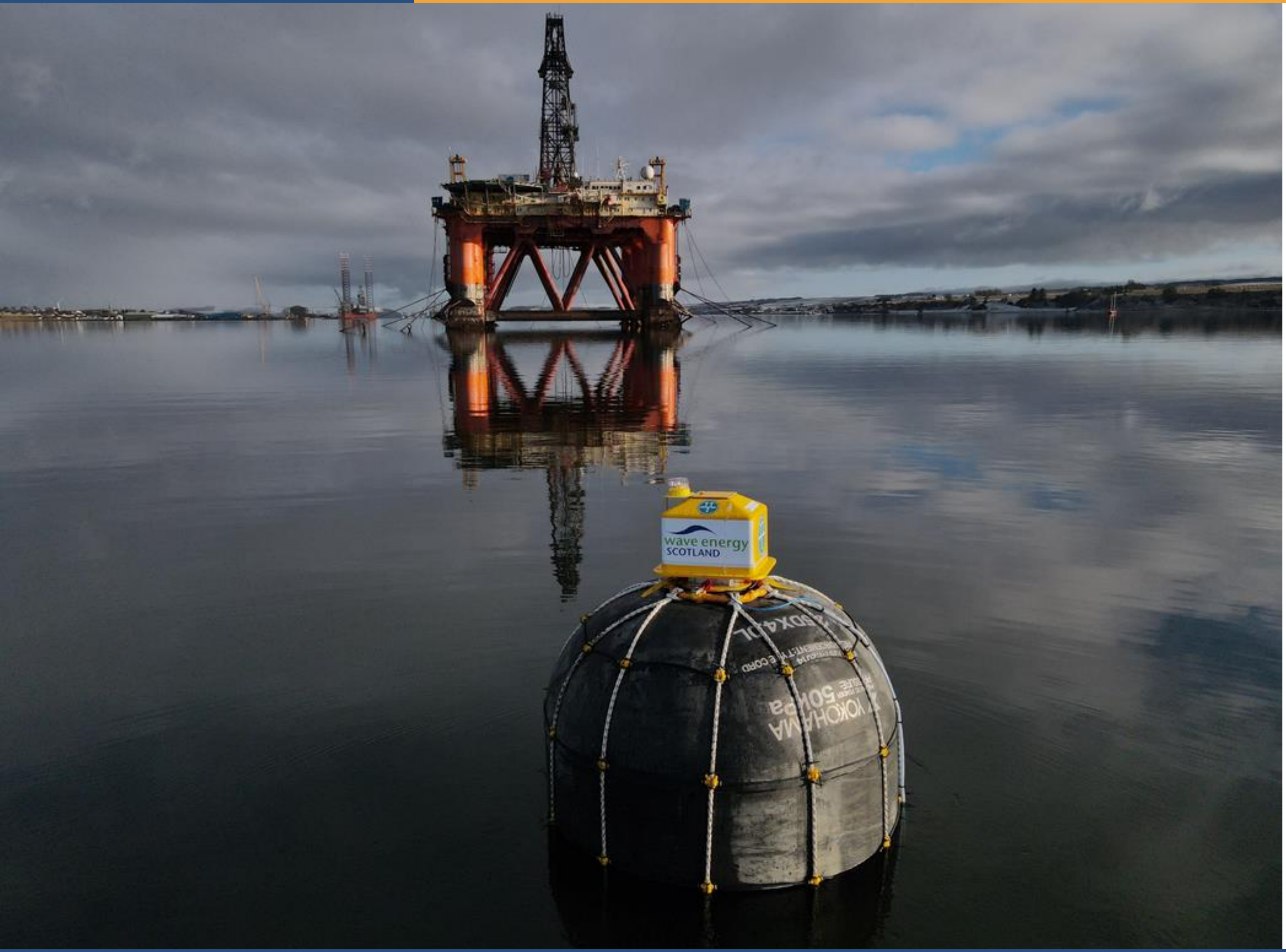
Design Tool overview



Lead Contractor
Tension Technology International Ltd
Inverness

tensiontech.com

Structural Materials & Manufacturing Processes

Contents

Why use the Netbuoy™ system

NetBuoy™ focusses on two strands on the path towards cost-competitive wave energy:

- Impermeable fabrics to provide compliant and thus load shedding/peak load resistant buoyant modules
- Fibre rope 'load nets' to encapsulate the buoyant modules, applying distributed restraint loads and agglomerating the distributed load back to a single or number of structural points to connect to other parts of the WEC system such as the PTO.

Why use the Netbuoy™ system

netbuoy™
TTI Marine Renewables

The primary advantages of NetBuoy™ over steel or concrete structures are:

- The NetBuoy™ system replaces steel or concrete prime mover volumes with more cost-effective and lighter materials
- NetBuoy™ can be deflated for transportation, so devices pack down into smaller volumes to ease transport on land and at sea
- NetBuoy™ can aid in the installation process, for example by using its inflation to tension up the mooring system. Reducing the initial hook up-tension could allow for use of smaller vessels and reduce the risk inherent in making connections under tension

Summary of the Design Tool

The NetBuoy™ Design Tool was created by TTI Marine Renewables as part of the Wave Energy Scotland *Structural Materials and Manufacturing Processes* Stage 3 project.

The intent of the Design Tool is to provide potential customers (wave developers) with an estimate of the manufactured cost and mass of a NetBuoy™ system that could replace conventional prime mover structures.

The Design Tool is intended to be used as a starting point for communication between TTI and potential customers.

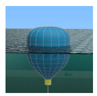
How to use the Design Tool

Visit the Netbuoy™ site

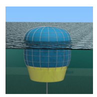
1. Complete the inputs and submit.
2. The tool will check the inputs to ensure they are within expected bounds.
3. If there are any issues, an error list is displayed. The user should update their inputs accordingly, if possible.
4. If there are no errors the outputs from the tool are displayed.
5. At this stage the user can update and resubmit inputs to update the design with different parameters.

Inputs – Integration type

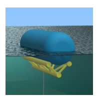
Choice of five integration types representing ways to integrate NetBuoy™ into the structure of a device



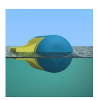
Point Absorber Buoy: NetBuoy™ makes up all the buoyant volume of the system. Central axis of cylindrical buoy is vertical.



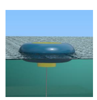
Point Absorber with Machine Room: NetBuoy™ is mounted on top of structure. Central axis of cylindrical buoy is vertical.



Top Mounted: NetBuoy™ is mounted on top of the supporting structure. Central axis of the cylindrical buoy is horizontal.



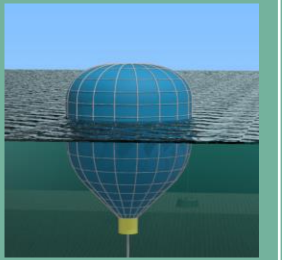
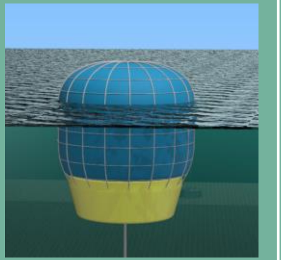
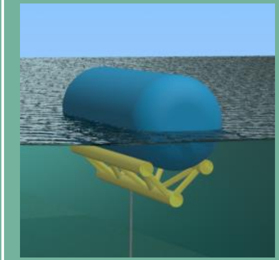
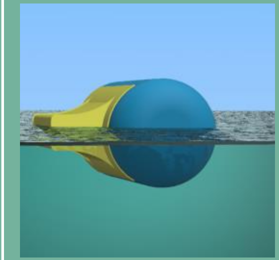
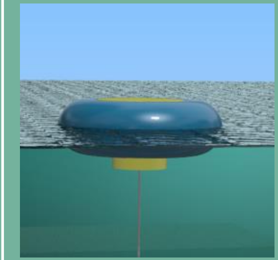
Side Mounted: NetBuoy™ is mounted on the side of the supporting structure. Central axis of the cylindrical buoy is horizontal.



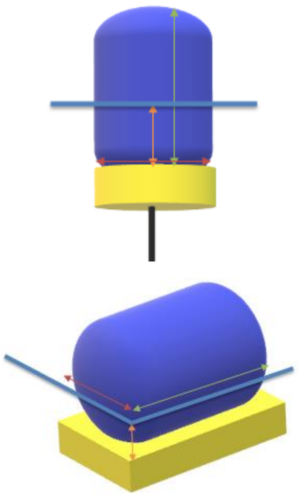
Toroidal: NetBuoy™ is mounted around a central structure.

The user should select the most appropriate connection method for the expected use case. Guidance is given on the next slide.

Inputs – Integration Type

WEC Type					
Point Absorber	✓	✓			✓
Attenuator			✓	✓	
Hinged Raft			✓	✓	
Terminator			✓	✓	

Inputs - Values - Cylindrical



Length [m]
Diameter [m]
Draft [m]

The next set of inputs are numerical values. They are defined as:

Required Length: axial length of the cylindrical buoy

Required Diameter: diameter of the cylindrical buoy

Target Still Water Draft: draft of the cylindrical buoy

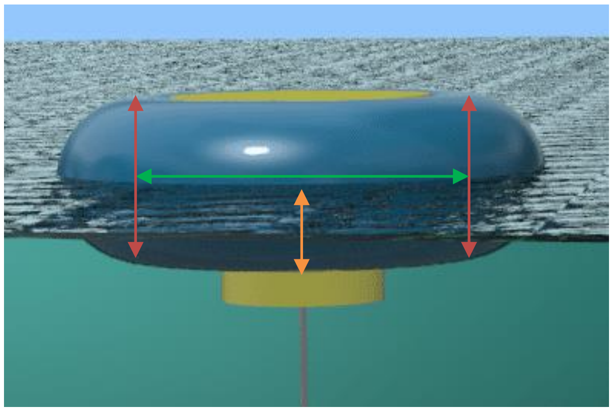
- If the central axis of the cylinder is vertical the draft is measured *along* this axis.
- If the central axis of the cylinder is horizontal the draft is measured *perpendicular* to this axis.

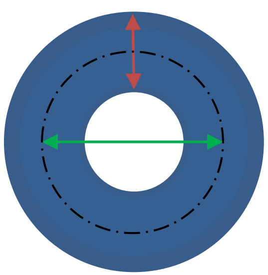
Measuring points for dimensions are shown on the images.

Still Water Draft can be greater than the Length or Diameter to account for fully submerged buoys.

Inputs - Values - Toroid

Major diameter [m]
Minor diameter [m]
Draft [m]





The next set of inputs are numerical values. They are defined as:

> Major Diameter: Diameter of revolution of the circular cross section
>
> Diameter of Tube (Minor Diameter): Diameter of the circular area which is revolved to make the toroid.
>
> Target Still Water Draft: draft of the toroid, measured form the bottom of the buoy.

Measuring points for dimensions are shown on the images.

Still Water Draft can be greater than the Tube Diameter to account for fully submerged buoys.

Outputs - Overview

All outputs are approximations.

The first three outputs are Length, Diameter and Still Water Draft. These confirm the values input by the user for the calculation.

Displacement is the volume of the submerged section of the buoy.

Buoyant pod mass is based on size and required material strength.

Net mass is the weight of the net based on required strength and material choice.

Buoyant pod cost is based on material density and construction.

Net cost is based on the estimated loads in the system.

The total cost is the manufactured cost of the NetBuoy™.

What to do with the results

The results inform the user to the potential of the NetBuoy™ system to replace parts of the structure of their device.

If the user has further interest in the use of a NetBuoy™ in their device they can contact TTI directly (https://netbuoy.co.uk/contact).

How the Design Tool works

This section gives a high-level overview of the methodology behind the NetBuoy™ Design Tool. It covers key steps:

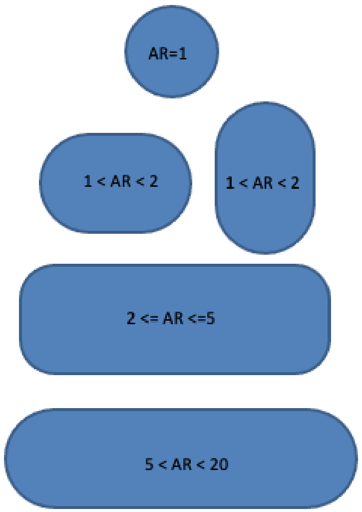
- Validation of Inputs
- Calculation of General Properties (Volumes, Areas and Displacements).
- Material Strength Requirement
- Net Definition
- Cost Estimates of Buoyant Pod and Net

Validation of inputs

Inputs are checked to ensure that they are within reasonable bounds. The following checks are made:

- All necessary inputs are defined and are in the correct form i.e. numbers not letters.
- Numerical inputs are greater than 0.
- The aspect ratio (L/D) of the buoy is between 1 and 20.

Calculation of general properties

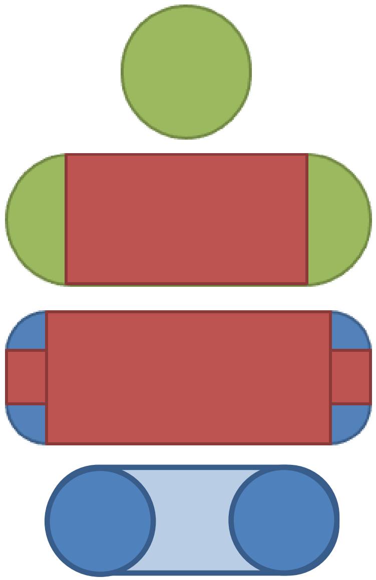


The shape of the cylindrical buoyant pods are dependant on the aspect ratio:

- **AR = 1:** buoyant pod is a sphere
- **AR < 2 or 5 < AR < 20:** buoyant pod is a cylinder with hemispherical ends
- **2 <= AR <= 5**: buoyant pod is a cylinder with fillets on the ends and radius = ¼ of the pod's diameter.

These shapes define the basic geometries to be used in calculating the overall volumes, displacements and surface areas.

Calculation of general properties - volumes

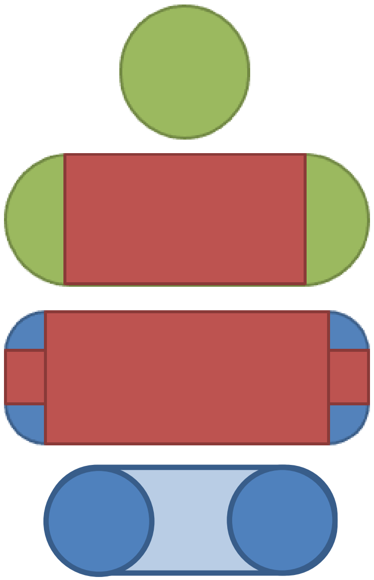


The buoyant pod geometries can be broken up into the following shapes for the purpose of volume calculation:

- Cylinder (red)
- Sphere (green)
- Toroid / revolved quarter circles (blue)

The most complex volume is that of an aspect ratio of between 2 and 5. In this case the shape was split into three sections. In red are the simple cylinders used. In blue Pappus's Second Theorem was used to calculate the volume of the revolved quarter circles.

Calculation of general properties - displacement



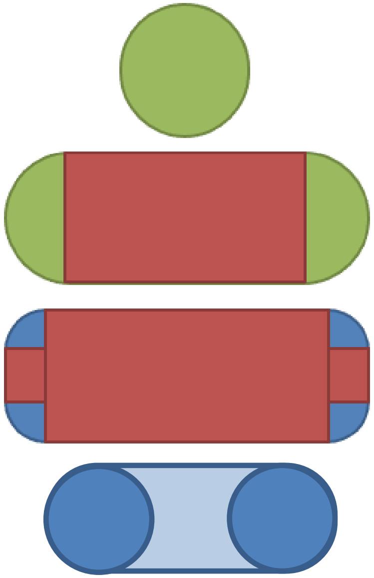
The calculation of the displacement of the buoyant pod follows similar methodologies to that used for the volumes.

The additional consideration is the draft variable. This requires some more abnormal volume calculations. For example:

- Spherical caps
- Cylindrical caps
- Partial toroid

Of these the partial toroid was the only one not calculated analytically. Instead a function was created by fitting a curve to data from 3D CAD models of the shape.

Calculation of general properties - areas

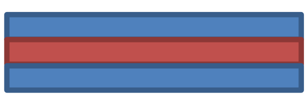


The buoyant pod geometries can be broken up into the following shapes for the purpose of surface area calculation:

- Cylinder
- Sphere
- Toroid

Again the buoyant pod is split into simpler shapes, using basic geometry to calculate the areas. To calculate the surface area of the Toroidal section, Pappus's First Theorem was used.

Material strength requirements



The next stage of the Design Tool is to specify the material properties of the buoyant pod.

Based on the specified draft of the buoy, hydrostatic pressure at the lowest point of the buoy can be calculated. To maintain the shape of the buoy, the rule is that internal pressure must exceed this pressure. This internal pressure is then used alongside the diameter to calculate the hoop stress (thin-walled pressure vessel equations).

The material is constructed in three layers. The inner and outer layers (in blue) have predefined thickness independent of size and are not considered load-bearing. The central layer is load-bearing layer: its thickness is dependant on the hoop stress.

The mass of the buoyant pod can then be calculated based on its known density.

Net definition

The number of lines in the net are defined based on a fixed target line spacing.

The tool has a lower limit on the number of meridional and circumferential lines used. This ensures proper containment of smaller buoys. Depending on the orientation of the buoyant pod:

- If the central axis of the buoyant pod is horizontal the *circumferential* lines are the primary load lines.
- If the central axis of the buoyant pod is vertical the *meridional* lines are the primary load lines.

Expected net line loads are calculated from displacement, a design factor to account for the dynamics of the device as defined in FEED, and Net geometry.

The secondary lines are specified to have a diameter ½ of the primary lines' diameter.

Cost estimates of buoyant pod and net

For the buoyant pod the cost can be calculated from the mass of the materials. Given that the thickness and surface area are known, the mass and therefore cost of the buoyant pod can be estimated.

Similarly, the costs of the ropes for the net can be estimated from their material mass.

All costing factors have been based on Stage II FEED work and preceding costing work. They are deemed to be AACE Class 3 (American Association for Cost Engineering) giving an expected accuracy range of -20% to +30%.

Tension Technology International Ltd

Inverness

tensiontech.com