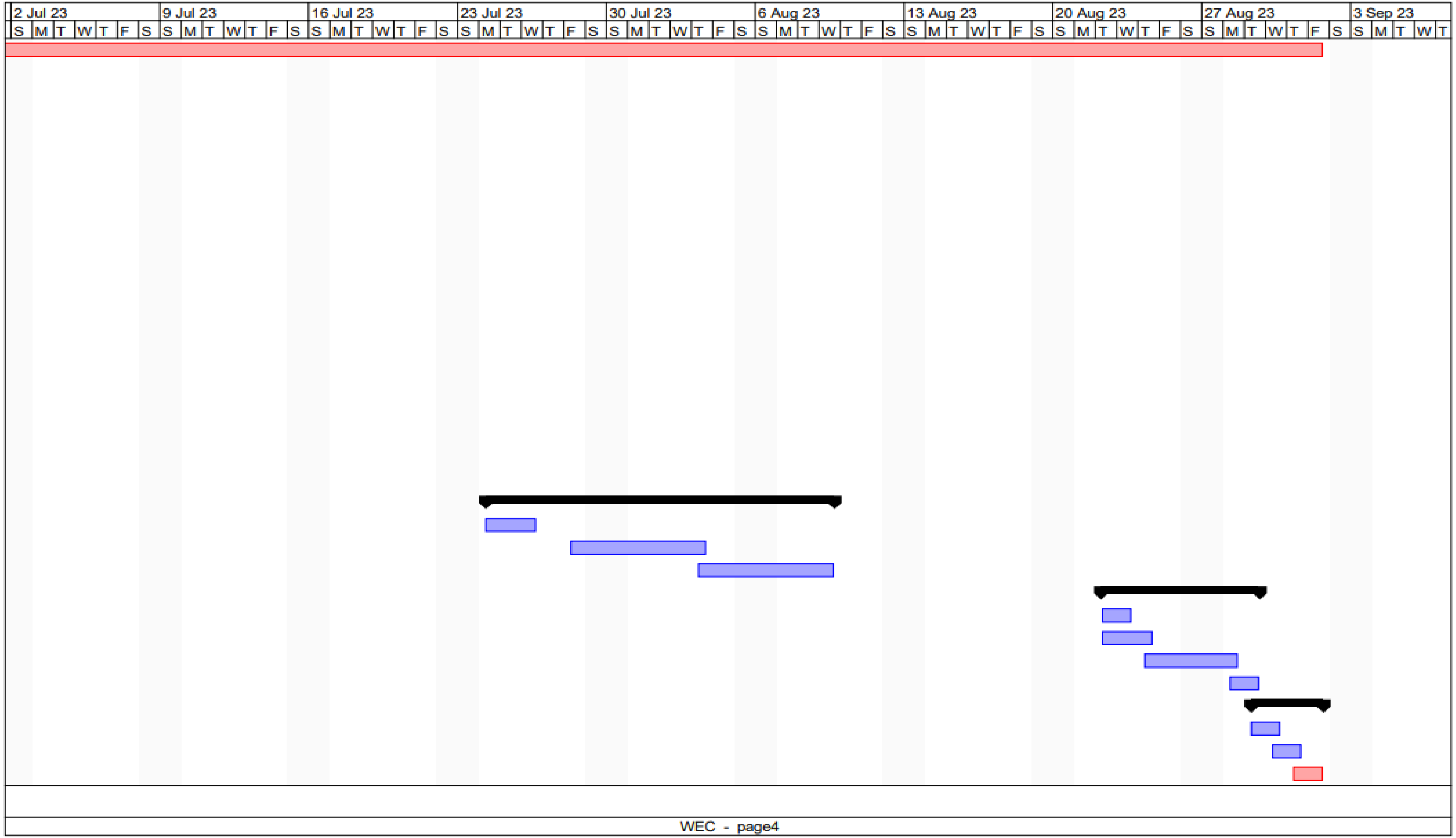
		Name	Duration	Start	Finish	Predecessors
1		WEC	133 days	3/1/23 8:00 AM	9/1/23 5:00 PM	
2		**Conceptual Design**	**23 days**	**3/1/23 8:00 AM**	**3/31/23 5:00 PM**	
3		1.1 WEC mission definition	11 days	3/1/23 8:00 AM	3/15/23 5:00 PM	
4		1.2 Development of WEC Designs	13 days	3/15/23 8:00 AM	3/31/23 5:00 PM	
5		**1.3 Development of WEC Concept**	**14 days**	**4/18/23 7:00 AM**	**5/5/23 5:00 PM**	
6		1.3.1 Concept "A" Discussion/research	9 days	4/18/23 7:00 AM	4/28/23 5:00 PM	
7		1.3.2 Concept "B" Discussion/research	2 days	4/28/23 7:00 AM	5/1/23 5:00 PM	
8		1.3.3 Concept "C" Disussion/ research	4 days	5/1/23 7:00 AM	5/4/23 5:00 PM	
9		1.4 Selection of Suitable Concept	2 days	5/4/23 7:00 AM	5/5/23 5:00 PM	
10		**2. Prelimenary Design**	**10 days?**	**5/10/23 7:00 AM**	**5/23/23 5:00 PM**	
11		2.1 Developing Design for selected concept	4 days?	5/10/23 7:00 AM	5/15/23 5:00 PM	
12		2.1.1 Design A for Concept	3 days	5/15/23 7:00 AM	5/17/23 5:00 PM	
13		2.1.2 Desgin B for Concept	3 days?	5/17/23 7:00 AM	5/19/23 5:00 PM	
14		2.1.3 Design C for Concept	2 days?	5/19/23 7:00 AM	5/22/23 5:00 PM	
15		2.2 Report Draft and Discussion	2 days?	5/22/23 7:00 AM	5/23/23 5:00 PM	
16		**3. Detail Design of WEC**	**19 days?**	**5/24/23 8:00 AM**	**6/19/23 5:00 PM**	
17		3.1 Completion of Selection	5 days?	5/24/23 8:00 AM	5/30/23 5:00 PM	
18		3.3 Completion of WEC Design	9 days?	5/30/23 8:00 AM	6/9/23 5:00 PM	
19		3.4 Completion of Testing PLan	5 days?	5/30/23 8:00 AM	6/5/23 5:00 PM	
20		3.5 Documentaition update	7 days?	6/9/23 8:00 AM	6/19/23 5:00 PM	
21		**4.Product development**	**13 days?**	**7/24/23 8:00 AM**	**8/9/23 5:00 PM**	
22		4.1 Procuration of components	3 days	7/24/23 8:00 AM	7/26/23 5:00 PM	
23		4.2 Assembly of Tank	5 days?	7/28/23 8:00 AM	8/3/23 5:00 PM	
24		4.3 Pluging Electrical components and wiring	5 days?	8/3/23 8:00 AM	8/9/23 5:00 PM	
25		**5.Design Valdiation ,Verfication and Testing**	**6 days?**	**8/22/23 7:00 AM**	**8/29/23 5:00 PM**	
26		5.1 Testing Servo motors	2 days	8/22/23 8:00 AM	8/23/23 5:00 PM	
27		5.2 Testing Wave Creator & Tank	3 days?	8/22/23 7:00 AM	8/24/23 5:00 PM	
28		5.3 Product Validation and verification	3 days?	8/24/23 7:00 AM	8/28/23 5:00 PM	
29		5.4 Result Comparision	2 days?	8/28/23 7:00 AM	8/29/23 5:00 PM	
30		**6. Normal Operation**	**4 days?**	**8/29/23 8:00 AM**	**9/1/23 5:00 PM**	
31		6.1 Data Acqusition	2 days?	8/29/23 8:00 AM	8/30/23 5:00 PM	
32		6.2 Documentation Update	2 days?	8/30/23 7:00 AM	8/31/23 5:00 PM	
33		6.3 Promotional material Update	2 days?	8/31/23 7:00 AM	9/1/23 5:00 PM	

WEC - page1


Resource Names
26 Feb 23
5 Mar 23
12 Mar 23
19 Mar 23
26 Mar 23
2 Apr 23
9 Apr 23
16 Apr 23
23 A
S M T W T F S
WEC - page2

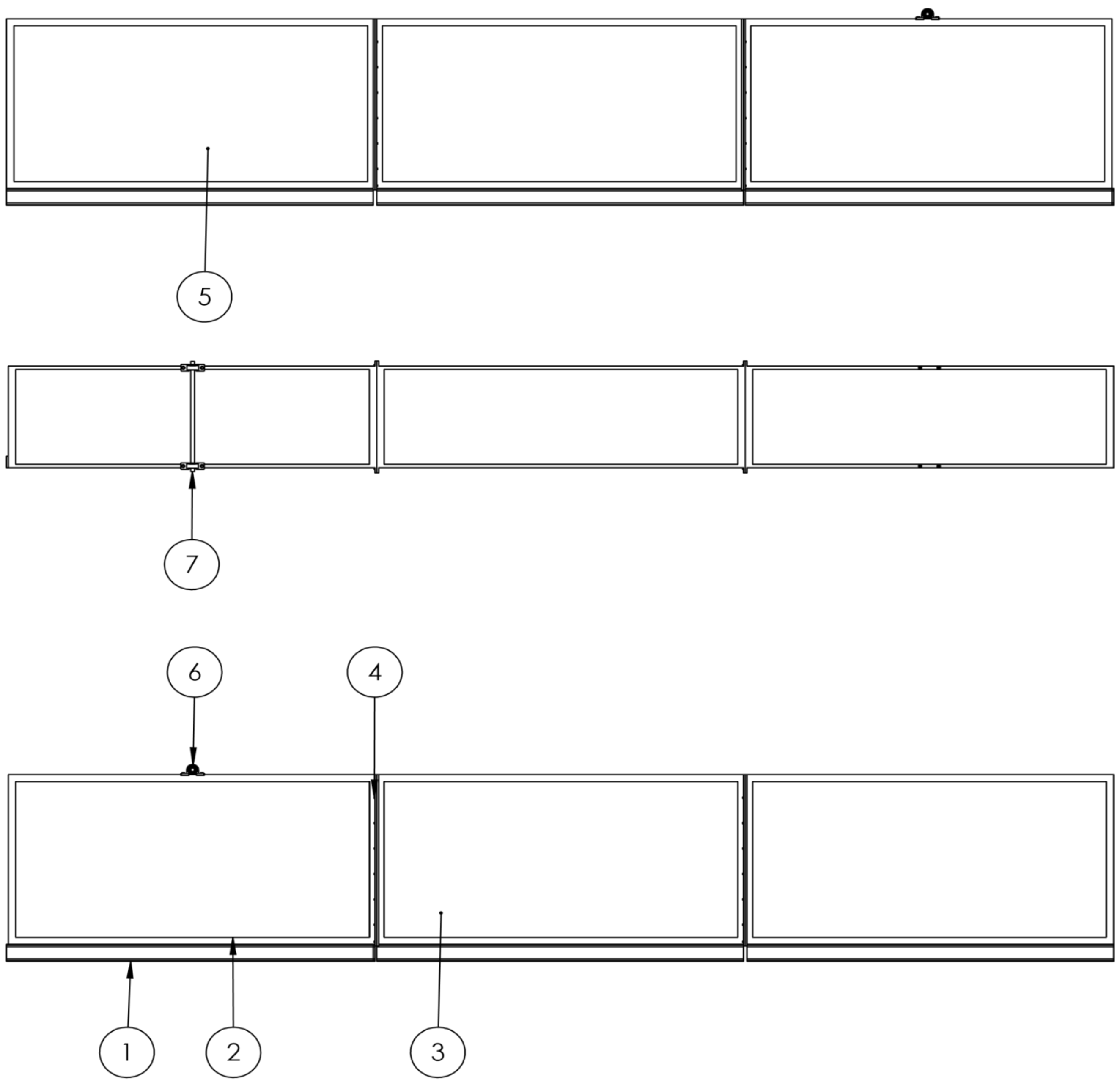


pr 23
30 Apr 23
7 May 23
14 May 23
21 May 23
28 May 23
4 Jun 23
11 Jun 23
18 Jun 23
25 Jun 23


2 Jul 23
9 Jul 23
16 Jul 23
23 Jul 23
30 Jul 23
6 Aug 23
13 Aug 23
20 Aug 23
27 Aug 23
3 Sep 23
WEC - page4

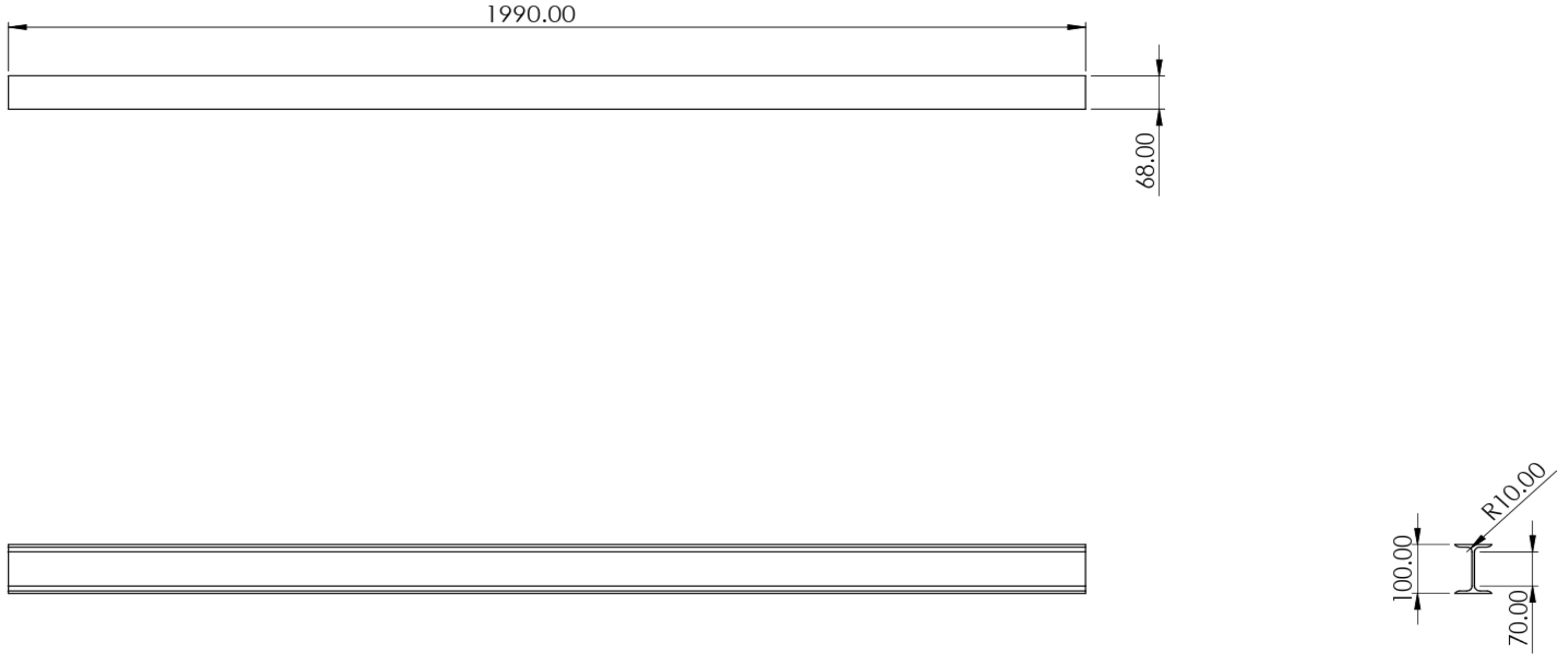
APPENDIX F: Engineering Drawings

Engineering Drawings are shown in the next page.



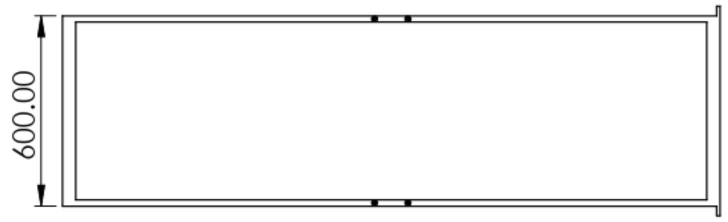
Item No	Description	Material	QYT.
7	Wave Maker	Galvanized Steel	1
6	Bearings		2
5	PlexiGlass	Arcylic Sheet	3
4	Hex Flang Bolts	ASTM A307. Stainless Steel	39
3	Steel Sheet	ASTM A653-09, Galvanized Steel	8
2	Iron Angle	EN10056-1, Carbon Steel	-
1	I Beam	EN 10024, Structural Steel	2

	Name	Sign	Date	Eastern Mediterranean University "Virtue, Knowledge, Advancement" Mechanical Engineering Department
Drawn By	Mohamed musa	MM	12/9/2023	
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1:25	Title: Ocean Wave Energy Tank			Drawing No: A-1

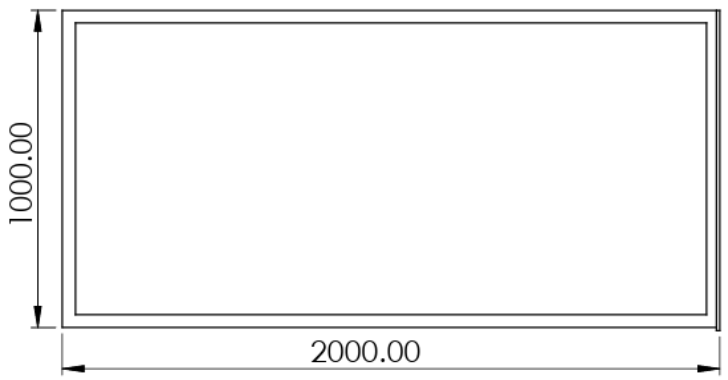


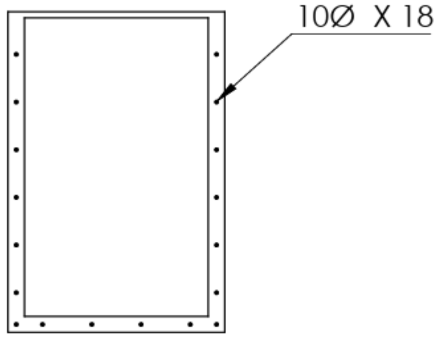
All dimensions are in milimeter

	Name	Sign	Date	Eastern Mediterranean University "Virtue, Knowledge, Advancement"
Drawn By	Mohamed musa	MM	12/9/2023	Mechanical Engineering Department
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1:10	Title: I - Beam			Drawing No: 1-1



Description :
Iron angle welded
togther to manufacture
this segment

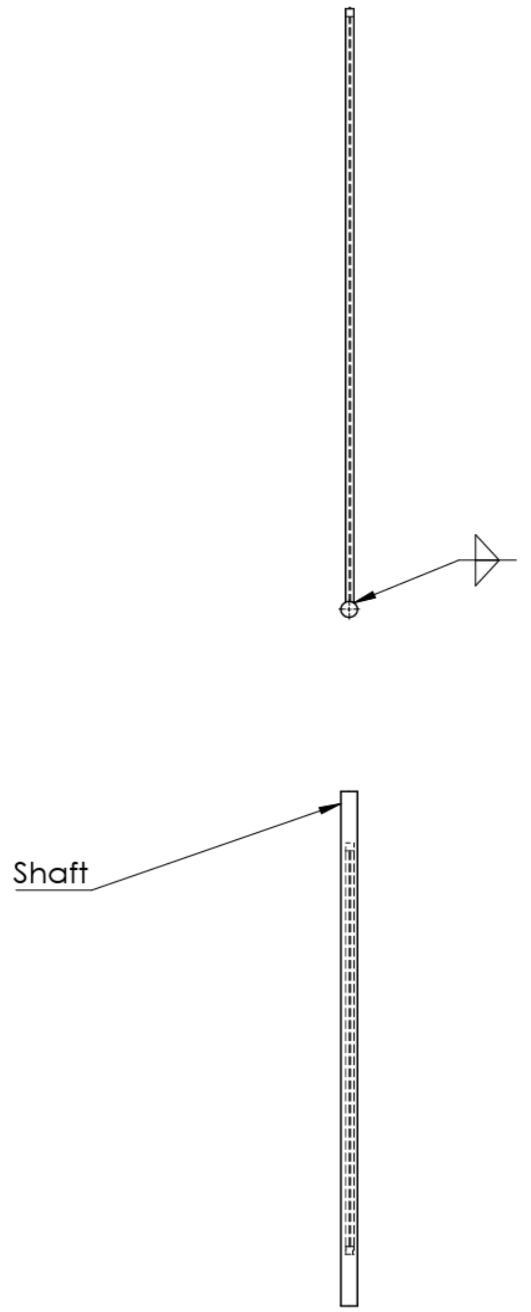


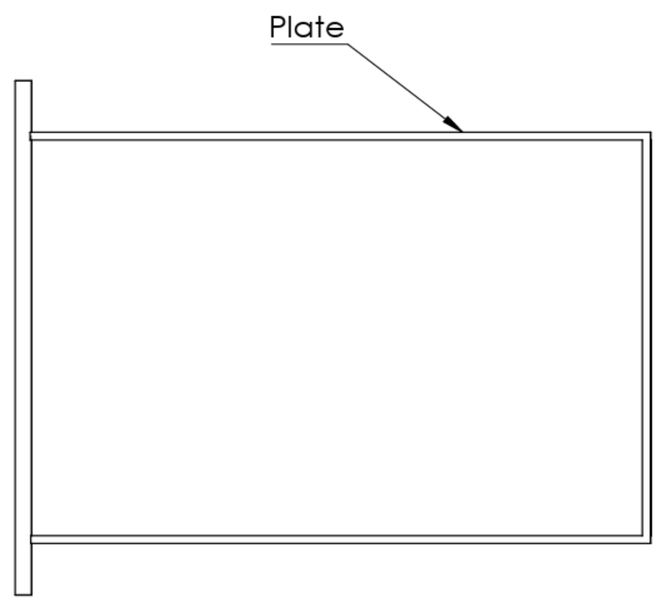


All dimensions are in millimeter

	Name	Sign	Date	Eastern Mediterranean University
Drawn By	Mohamed musa	MM	12/9/2023	Mechanical Engineering Department
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1:20	Title: Wave Ganaratore Segment			Drawing No: 1-2

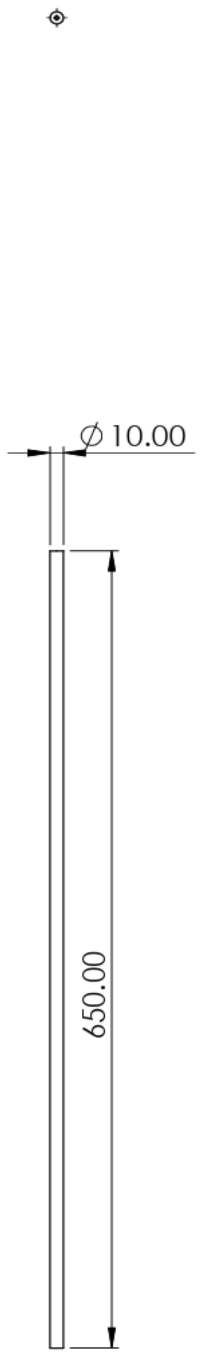
Description: A steel plate welded to a shaft to manufacture the wave maker





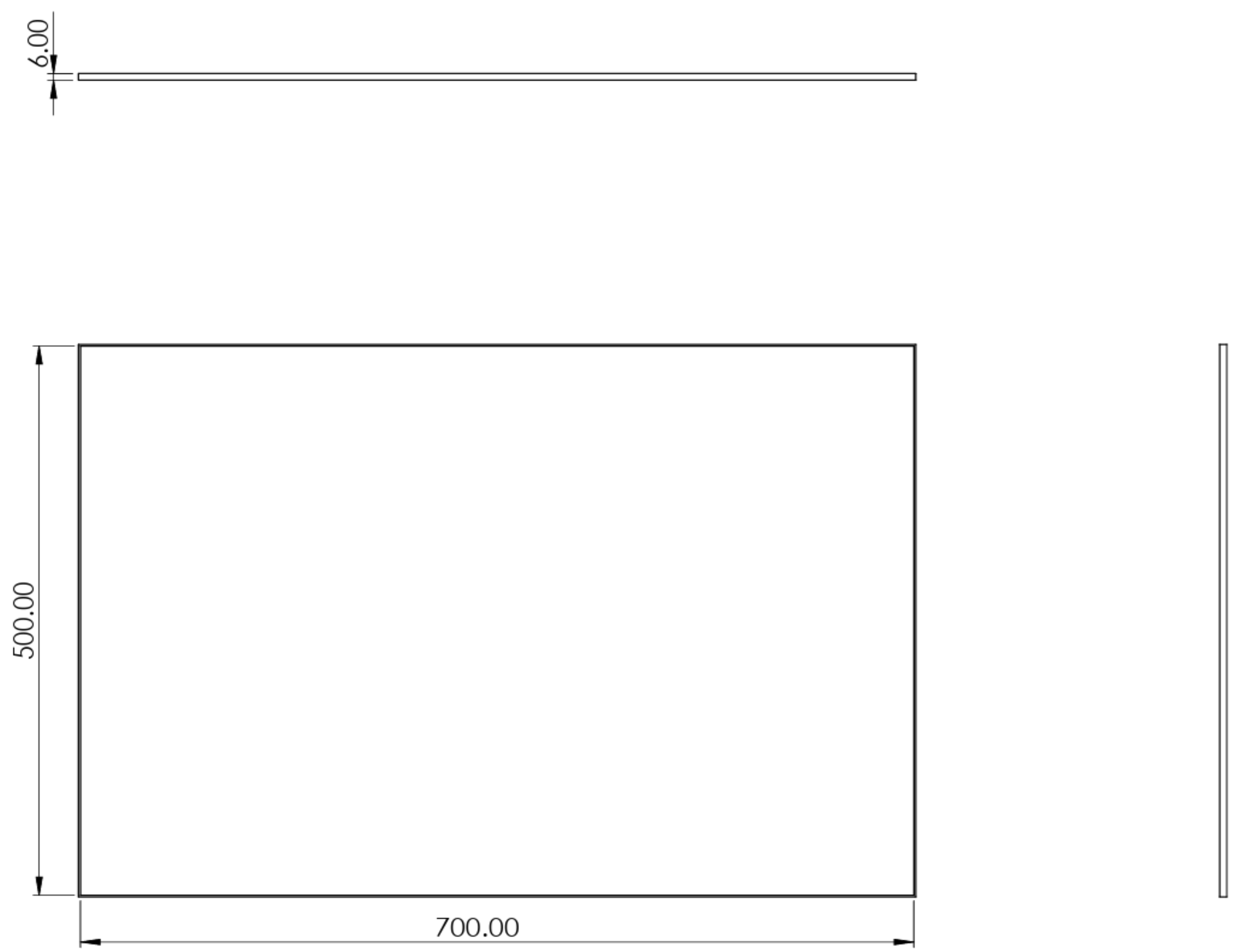
All dimension are in milimetter

	Name	Sign	Date	Mechanical Engineering Department
Drawn By	Mohamed musa	MM	12/9/2023	
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1:8	Title: Wave Maker			Drawing No: A-2



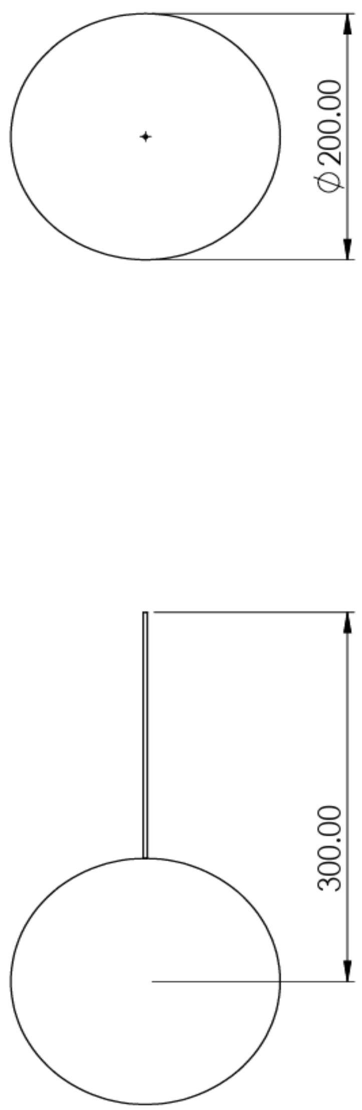
All dimensions are in millimeter

	Name	Sign	Date	Eastern Mediterranean University "Virtue, Knowledge, Advancement" Mechanical Engineering Department
Drawn By	Mohamed musa	MM	12/9/2023	
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1:5	Title: Shaft			Drawing No: 1-3



All dimensions are in millimeter

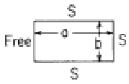
	Name	Sign	Date	Eastern Mediterranean University "Virtue, Knowledge, Advancement"
Drawn By	Mohamed musa	MM	12/9/2023	Mechanical Engineering Department
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1-5	Title: Plate			Drawing No: 1-4



All dimensions are in millimeter

	Name	Sign	Date	Eastern Mediterranean University "Virtue, Knowledge, Advancement"
Drawn By	Mohamed musa	MM	12/9/2023	Mechanical Engineering Department
Checked By	Cafer Kizilors	CK	13/9/2023	
Scale: 1:5	Title: Bouy			Drawing No: 1-5

APPENDIX G: LOAD CALCULATIONS RESULTS

2. Rectangular plate; three edges simply supported, one edge (b) free 	2a. Uniform over entire plate	$\sigma_{max} = \frac{\beta q b^2}{t^2}$ and $y_{max} = \frac{-\alpha q b^4}{Et^3}$ (Ref. 8 for $v = 0.3$)
	2d. Uniformly increasing along the a side	$\sigma_{max} = \frac{\beta q b^2}{t^2}$ and $y_{max} = \frac{-\alpha q b^4}{Et^3}$ (Ref. 8 for $v = 0.3$)

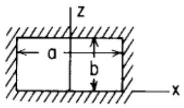
Case 2a:

a/b	0.50	0.667	1.0	1.5	2.0	4.0
β	0.36	0.45	0.67	0.77	0.79	0.80
α	0.080	0.106	0.140	0.160	0.165	0.167

Case 2d:

a/b	0.50	0.667	1.0	1.5	2.0	2.5	3.0	3.5	4.0
β	0.11	0.16	0.20	0.28	0.32	0.35	0.36	0.37	0.37
α	0.026	0.033	0.040	0.050	0.058	0.064	0.067	0.069	0.070

8. Rectangular plate, all edges fixed

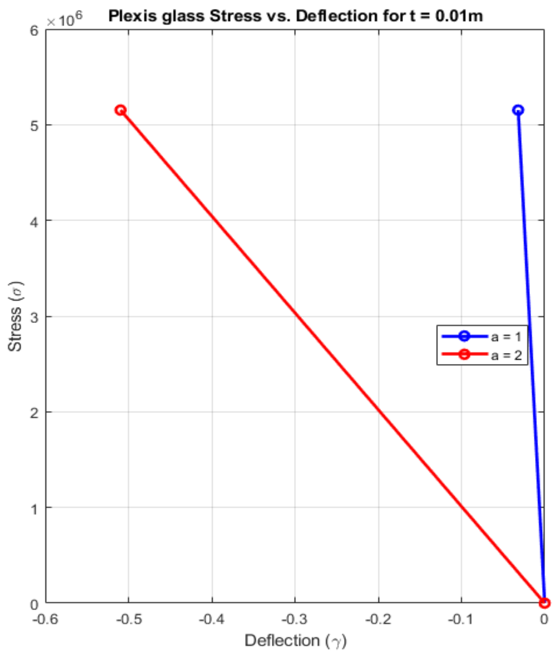


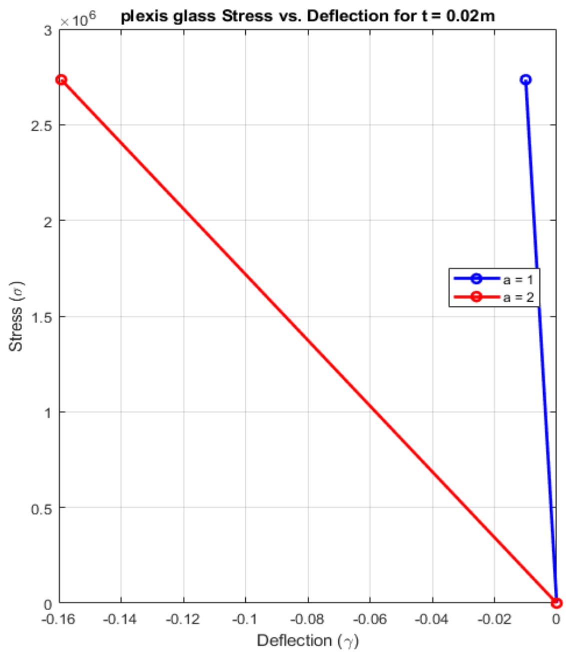
8a. Uniform over entire plate

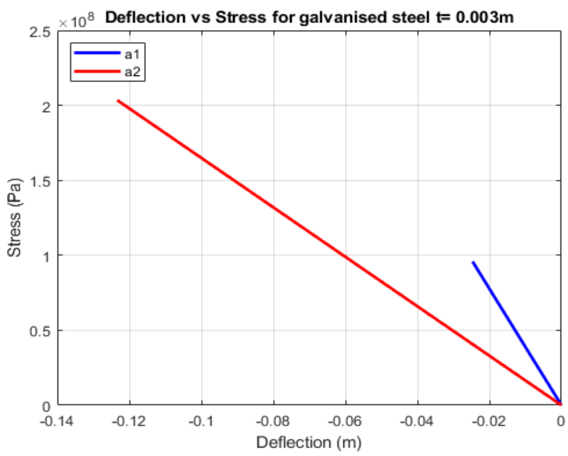
(At center of long edge) $\sigma_{max} = \frac{-\beta_1 q b^2}{t^2}$

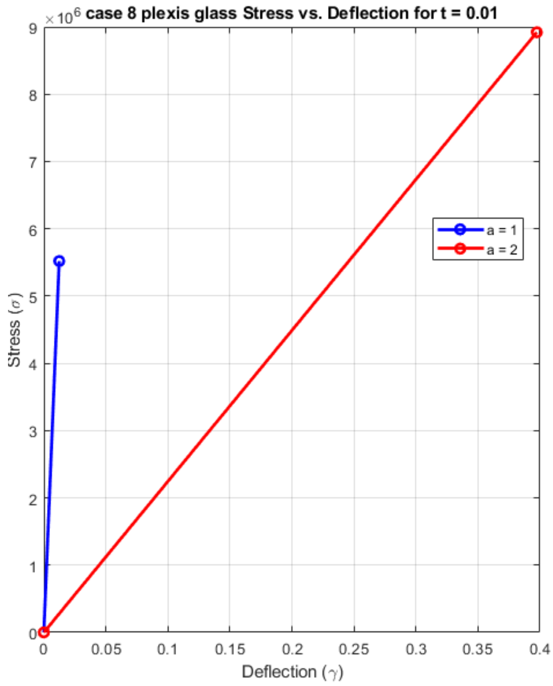
(At center) $\sigma = \frac{\beta_2 q b^2}{t^2}$ and $y_{max} = \frac{\alpha q b^4}{Et^3}$

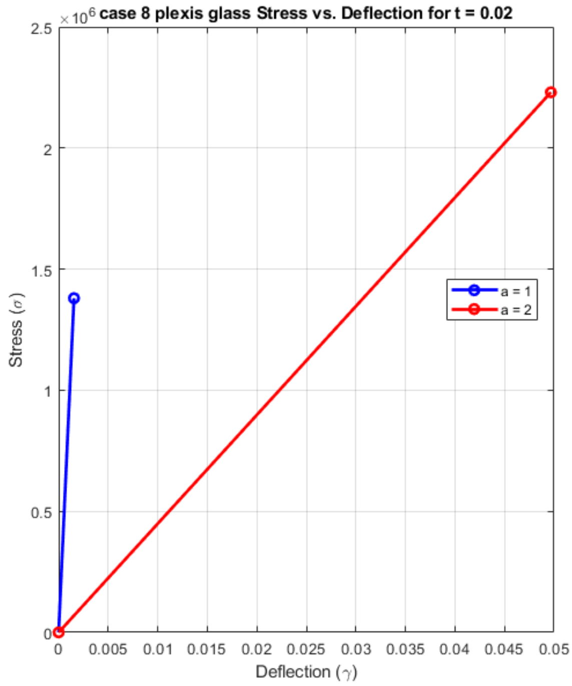
a/b	1.0	1.2	1.4	1.6	1.8	2.0	∞
β_1	0.3078	0.3834	0.4356	0.4680	0.4872	0.4974	0.5000
β_2	0.1386	0.1794	0.2094	0.2286	0.2406	0.2472	0.2500
α	0.0138	0.0188	0.0226	0.0251	0.0267	0.0277	0.0284











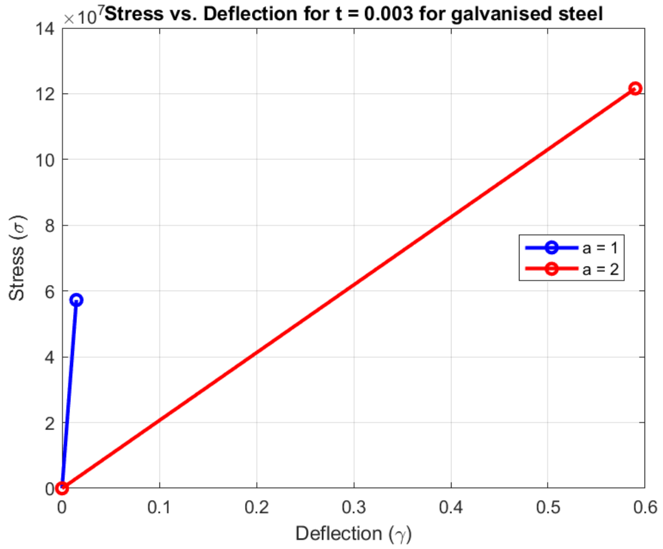


Table 21 Stress and Deflection calculations for Galvanized steel Simply Supported

All formulas are obtained from Table 11.4 Roark's formula for stress (MPa) and Deflection(m)				
Case No 1: Rectangular plate; all edges are simply Supported edges simply supported				
For a=b=1	α=	0.0444	β=	0.2874
For t=0.003m alpha and beta 1	q(N)=	812.5		
Maximum Stress: $\sigma = \beta q b^2/t^2$	E(Pa)=	2.00E+11		
2.5E+07				
Maximum Deflection: $\gamma = -\alpha q b^4/Et^3$				
0.0067				
For a=2 b=1	α=	0.111	β=	0.6102

Maximum Stress: σ=βqb^2/t^2				
5.5E+07				
Maximum Deflection: γ=-αqb^4/Et^3				
0.017				
For t=0.003m alpha and beta 2				
For a=b=1				
Maximum Stress: σ=βqb^2/t^2				
2.5E+07				
Maximum Deflection: γ=-αqb^4/Et^3				
-0.11				
For a=2 b=1				
Maximum Stress: σ=βqb^2/t^2				
5.5E+07				
Maximum Deflection: γ=-αqb^4/Et^3				
-0.27				

Table 22 Stress and Deflection calculations for Galvanized steel Fixed on all ends

All formulas are obtained from Table 11.4 Roark's formula for stress (MPa) & Deflection(m)						
Case No 8: Rectangular plate; all edges are Fixed edges simply supported						
For a=b=1	α=	0.0138	β1=	0.3078	β2=	0.1386
For t=0.01m	q(N)=	812.5				
Maximum Stress: σ=β1qb^2/t^2	E(Pa)=	2.00E+11				
-2.50E+06						
Stress at Centre: σ=β2qb^2/t^2						
1.13E+06						
Maximum Deflection: γ=αqb^4/Et^3	α=	0.0277	β1=	0.4974	β2=	0.2472
5.61E-05						
For a=2 b=1						
Maximum Stress: σ=β1qb^2/t^2						
-4.04E+06						

Stress at Centre: $\sigma=\beta 2qb^2/t^2$						
2.01E+06						
Maximum Deflection: $\gamma=\alpha qb^4/Et^3$						
1.13E-04						
For t=0.02m						
For a=b=1						
Maximum Stress: $\sigma=\beta 1qb^2/t^2$						
-6.25E+05						
Stress at Centre: $\sigma=\beta 2qb^2/t^2$						
2.82E+05						
Maximum Deflection: $\gamma=\alpha qb^4/Et^3$						
7.01E-06						
For a=2 b=1						
Maximum Stress: $\sigma=\beta 1qb^2/t^2$						
-1.01E+06						
Stress at Centre: $\sigma=\beta 2qb^2/t^2$						
5.02E+05						
Maximum Deflection: $\gamma=\alpha qb^4/Et^3$						
1.41E-05						

Table 23 Table with calculations and values of calculating deflection of plexi glass when simply supported

All formulas are obtained from Table 11.4 Roark's formula for stress (MPa) & Deflection(m) all length units in meters				
Case No 1: Rectangular plate; all edges are simply Supported edges simply supported	a= long side	b= short side		
For a=b=1m	α=	0.0444	β=	0.2874
For t=0.01m	q(N)=	812.5		
Maximum Stress: $\sigma=\beta qb^2/t^2$	E(Pa)=	2.50E+09		
2.34E+06				

$\gamma=-\alpha qb^4/Et^3$

Maximum Deflection:				
1.44E-02				
For a=2m b=1m	α=	0.111	β=	0.6102
Maximum Stress: $σ=βqb^2/t^2$				
4.96E+06				
Maximum Deflection: $γ=-αqb^4/Et^3$				
3.61E-02				
For t=0.02m				
For a=b=1m				
Maximum Stress: $σ=βqb^2/t^2$				
5.84E+05				
Maximum Deflection: $γ=-αqb^4/Et^3$				
1.80E-03				
For a=2m b=1m				
Maximum Stress: $σ=βqb^2/t^2$				
1.24E+06				
Maximum Deflection: $γ=-αqb^4/Et^3$				
4.51E-03				

Table 24 Table containing values and calculations of plexis glass sheets when all ends fixed

All formulas are obtained from Table 11.4 Roark's formula for stress (MPa) & Deflection(m)						
Case No 8: Rectangular plate; all edges are Fixed edges simply supported						
For a=b=1m	α=	0.0138	β1=	0.3078	β2=	0.1386
For t=0.01m	q(N)=	812.5				
Maximum Stress: $σ=β1qb^2/t^2$	E(Pa)=	2.50E+09				
-2.50E+06						
Stress at Centre: $σ=β2qb^2/t^2$						
1.13E+06						
Maximum Deflection: $γ=αqb^4/Et^3$	α=	0.0277	β1=	0.4974	β2=	0.2472
4.49E-03						

For a=2m b=1m						
Maximum Stress: $\sigma=\beta 1 q b^2/t^2$						
-4.04E+06						
Stress at Centre: $\sigma=\beta 2 q b^2/t^2$						
2.01E+06						
Maximum Deflection: $\gamma=\alpha q b^4/E t^3$						
9.00E-03						
For t=0.02m						
For a=b=1m						
Maximum Stress: $\sigma=\beta 1 q b^2/t^2$						
-6.25E+05						
Stress at Centre: $\sigma=\beta 2 q b^2/t^2$						
2.82E+05						
Maximum Deflection: $\gamma=\alpha q b^4/E t^3$						
5.61E-04						
For a=2m b=1m						
Maximum Stress: $\sigma=\beta 1 q b^2/t^2$						
-1.01E+06						
Stress at Centre: $\sigma=\beta 2 q b^2/t^2$						
5.02E+05						
Maximum Deflection: $\gamma=\alpha q b^4/E t^3$						
1.13E-03						

Case 8 for galvanized

```
% Constants
q = 1793.5;       % Value for q
E = 2e11;         % Value for E (Young's modulus)

% Constants for alpha and beta when a = 1
alpha1 = 0.0444;
beta1 = 0.2874;
beta1_center = 0.111; % Changed the value for beta1_center as specified

% Constants for alpha and beta when a = 2
alpha2 = 0.111;
beta2 = 0.6102;
beta2_center = 0.222; % Changed the value for beta2_center as specified
```

```
% Fixed values for b and t
b = 1;
t = 0.003;

% Calculate stress and deflection for a = 1
deflection_values_a1 = alpha1 * q * 1^4 / (E * t^3);
stress_values_a1 = beta1 * q * b^2 / t^2 + deflection_values_a1 * beta1_center;

% Calculate stress and deflection for a = 2
deflection_values_a2 = alpha2 * q * 2^4 / (E * t^3);
stress_values_a2 = beta2 * q * b^2 / t^2 + deflection_values_a2 * beta2_center;

% Plot stress against deflection for a = 1 and a = 2
figure;
plot([0, deflection_values_a1], [0, stress_values_a1], 'bo-', 'LineWidth', 2);
hold on;
plot([0, deflection_values_a2], [0, stress_values_a2], 'ro-', 'LineWidth', 2);
xlabel('Deflection (\gamma)');
ylabel('Stress (\sigma)');
title('Stress vs. Deflection for t = 0.003 for galvanised steel case 8');
legend('a = 1', 'a = 2', 'Location', 'Best');
grid on;
```

case 8 for plexis

```
% Constants
q = 1793.5;      % Value for q
E = 2e9;        % Value for E (Young's modulus)

% Constants for alpha and beta when a = 1
alpha1 = 0.0138;
beta1 = 0.3078;
beta1_center = 0.1386;

% Constants for alpha and beta when a = 2
alpha2 = 0.0277;
beta2 = 0.4974;
beta2_center = 0.2472;

% Fixed values for b
b = 1;

% Values of t for the two cases
t_values = [0.01, 0.02];

% Create a figure with subplots
figure;

for k = 1:numel(t_values)
   t = t_values(k);

   % Calculate stress and deflection for a = 1
   alpha = alpha1;
   beta = beta1;
   beta_center = beta1_center;

   deflection_values = alpha * q * 1^4 / (E * t^3);
   stress_values = beta * q * b^2 / t^2 + deflection_values * beta_center;

   % Plot stress against deflection for a = 1
   subplot(1, 2, k);
   plot([0, deflection_values], [0, stress_values], 'bo-', 'LineWidth', 2);
   xlabel('Deflection (\gamma)');
```

```
    ylabel('Stress (\sigma)');
    title(['case 8 plexis glass Stress vs. Deflection for a = 1, t = ' num2str(t)]);
    grid on;

    % Calculate stress and deflection for a = 2
    alpha = alpha2;
    beta = beta2;
    beta_center = beta2_center;

    deflection_values = alpha * q * 2^4 / (E * t^3);
    stress_values = beta * q * b^2 / t^2 + deflection_values * beta_center;

    % Plot stress against deflection for a = 2
    hold on;
    plot([0, deflection_values], [0, stress_values], 'ro-', 'LineWidth', 2);
    xlabel('Deflection (\gamma)');
    ylabel('Stress (\sigma)');
    title(['case 8 plexis glass Stress vs. Deflection for t = ' num2str(t)]);
    legend('a = 1', 'a = 2', 'Location', 'Best');
    grid on;
end
```

case 1 for galvanized

```
% Given parameters
b = 1; % Given value of b

% Given values for the first calculation
alpha1 = 0.0444;
beta1 = 0.2874;
E = 2e11; % Given value of E (Young's modulus)
t = 0.003; % Given thickness t
a1 = 1; % Given value of a for the first calculation

% Given values for the second calculation
alpha2 = 0.111;
beta2 = 0.6102;
a2 = 2; % Given value of a for the second calculation

% Fixed value of force q
q = 1793; % Given force q

% Calculate stress and deflection for both calculations
stress1 = beta1 * q * b^2 / t^2;
deflection1 = -alpha1 * q * b^4 / (E * t^3) * a1^4;

stress2 = beta2 * q * b^2 / t^2;
deflection2 = -alpha2 * q * b^4 / (E * t^3) * a2^4;

% Plot deflection versus stress linearly
figure;
plot([deflection1, deflection2], [stress1, stress2], 'b', 'LineWidth', 2);
xlabel('Deflection (m)');
ylabel('Stress (Pa)');
legend('a1', 'a2', 'Location', 'northwest');
title('Deflection vs Stress for galvanized steel t = 0.003m, q = 1793 N');
grid on;
```

case 8 for plexis

```
% Constants
q = 1793;        % Value for q
E = 2.5e9;        % Value for E (Young's modulus)
```

```
% Constants for alpha and beta for thickness t = 0.01m
alpha1 = 0.0444;
beta1 = 0.2874;

% Constants for alpha and beta for thickness t = 0.02m
alpha2 = 0.111;
beta2 = 0.6102;

% Fixed values for a and b
a_values = [1, 2];
b = 1;

% Calculate stress and deflect.ion for thickness t = 0.01m (alpha1 and beta1)
t = 0.01;

% Initialize arrays to store stress and deflection values
stress_values_01 = zeros(numel(a_values), 2);
deflection_values_01 = zeros(numel(a_values), 2);

% Calculate stress and deflection for each value of a and alpha1 and beta1
for i = 1:numel(a_values)
    a = a_values(i);
    deflection_values_01(i, 1) = -alpha1 * q * a^4 / (E * t^3);
    stress_values_01(i, 1) = beta1 * q * b^2 / t^2;
end

% Calculate stress and deflection for thickness t = 0.02m (alpha2 and beta2)
t = 0.02;

% Initialize arrays to store stress and deflection values
stress_values_02 = zeros(numel(a_values), 2);
deflection_values_02 = zeros(numel(a_values), 2);

% Calculate stress and deflection for each value of a and alpha2 and beta2
for i = 1:numel(a_values)
    a = a_values(i);
    deflection_values_02(i, 1) = -alpha2 * q * a^4 / (E * t^3);
    stress_values_02(i, 1) = beta2 * q * b^2 / t^2;
end

% Plot stress against deflection for thickness t = 0.01m and t = 0.02m in a single figure
figure;

% Plot for thickness t = 0.01m
subplot(1, 2, 1);
plot([0, deflection_values_01(1, 1)], [0, stress_values_01(1, 1)], 'bo-', 'LineWidth', 2);
hold on;
plot([0, deflection_values_01(2, 1)], [0, stress_values_01(2, 1)], 'ro-', 'LineWidth', 2);
xlabel('Deflection (\gamma)');
ylabel('Stress (\sigma)');
title('Plexis glass Stress vs. Deflection for t = 0.01m');
legend(['a = ' num2str(a_values(1))], ['a = ' num2str(a_values(2))], 'Location', 'Best');
grid on;

% Plot for thickness t = 0.02m
subplot(1, 2, 2);
plot([0, deflection_values_02(1, 1)], [0, stress_values_02(1, 1)], 'bo-', 'LineWidth', 2);
hold on;
plot([0, deflection_values_02(2, 1)], [0, stress_values_02(2, 1)], 'ro-', 'LineWidth', 2);
xlabel('Deflection (\gamma)');
ylabel('Stress (\sigma)');
title('plexis glass Stress vs. Deflection for t = 0.02m');
```

```
legend(['a = ' num2str(a_values(1))], ['a = ' num2str(a_values(2))], 'Location', 'Best');
grid on;
%%
```

APPENDIX H: COMPONENT SPECIFICATIONS:

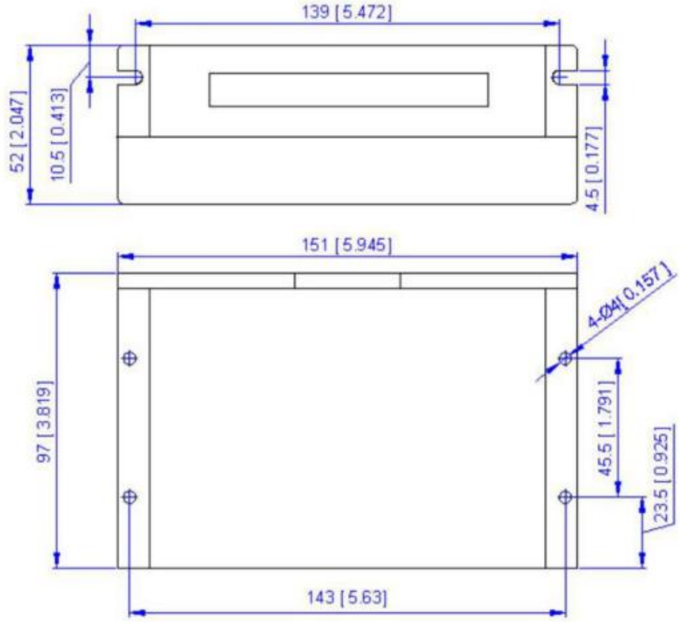
Stepper Motor (1-1-3):

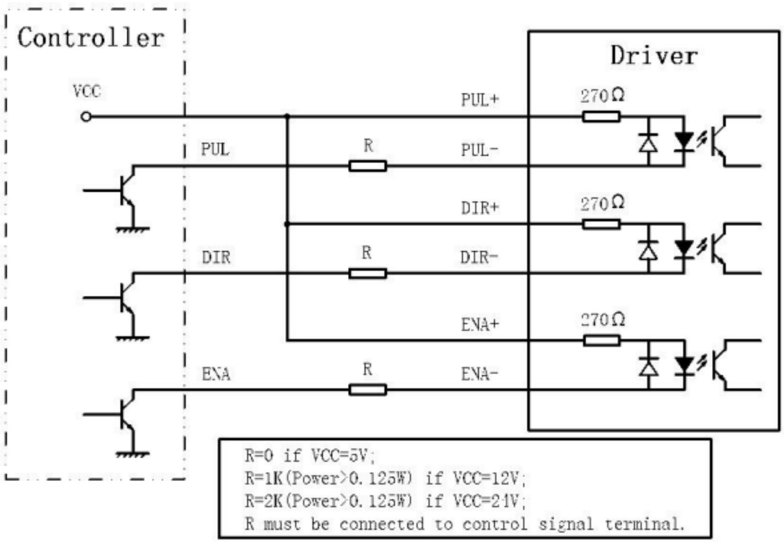
Electrical Specifications (Tj = 25℃/77℉)

Parameters	Min	Typical	Max
Output current	2.4A		7.2 A
Supply voltage	+20VDC	+48VDC	+80VDC
Logic signal current	7mA	10 mA	16 mA
Pulse input frequency	0		200 kHz
Isolation resistance	500 MΩ		

Operating Environment

Environment	Avoid dust, oil fog and corrosive gases
Ambient Temperature	0℃ — 50℃
Humidity	40%RH — 90%RH
Operating Temperature	70℃ Max
Vibration	5.9m/s2 Max
Storage Temperature	-20℃ — 65℃





Microcontroller (1-2-4):

Board		Arduino Uno R3	Arduino Nano	Arduino Pro Mini	Leonardo	Micro	Nano Every	Mega2560 Rev3
Microcontroller		ATmega328p	ATmega328p	ATmega328p	ATmega32u4	ATmega32u4	ATMega4809	ATmega2560
FPGA		No	No	No	No	No	No	No
USB connector		USB-B	Mini-B USB	Mini-B USB	Micro USB (USB-B)	Micro USB	Micro USB	USB-B
I/O	Digital only I/O pin	14	14	14	20	20	14	54
	Analog input pins	6	8	8	12	12	8	16
	Analog output pins	0	0	0	0	0	0	0
	PWM Pins	6	6	6	7	7	5	15
Communication	UART	yes	yes	yes	yes	yes	yes	yes, 4
	I2c	yes	yes	yes	yes	yes	yes	yes
	SPI	yes	yes	yes	yes	yes	yes	yes
	CAN	No	No	No	No	No	No	No
	Bluetooh	No	No	No	No	No	No	No
	WIFI	No	No	No	No	No	No	No
Power	I/O voltage	5v	5v	5v	5v	5v	5v	5V
	Input nominal volta	7-12V	7-12V	7-12V	7-12V	7-12V	7-21V	7-12V
	DC Current per I/O	20mA	20mA	20mA	10mA	10mA	20mA	20mA
	Powersupply conn	Barrel Jack	GPIO header	GPIO header	Barrel Jack	GPIO header	GPIO header	Barrel Jack
	Battery Powered	No	No	No	No	No	No	No
Clock speed	Main processor	ATmega328P 16MHz	ATmega328P 16MHz	ATmega328P 16MHz	ATmega32u4 16MHz	ATmega32u4 16MHz	20MHz	16MHz
RTC		No	No	No	No	No	No	No
USB to Serial		ATmega16U2 16MHz	FT232RL	No onboard USB-TTL Converter	Native	Native	ATSAMD11D14A	ATmega16U2 16MHz
Memmory	Flash	32KB	32KB	32KB	32KB	32KB	48KB	256KB
	SRAM	2KB	2KB	2KB	2.5KB	2.5KB	6KB	8KB
	EEPROM	1KB	1KB	1KB	1KB	1KB	256B	4KB
Dimensions	Weight	25 g	5 g	5 g	20 g	13 g	5 g	37 g
	Width	53.4 mm	18mm	18mm	53.3 mm	18 mm	18 mm	53.3 mm
	Length	68.6 mm	45mm	45mm	68.6 mm	48 mm	45 mm	101.5 mm

Board	Name	Arduino UNO R3
	SKU	A000066

Microcontroller	ATmega328P	
USB connector	USB-B	
Pins	Built-in LED Pin	13
	Digital I/O Pins	14
	Analog input pins	6
	PWM pins	6
Communication	UART	Yes
	I2C	Yes
	SPI	Yes
Power	I/O Voltage	5V
	Input voltage (nominal)	7-12V
	DC Current per I/O Pin	20 mA
	Power Supply Connector	Barrel Plug
Clock speed	Main Processor	Atmega328P 16 MHz
	USB-Serial Processor	Atmega16U2 16 MHz
Memory	Atmega328P	2KB SRAM, 32KB FLASH, 1KB EEPROM
Dimensions	Weight	25 g
	Width	53.4 mm
	Length	68.6 mm

Capacity: 650mAh

Rated energy:4wh

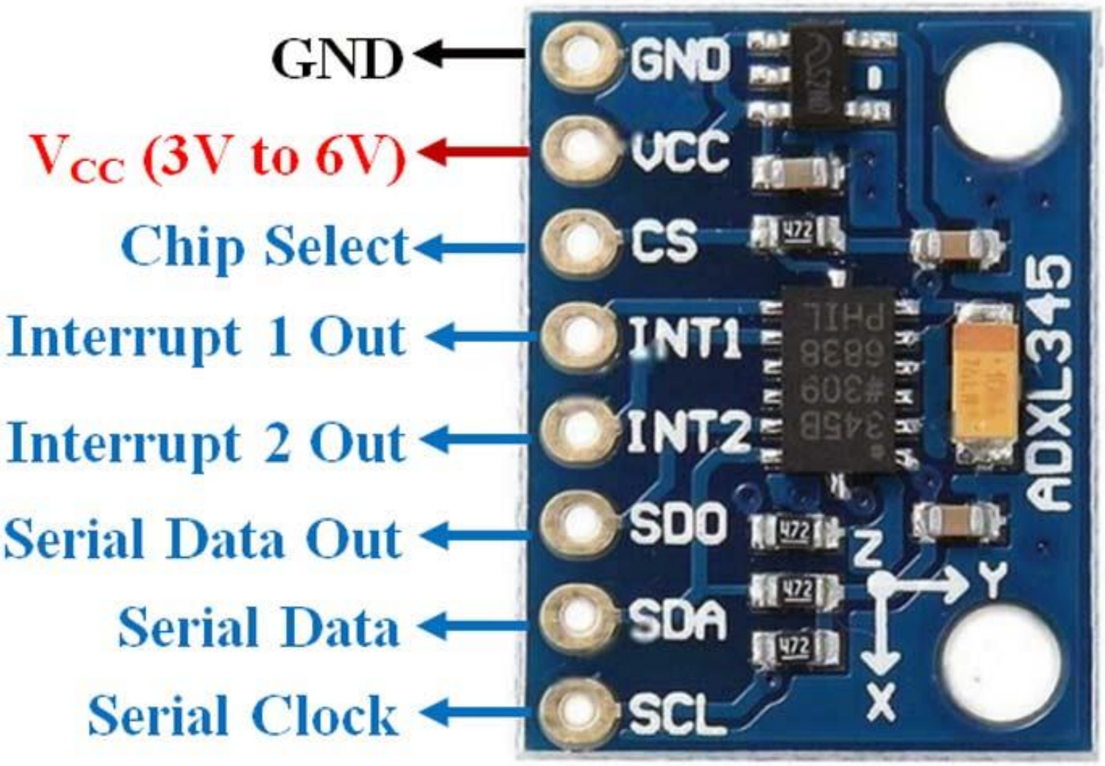
Output voltage: 8.4V

Charging voltage: 5V

Charging via: only by micro USB cable

Full charge time: approximately 3 hour

Accelerometer (1-2-4-1):



PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

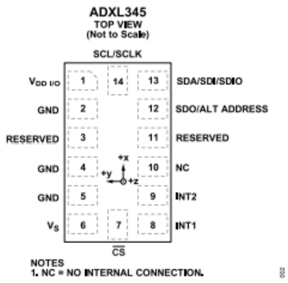
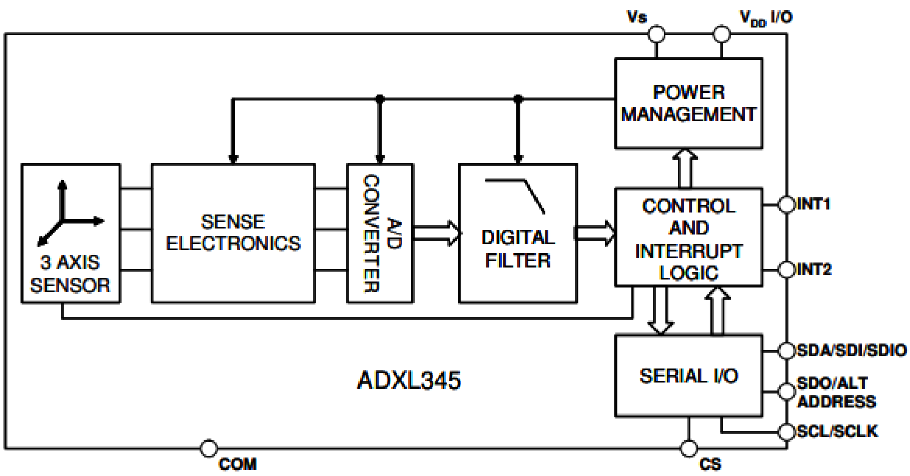


Figure 3. Pin Configuration (Top View)

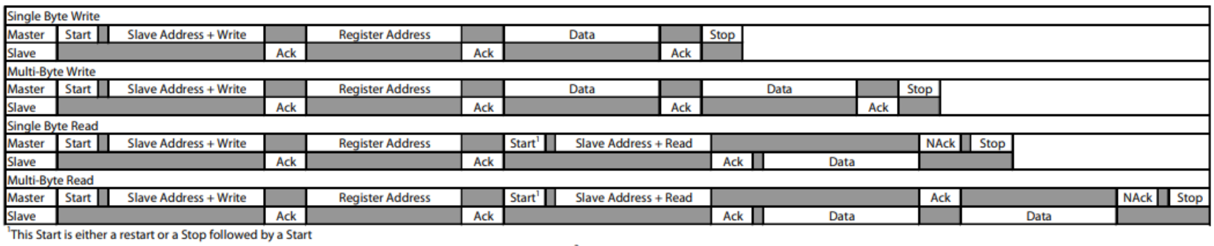
Table 5. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	$V_{DD\ I/O}$	Digital Interface Supply Voltage.
2	GND	This pin must be connected to ground.
3	RESERVED	Reserved. This pin must be connected to V_S or left open.
4	GND	This pin must be connected to ground.
5	GND	This pin must be connected to ground.
6	V_S	Supply Voltage.
7	$\overline{CS}$	Chip Select.
8	INT1	Interrupt 1 Output.
9	INT2	Interrupt 2 Output.
10	NC	Not Internally Connected.
11	RESERVED	Reserved. This pin must be connected to ground or left open.
12	SDO/ALT ADDRESS	Serial Data Output (SPI 4-Wire)/Alternate I^2C Address Select (I^2C).
13	SDA/SDI/SDIO	Serial Data (I^2C)/Serial Data Input (SPI 4-Wire)/Serial Data Input and Output (SPI 3-Wire).
14	SCL/SCLK	Serial Communications Clock. SCL is the clock for I^2C, and SCLK is the clock for SPI.

FUNCTIONAL BLOCK DIAGRAM

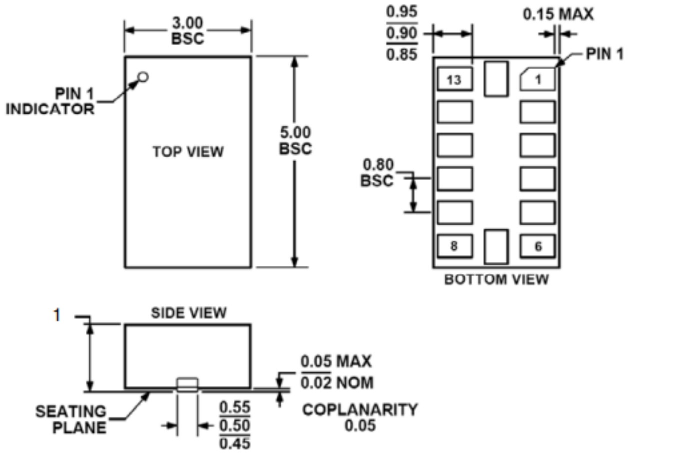


Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range	User Selectable		±2, 4, 8, 16		*g*
Nonlinearity	Percentage of full scale		±0.5		%
Inter-Axis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity[2]			±1		%
OUTPUT RESOLUTION	Each axis				
All g-ranges	10-bit mode		10		Bits
±2 *g* range	Full-Resolution		10		Bits
±4 *g* range	Full-Resolution		11		Bits
±8 *g* range	Full-Resolution		12		Bits
±16 *g* range	Full-Resolution		13		Bits
SENSITIVITY	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±2 *g* 10-bit or Full-Resolution	232	256	286	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±2 *g* 10-bit or Full-Resolution	3.5	3.9	4.3	m*g*/LSB
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±4 *g* 10-bit mode	116	128	143	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±4 *g* 10-bit mode	7.0	7.8	8.6	m*g*/LSB
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±8 *g* 10-bit mode	58	64	71	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±8 *g* 10-bit mode	14.0	15.6	17.2	m*g*/LSB
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±16 *g* 10-bit mode	29	32	36	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±16 *g* 10-bit mode	28.1	31.2	34.3	m*g*/LSB
Sensitivity Change due to Temperature			±0.02		%/°C
0 *g* BIAS LEVEL	Each axis				
0 *g* Output (X_{OUT}, Y_{OUT}, Z_{OUT})	V_S = 2.5 V, T_A = 25°C	-150	0	+150	m*g*
0 *g* Offset vs. Temperature			<±1		m*g*/°C
NOISE PERFORMANCE					
Noise (x-, y-axes)	Data Rate = 100 Hz, ±2 *g* 10-bit or Full-Res.		<1		LSB RMS
Noise (z-axis)	Data Rate = 100 Hz, ±2 *g* 10-bit or Full-Res.		<1.5		LSB RMS
OUTPUT DATA RATE / BANDWIDTH	User Selectable				
Measurement Rate[3]		0.1		3200	Hz
SELF TEST					
Output Change X		+0.31		+1.02	*g*
Output Change Y		-0.31		-1.02	*g*
Output Change Z		+0.46		+1.64	*g*
POWER SUPPLY					
Operating Voltage Range (V_S)		2.0	2.5	3.6	V
Interface Voltage Range ($V_{DD\ I/O}$)		1.7	1.8	V_S	V
Supply Current	Data Rate > 100 Hz		130	150	µA
Supply Current	Data Rate < 10 Hz		25		µA
Standby Mode Leakage Current			0.1	2	µA
Turn-On Time[4]	Data Rate = 3200 Hz		1.4		ms
TEMPERATURE					
Operating Temperature Range		–40		85	°C
WEIGHT					
Device Weight			20		mgrams



[1]This Start is either a restart or a Stop followed by a Start

Hex	Dec	Name	Type	Reset Value	Description
0	0	DEVID	R	11100101	Device ID.
1	1	Reserved			Reserved. Do not access.
to					Reserved. Do not access.
1C	28	Reserved			Reserved. Do not access.
1D	29	THRESH_TAP	R/W	00000000	Tap threshold
1E	30	OFSX	R/W	00000000	X axis offset
1F	31	OFSY	R/W	00000000	Y axis offset
20	32	OFSZ	R/W	00000000	Z axis offset
21	33	DUR	R/W	00000000	Tap duration
22	34	LATENT	R/W	00000000	Tap latency
23	35	WINDOW	R/W	00000000	Tap window
24	36	THRESH_ACT	R/W	00000000	Activity threshold
25	37	THRESH_INACT	R/W	00000000	Inactivity threshold
26	38	TIME_INACT	R/W	00000000	Inactivity time
27	39	ACT_INACT_CTL	R/W	00000000	Axis enable control for ACT/INACT
28	40	THRESH_FF	R/W	00000000	Free-fall threshold
29	41	TIME_FF	R/W	00000000	Free-fall time
2A	42	TAP_AXES	R/W	00000000	Axis control for Tap/Double Tap
2B	43	ACT_TAP_STATUS	R	00000000	Source of Tap/Double Tap
2C	44	BW_RATE	R/W	00001010	Data Rate and Power Mode control
2D	45	POWER_CTL	R/W	00000000	Power Save features control
2E	46	INT_ENABLE	R/W	00000000	Interrupt enable control
2F	47	INT_MAP	R/W	00000000	Interrupt mapping control
30	48	INT_SOURCE	R	00000000	Source of interrupts
31	49	DATA_FORMAT	R/W	00000000	Data format control
32	50	DATAX0	R	00000000	X axis data
33	51	DATAX1	R	00000000	
34	52	DATAY0	R	00000000	Y axis data
35	53	DATAY1	R	00000000	
36	54	DATAZ0	R	00000000	Z axis data
37	55	DATAZ1	R	00000000	
38	56	FIFO_CTL	R	00000000	FIFO control
39	57	FIFO_STATUS	R/W	00000000	FIFO status



ORDERING GUIDE

Model	Measurement Range	Specified Voltage (V)	Temperature Range	Package Description	Package Option
ADXL345BCCZ[1]	±2, 4, 8, 16*g*	2.5	−40°C to +85°C	14-Lead Land Grid Array Package [LGA]	TBD
ADXL345BCCZ–RL[1]	±2, 4, 8, 16*g*	2.5	−40°C to +85°C	14-Lead Land Grid Array Package [LGA]	TBD
ADXL345BCCZ–RL7[1]	±2, 4, 8, 16*g*	2.5	−40°C to +85°C	14-Lead Land Grid Array Package [LGA]	TBD
EVAL-ADXL345Z[1]				Evaluation Board	

Bluetooth Module (1-2-4-2):

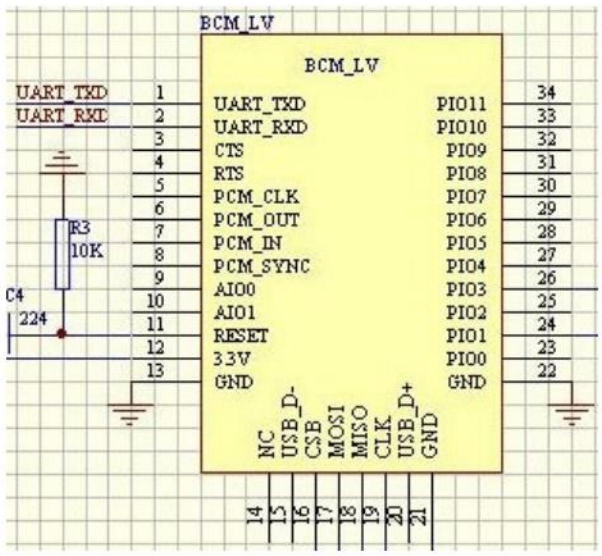


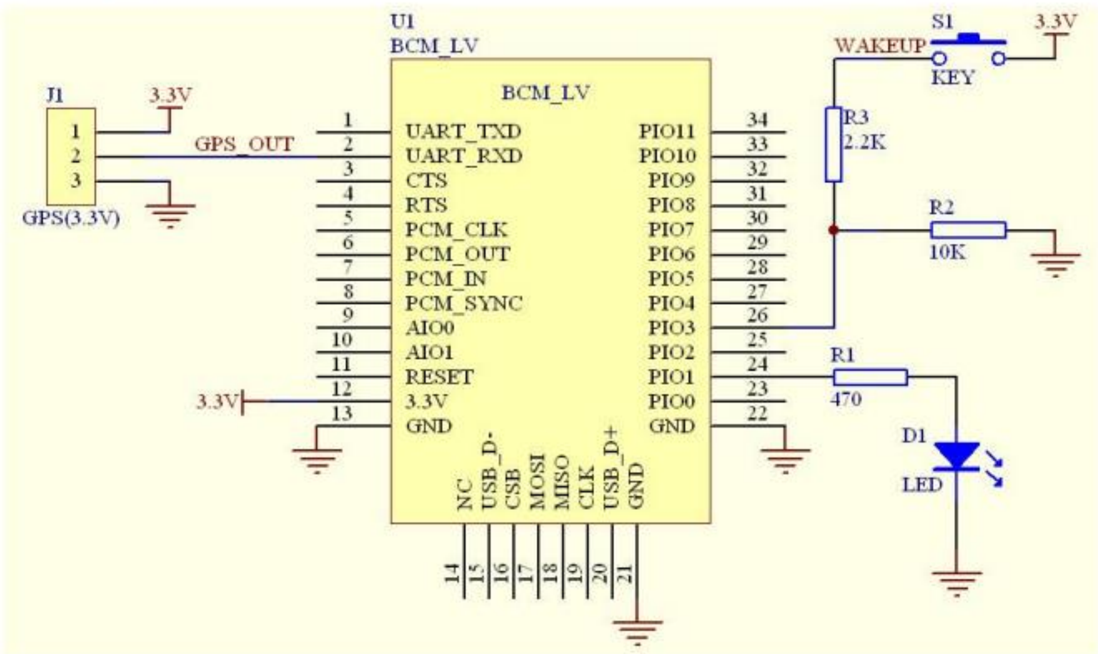
Figure 3 PIN configuration

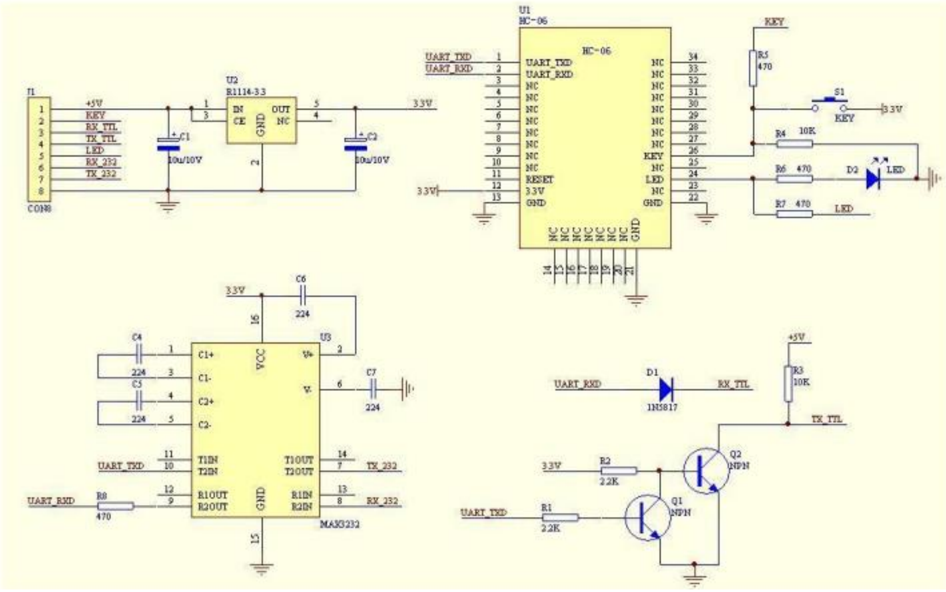
The PINs at this block diagram is as same as the physical one.

PIN Name	PIN #	Pad type	Description	Note
GND	13 21 22	VSS	Ground pot	
1V8	14	VDD	Integrated 1.8V (+) supply with On-chip linear regulator output within 1.7-1.9V	
VCC	12	3.3V		
AIO0	9	Bi-Directional	Programmable input/output line	
AIO1	10	Bi-Directional	Programmable input/output line	

PIO0	23	Bi-Directional RX EN	Programmable input/output line, control output for LNA(if fitted)	
PIO1	24	Bi-Directional TX EN	Programmable input/output line, control output for PA(if fitted)	
PIO2	25	Bi-Directional	Programmable input/output line	
PIO3	26	Bi-Directional	Programmable input/output line	
PIO4	27	Bi-Directional	Programmable input/output line	
PIO5	28	Bi-Directional	Programmable input/output line	
PIO6	29	Bi-Directional	Programmable input/output line	CLK_REQ
PIO7	30	Bi-Directional	Programmable input/output line	CLK_OUT
PIO8	31	Bi-Directional	Programmable input/output line	
PIO9	32	Bi-Directional	Programmable input/output line	
PIO10	33	Bi-Directional	Programmable input/output line	
PIO11	34	Bi-Directional	Programmable input/output line	
RESETB	11	CMOS Input with weak internal pull-down		
UART_RTS	4	CMOS output, tri-stable with weak internal pull-up	UART request to send, active low	
UART_CTS	3	CMOS input with weak internal pull-down	UART clear to send, active low	
UART_RX	2	CMOS input with weak internal pull-down	UART Data input	
UART_TX	1	CMOS output, Tri-stable with weak internal pull-up	UART Data output	
SPI_MOSI	17	CMOS input with weak internal pull-down	Serial peripheral interface data input	
SPI_CSB	16	CMOS input with weak internal	Chip select for serial peripheral interface, active low	

		pull-up		
SPI_CLK	19	CMOS input with weak internal pull-down	Serial peripheral interface clock	
SPI_MISO	18	CMOS input with weak internal pull-down	Serial peripheral interface data Output	
USB_-	15	Bi-Directional		
USB_+	20	Bi-Directional		
1.8V	14		1.8V external power supply input	Default : 1.8V internal powe r supply.
PCM_CLK	5	Bi-Directional		
PCM_OUT	6	CMOS output		
PCM_IN	7	CMOS Input		
PCM_SYNC	8	Bi-Directional		





Magnets (1-2-2):

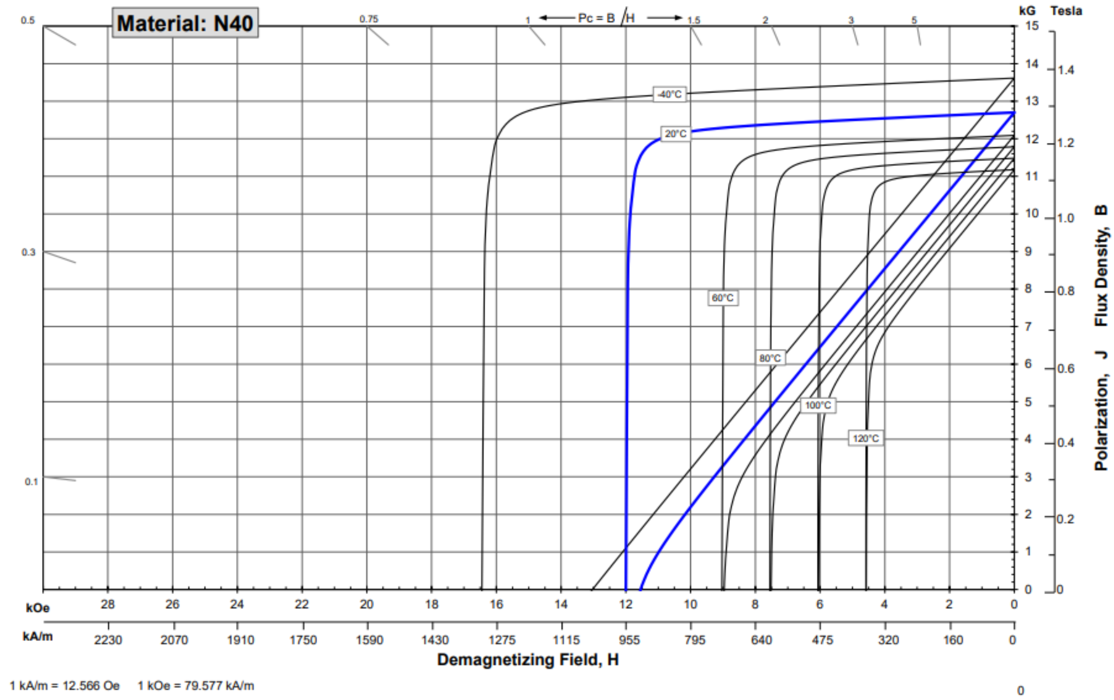
Sintered Neodymium-Iron-Boron Magnets

These are also referred to as "Neo" or NdFeB magnets. They offer a combination of high magnetic output at moderate cost. Please contact Arnold for additional grade information and recommendations for protective coating. Assemblies using these magnets can also be provided.

	Characteristic	Units	min.	nominal	max.
Magnetic Properties	**Br**, Residual Induction	Gauss	12,500	12,700	12,900
		mT	1250	1270	1290
	H_{cB}, Coercivity	Oersteds	11,600	11,950	12,300
		kA/m	923	951	979
	H_{cJ}, Intrinsic Coercivity	Oersteds	12,000		
		kA/m	955		
	BHmax, Maximum Energy Product	MGOe	38	40	42
		kJ/m³	302	318	334

	Characteristic	Units	C //	C ⊥
Thermal Properties	Reversible Temperature Coefficients (1)			
	of Induction, α(Br)	%/°C	-0.12	
	of Coercivity, α(Hcj)	%/°C	-0.62	
	Coefficient of Thermal Expansion (2)	ΔL/L per °Cx10^{-6}	7	-1
	Thermal Conductivity	kcal/mhr°C	5.3	5.8
	Specific Heat (3)	cal/g°C	0.11	
	Curie Temperature, Tc	°C	310	
Other Properties	Flexural Strength	psi	41,300	
		MPa	285	
	Density	g/cm³	7.6	
	Hardness, Vickers	Hv	620	
	Electrical Resistivity, ρ	μΩ • cm	150 // 130 ⊥	

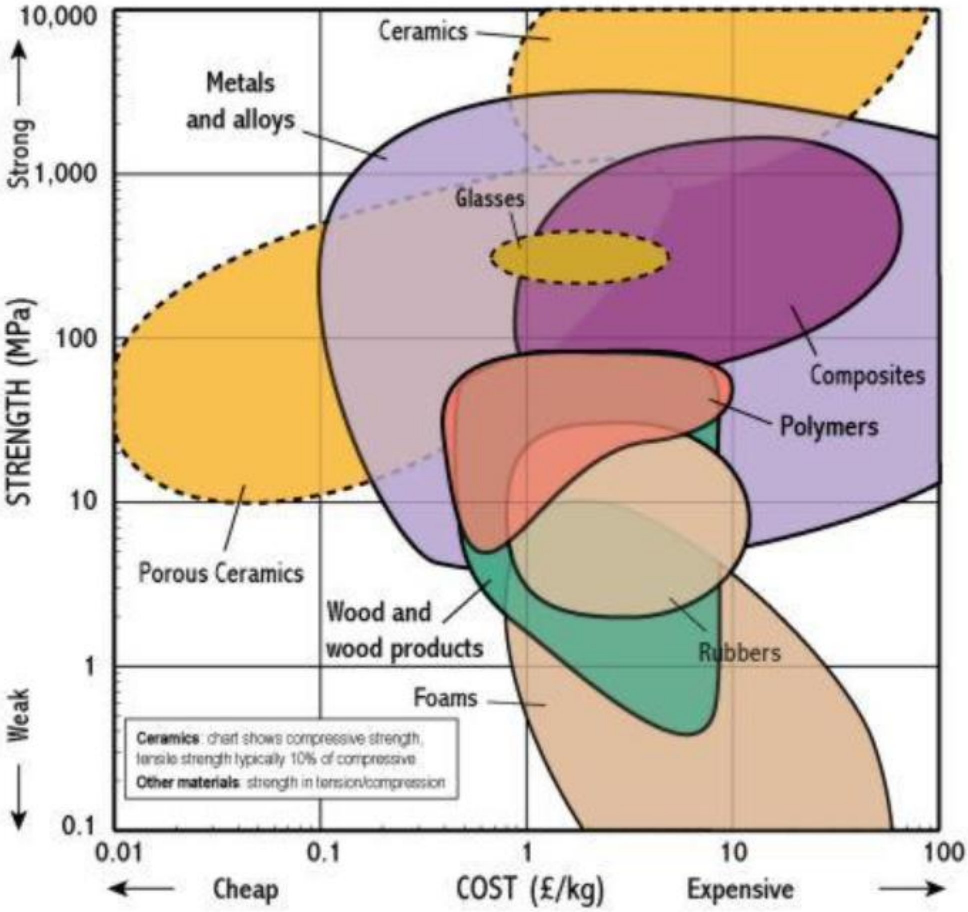
Notes: (1) Coefficients measured between 20 and 80 °C
(2) Between 20 and 200 °C. Values are typical and can vary.
(3) Between 20 and 140 °C

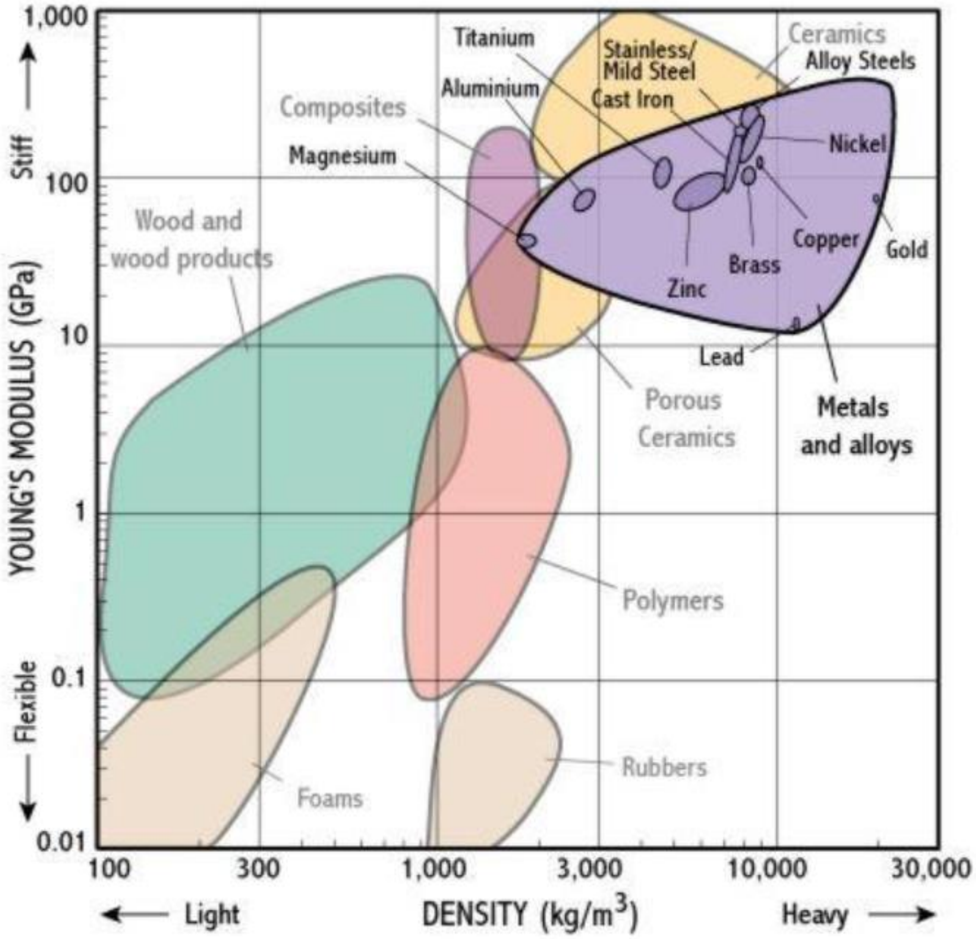


Notes The material data and demagnetization curves shown above represent typical properties that may vary due to product shape and size.
Demagnetization curves show nominal Br and minimum Hci.
Magnets can be supplied thermally stabilized or magnetically calibrated to customer specifications.
Additional grades are available. Please contact the factory for information.

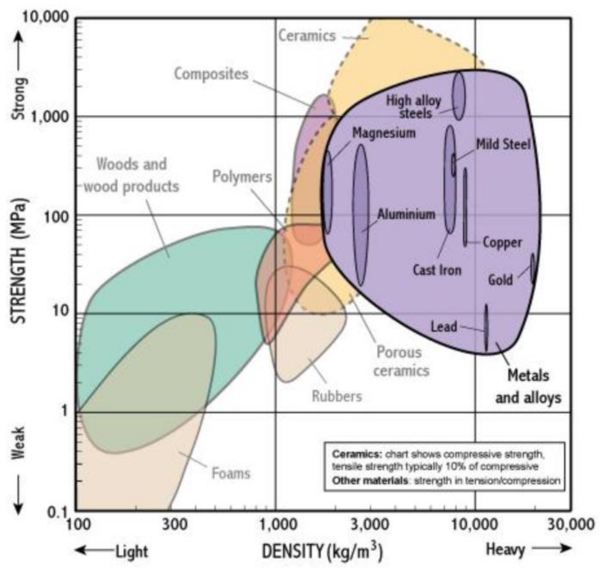
Materiel	:	NdFeB
Weight	:	50-100 grams
Length	:	10-30mm
Force	:	50-75kg
Width / Diameter	:	11-30mm
Coating Type	:	Nickel
Height	:	6-10mm
Color	:	Gray
Shape	:	Round

APPENDIX I: ASHBY CHARTS

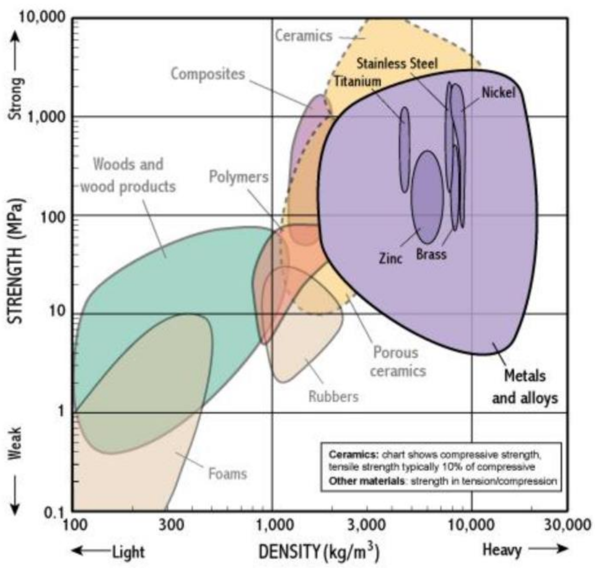




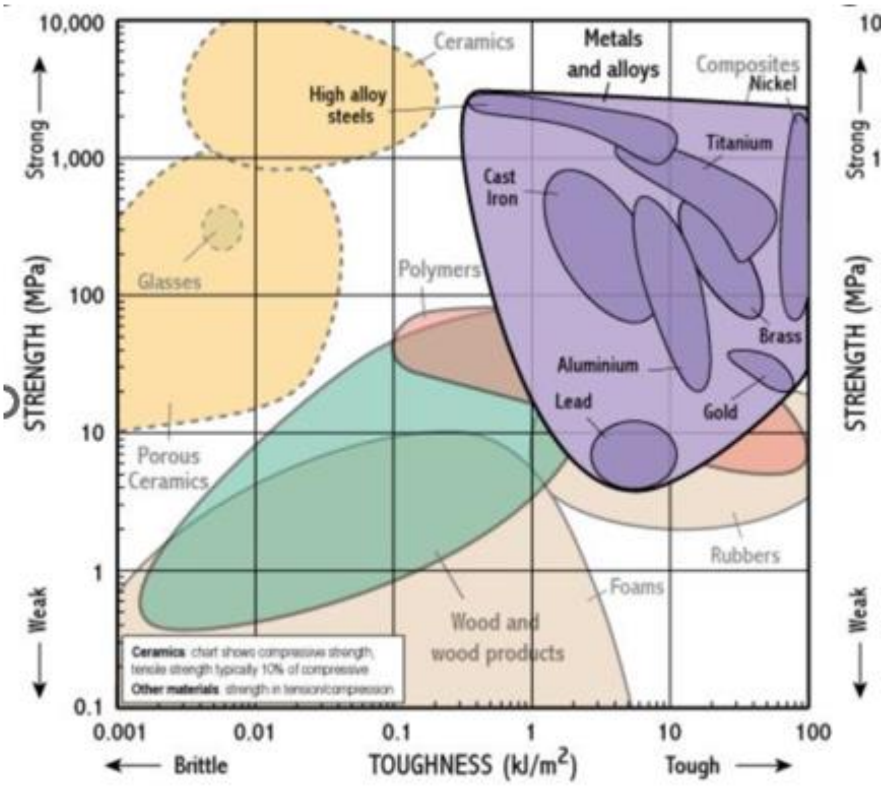
1,000
100
10
1
0.1
0.01
Stiff
Flexible
YOUNG'S MODULUS (GPa)
100
300
1,000
3,000
10,000
30,000
Light
DENSITY (kg/m^3)
Heavy
Titanium
Stainless/
Mild Steel
Ceramics
Alloy Steels
Aluminium
Cast Iron
Composites
Nickel
Magnesium
Wood and
wood products
Copper
Gold
Brass
Zinc
Lead
Porous
Ceramics
Metals
and alloys
Polymers
Rubbers
Foams



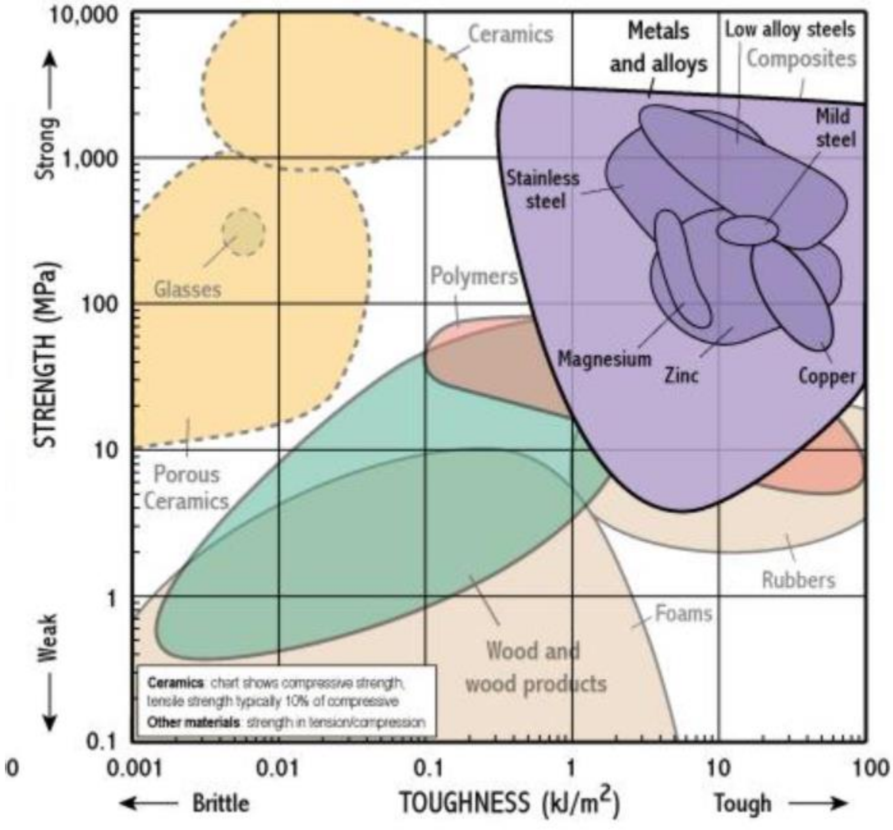
10,000
1,000
100
10
1
0.1
Strong
Weak
STRENGTH (MPa)
Ceramics
Composites
High alloy
steels
Magnesium
Mild Steel
Woods and
wood products
Polymers
Aluminium
Copper
Cast Iron
Gold
Lead
Porous
ceramics
Metals
and alloys
Rubbers
Foams
Ceramics: chart shows compressive strength,
tensile strength typically 10% of compressive
Other materials: strength in tension/compression
100
300
1,000
3,000
10,000
30,000
Light
DENSITY (kg/m^3)
Heavy



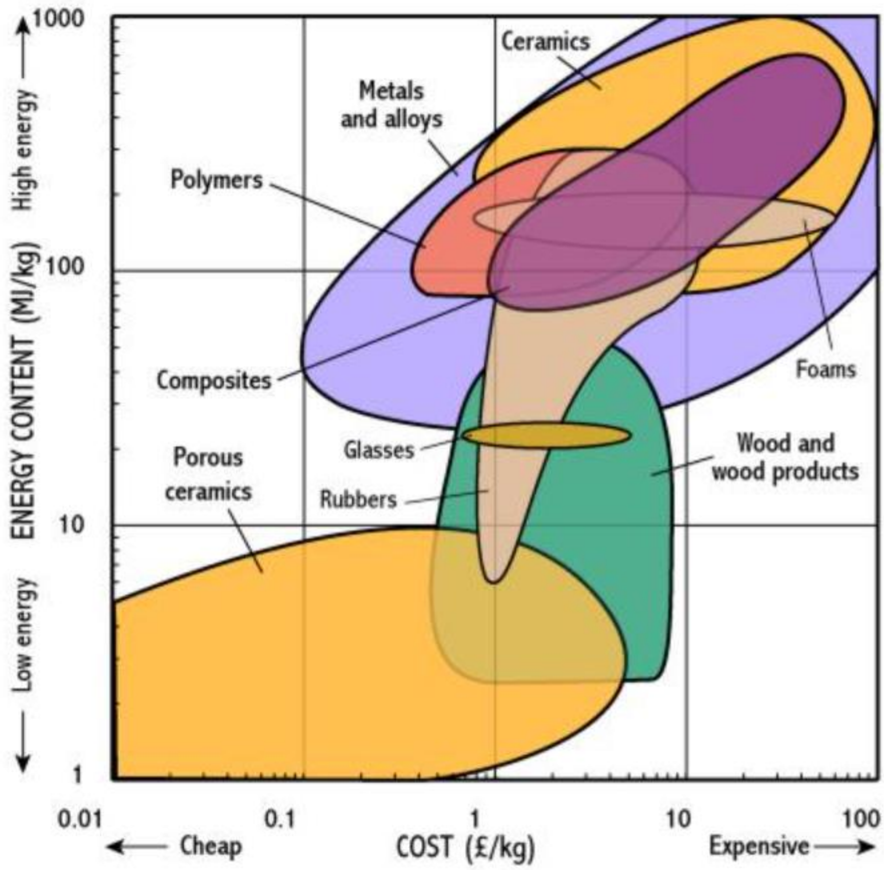
10,000
1,000
100
10
1
0.1
Strong
Weak
STRENGTH (MPa)
Ceramics
Stainless Steel
Titanium
Composites
Nickel
Woods and
wood products
Polymers
Zinc
Brass
Porous
ceramics
Metals
and alloys
Rubbers
Foams
Ceramics: chart shows compressive strength,
tensile strength typically 10% of compressive
Other materials: strength in tension/compression
100
300
1,000
3,000
10,000
30,000
Light
DENSITY (kg/m^3)
Heavy



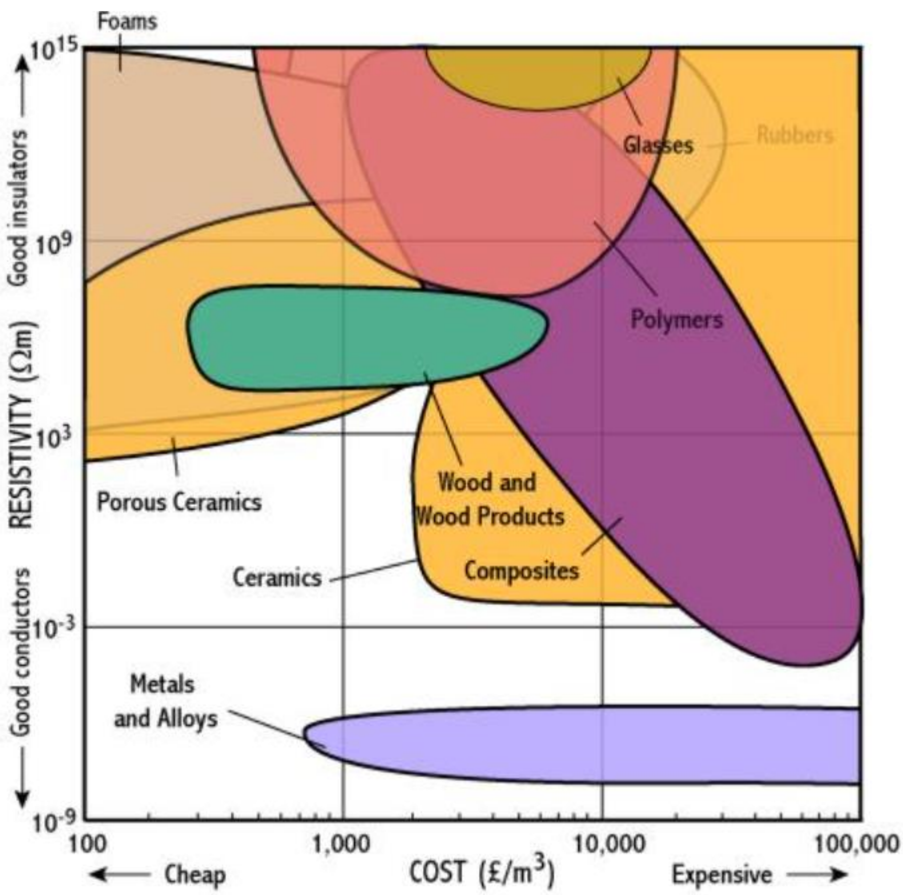
Ceramics
Metals and alloys
Composites
Nickel
High alloy steels
Titanium
Cast Iron
Glasses
Polymers
Brass
Aluminium
Lead
Gold
Porous Ceramics
Rubbers
Foams
Wood and wood products
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression
STRENGTH (MPa)
Strong
Weak
TOUGHNESS (kJ/m²)
Brittle
Tough



Ceramics
Metals and alloys
Low alloy steels
Composites
Mild steel
Stainless steel
Glasses
Polymers
Magnesium
Zinc
Copper
Porous Ceramics
Rubbers
Foams
Wood and wood products
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression
STRENGTH (MPa)
Strong
Weak
TOUGHNESS (kJ/m²)
Brittle
Tough



ENERGY CONTENT (MJ/kg)
High energy
Low energy
1000
100
10
1
Ceramics
Metals and alloys
Polymers
Composites
Porous ceramics
Glasses
Rubbers
Foams
Wood and wood products
0.01
0.1
1
10
100
Cheap
COST (£/kg)
Expensive



Foams
RESISTIVITY (Ωm)
Good insulators
Good conductors
10^{15}
10^{9}
10^{3}
10^{-3}
10^{-9}
Glasses
Rubbers
Polymers
Porous Ceramics
Wood and Wood Products
Ceramics
Composites
Metals and Alloys
100
1,000
10,000
100,000
Cheap
COST (£/m^3)
Expensive

APPENDIX J: FMEA RANKING GUIDELINES

Effect	Severity of Effect	Ranking
Catastrophic	Resource not available / problem unknown	10
Extreme	Resource not available / problem known and cannot be controlled	9
Very high	Resource not available / problem known and can be control	8
High	Resource available/major violation of policies	7
Moderate	Resource available/major violation of the process	6
Low	Resource available/major violation of procedures	5
Very low	Resource available/minor violation of policies	4
Minor	Resource available/minor violations of process	3
Very minor	Resource available/minor violations of procedures	2
None	No effect	1

Probability of Failure	Failure Probability	Ranking
Very high: Failure is almost inevitable	>1 in 2	10
	1 in 3	9
High: Repeated failures	>1 in 8	8
	1 in 20	7
Moderate: Occasional failure	1 in 80	6
	1 in 400	5
	1 in 2000	4
Low: Relatively few failures	1 in 15000	3
	1 in 150000	2
Remote: Failure is unlikely	<1 in 1500000	1

Effect	Severity of Effect	Ranking
Uncertainty	Control **cannot** prevent/detect potential cause/mechanism and subsequent failure mode	10
Very Remote	**Very remote** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	9
Remote	**Remote** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	8
Very Low	The **very low** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	7
Low	The **low** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	6
Moderate	The **moderate** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	5
Moderately High	The **moderately high** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	4
High	The **high** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	3
Very High	The **very high** chance that the control will prevent/detect potential cause/mechanism and subsequent failure mode	2
Almost Certain	Control **will** prevent/detect potential cause/mechanism and subsequent failure mode	1

APPENDIX K: CODES

MATLAB CODES

BEMIO CODE:

```
hydro = struct();
hydro = readWAMIT(hydro,'rm3.out',[]);
hydro = radiationIRF(hydro,60,[],[],[],[]);
hydro = radiationIRFSS(hydro,[],[]);
hydro = excitationIRF(hydro,157,[],[],[],[]);
writeBEMIOH5(hydro)
```

```
simu = simulationClass();
simu.simMechanicsFile = 'RM3.slx';
simu.mode = 'normal';
simu.explorer = 'on';
simu.startTime = 0;
simu.rampTime = 100;
simu.endTime = 400;
simu.solver = 'ode4';
simu.dt = 0.1;
waves = waveClass('regular');
waves.height = 0.075;
waves.period = 0.76;

body(1) = bodyClass('hydroData/rm3.h5');
body(1).geometryFile = 'geometry/float.stl';
body(1).mass = 'equilibrium';
body(1).inertia = [20907301 21306090.66 37085481.11];
body(2) = bodyClass('hydroData/rm3.h5');
body(2).geometryFile = 'geometry/plate.stl';
body(2).mass = 'equilibrium';
body(2).inertia = [94419614.57 94407091.24 28542224.82];
constraint(1) = constraintClass('Constraint1');
constraint(1).location = [0 0 0];
pto(1) = ptoClass('PTO1');
pto(1).stiffness = 0;
pto(1).damping = 1200000;
pto(1).location = [0 0 0];
```

BLUETOOTH MODULE CODES:

```
global time;
global s;
clear all; close all; clc;
```

```
time=zeros(1,15);
fclose(instrfind);
s=serial('com14');
s.BytesAvailableFcnMode = 'terminator';
s.BytesAvailableFcn={@callbackSerial};
```

FUNCTION:

```
function callbackSerial(ser,~)
global time;
val = fscanf(ser);
numval = str2double(val);
time(16) = numval;
time(1)=[];
disp(time);
plot(time);
end
```

ARDUINO CODES:

```
#include <Wire.h>

#include <Adafruit_Sensor.h>

#include <Adafruit_ADXL345_U.h>

#include <SoftwareSerial.h>

SoftwareSerial mySerial(10,11);//RX,TX

Adafruit_ADXL345_Unified accel = Adafruit_ADXL345_Unified();

void setup(void)

{


   Serial.begin(9600);

   if(!accel.begin())

   {

      Serial.println("No valid sensor found");

      while(1);

   }

}
void loop(void)
{

   sensors_event_t event;
   accel.getEvent(&event);
```

```
Serial.print("Y: "); Serial.println(event.acceleration.y); Serial.print("  ");

Serial.println("m/s^2 ");

delay(500)}
```

Appendix L: User Manual

Purpose of the Manual

We appreciate you choosing our Ocean wave energy tank . This user manual will give you the knowledge you need to efficiently set up, use, and repair the Wave tank and its components. Before using it, carefully read this manual.

About the Ocean Wave Tank

The ocean wave energy tank is made up of 2 primary parts the wave generation mechanism and the Wave energy conversion mechanism. As well as a Sensor to allow adjustment of wave conditions to meet specific test requirements.

Setup:

• Ensure that the batteries for the sensor bouy Arduino are powered, as well as connecting the AC-DC convertor to the stepper motor and power supply.

• Connect laptop to accelerometer output via either Bluetooth or serial port.

• Open Matlab and copy the Bluetooth code and function in the appendix for collecting accelerometer plots.

Operation Sequence

1. Place drain closer at the drain.
2. Fill the tank about 0.7m or 0.5m for deep or intermediate waters respectively.
3. Place your wave energy convertor between the second and third segment.
4. Determine the wave conditions you want to achieve.
5. Activate the stepper motor and adjust the speed on the motor accordingly.
6. Observe the plot to determine if the wave conditions match required parameters.
7. Upon completion of test switch off the stepper motor until stationary.
8. Disconnect Bluetooth Module form connected device.
9. Disconnect or switch off all power supply and switch them off.
10. Remove the drain closer to remove water from the tank.
11. Cover the tank with a cover.

Safety Guidelines:

• Always prioritize your safety and the safety of others when using the Ocean wave tank.

• Familiarize yourself with the operation of the stepper motor.

• Make sure no one is in the tank before operating.

• Maintain a safe distance from the observing glass.

• Keep all objects that may damage the glass away from the tank stones, metal fragments etc.

• Do not exceed the motor operating range.

.

• Don't operate if shaft is moving out of bearings.

• Do not adjust or move the sensor bouy unless it is not functioning if so contact our customer support for assistance.

• Clean the wave tank before use for optimal operating conditions.

Maintenance

- The tank must be refurbished every 2 to 3 years.
- Test for leaking must be carried out before filling.

Appendix M: Ansys Report

Title

Generic Report

Date

2023/09/15 00:41:01

Contents

File Report

Table 1. File Information for FFF 0746.1

Case	FFF 0746.1
File Path	C:/Users/theli/OneDrive/Desktop/CFD 2_files/dp0/FFF/Fluent/FFF-0790.1.cdat
File Date	27 August 2023
File Time	03:59:10 PM
File Type	FLUENT
File Version	23.1.0

Mesh Report

Table 2. Mesh Information for FFF 0746.1

Domain	Nodes	Elements	Tetrahedra	Wedges	Pyramids	Hexahedra	Polyhedra
surface_body	28126	13728	0	0	0	13728	0

Table 3. Mesh Statistics for FFF 0746.1

Domain	Minimum Face Angle	Maximum Face Angle	Maximum Edge LengthRatio	Maximum Element Volume Ratio	Connectivity Range	
surface_body	87.9221 [degree]	92.1243 [degree]	1.07768	1.02742	1	4

Physics Report

Table 4. Domain Physics for FFF 0746.1

Domain - surface_body	
Type	cell

Table 5. Boundary Physics for FFF 0746.1

Domain	Boundaries	
surface_body	**Boundary - atm**	
	Type	PRESSURE-OUTLET
	Boundary - inlet	
	Type	VELOCITY-INLET
	Boundary - outlet	
	Type	PRESSURE-OUTLET
	Boundary - symmetry 1	
	Type	SYMMETRY
	Boundary - symmetry 2	

	Type	SYMMETRY
	Boundary - wall	
	Type	WALL

Figures:

Figure 1. Iso View of Wireframe

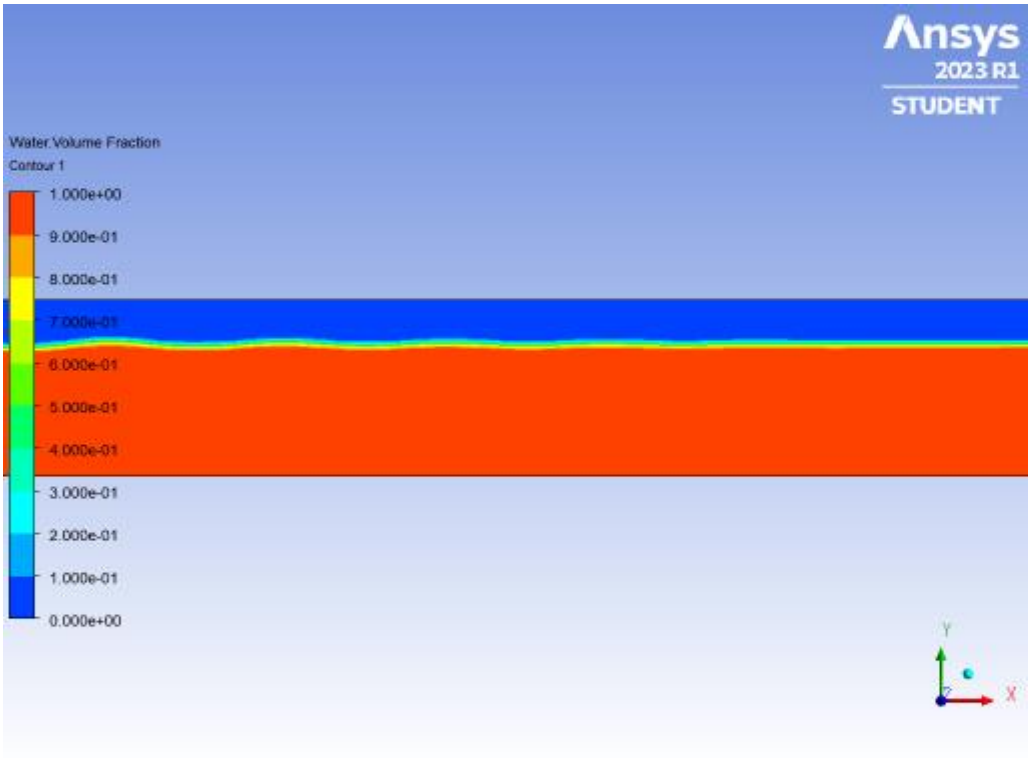


Chart 1.