# ACA Pen Llŷn a'r Sarnau SAC

## Prosiect Morwellt Porthdinllaen Seagrass Project

Adolygiad Angorfeydd

Mooring Review

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**Prepared by: MarineSpace Ltd**

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# Porthdinllaen Seagrass Project: Mooring Review

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# Glossary

| | |
|---|---|
| Anchor reaction load | The load put on the anchor by the boat |
| Compliance | Elasticity or cushioning effect. If there is no compliance it will create snatch or snap loads |
| Snap load | This occurs when there is a slack event followed by a relatively high-tension spike |

# Executive Summary


MarineSpace Ltd has been commissioned by Gwynedd Council to review potential mooring options to be used at Porthdinllaen to reduce the impact on the seagrass beds that are a designated feature of the Pen Llŷn a'r Sarnau Special Area of Conservation (SAC) located on the west coast of Wales.

The moorings at Porthdinllaen are separated into two discreet areas: the inner harbour and the outer harbour. The inner harbour moorings are intertidal and are installed landward of the old breakwater in the bay by the National Trust. Currently there are 35 moorings in the inner harbour area, consisting of either a concrete block poured into a fish box mould or more recently a 600mm x 600mm x 400mm mould with a short length of connector chain and a 5-7m long 22mm 4 strand polysteel rope riser. The 40 outer harbour moorings are subtidal and are installed seaward of the old breakwater in the bay by a contractor with a boat. Two mooring designs are employed in the outer harbour: the 'concrete block' and the 'two anchors'. However, the use of concrete blocks is rare and in general multi-point anchors are favoured. The outer harbour moorings have resulted in haloes of damaged seagrass surrounding the moorings due to the abrasive effect of the chain components.

MarineSpace selected a number of different mooring types and adaptations to review in discussion with the SAC Officer from Gwynedd Council. Three types of mooring were chosen, and the effects modelled by Orcades Marine Ltd to examine how they could work under the specific conditions expected to occur at Porthdinllaen. The objective of the modelling was to assess the relative performance of each mooring adaptation compared to each other in order to select an option to take forward to field trials. In modelling the different mooring adaptions it was necessary to make assumptions concerning each mooring type and also the site in order to produce a practical number of models. The three types of mooring that were modelled included:

- A mooring system using a rubber roller at the seabed and a synthetic rope;
- Retro-fitting of sub-surface buoys to the current mooring systems; and
- The Sealite synthetic mooring system, which is more inflexible than a standard rope.

Modelling was carried out at four different depths, which were selected to approximately represent the inner and outer regions of Porthdinllaen harbour at low and high tide. They do not represent real locations at Porthdinllaen harbour and were used to assess relative performance of the mooring adaptations at a range of depths.

The results showed that the two synthetic mooring systems were taut, even at the lowest tide of 1.5 m, therefore there was no compliance in the system and this is not considered appropriate for the area.

The retro-fitting of the sub-surface buoys was considered to be a viable option for the deeper moorings (approximately >4 m depth). This is due to there being no abrasion to the seagrass at the deepest depths of 10 m and the anchor reaction load being the lowest of all the systems tested. At depths shallower that 4m, the adaptation would result in no significant reduction in potential seagrass damage. In addition, even at the deeper depths the system still had some compliance in the system, which acts as cushioning in bad weather conditions.

It is recommended that the next step to environmentally friendly mooring at Porthdinllaen is to conduct *in situ* trials with sub-surface buoys to validate the models and determine whether the system would work under real conditions. A key competent of the trials would be to determine the height of the sub-surface buoy from the seabed at different water depths.

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# 1. Introduction

MarineSpace Ltd and Orcades Marine Ltd were commissioned by Gwynedd Council to review previous literature and surveys on the potential for eco-mooring modifications at Porthdinllaen. The review was used to identify mooring options in discussion with the SAC Officer, which were then modelled under conditions similar to Porthdinllaen in order to assess integrity and abrasion to the seabed. The results of the modelling were then used to recommend potential options for adapting the existing mooring systems used at Porthdinllaen.

## 1.1. Policy context

There are currently 108 Special Areas of Conservation (SACs) with marine components, 108 Special Protection Areas (SPAs) with marine components, and 28 Marine Conservation Zones (MCZs) within UK waters. SACs and SPAs are part of the Natura 2000 network, implemented as part of the EU Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) and Birds Directive (Council Directive 2009/147/EC on the conservation of wild birds) respectively.

In Europe, there are overarching regulations for monitoring the ecological quality of water systems: the EU Water Framework Directive (WFD; 2000/60/EC), for lakes, rivers, transitional, and coastal waters, and the EU Marine Strategy Framework Directive (MSFD; 2008/56/EC) for marine waters.

## 1.2. Anchoring and mooring

Anchoring and mooring are means for commercial and recreational vessels to maintain their position when afloat:

- Anchoring – deploying of a device of varying types, including fluke, plough, or mushroom anchors, to the seabed in order to keep a vessel (or other object) in position; and
- Mooring – making fast a vessel to any permanent structure or a structure to which a vessel can be moored; of most relevance to this study are mooring buoys of which there are a range, including standard systems made of dead weight anchor blocks, and commercial systems made by Ezyrider, Helix, Eco mooring, and Seaflex.

This review covers commercial and recreational mooring including mooring of recreational vessels, fishing vessels, and larger commercial vessels. To provide context, a small discussion is provided regarding the environmental impacts of anchoring.

Anchors can impact the seabed, causing physical abrasion, during deployment, when being dragged, and during recovery (e.g. Montefalcone *et al*., 2008). Anchors can penetrate up to 2.5 metres into the sediment in extreme cases (Allan, 1998). Swinging chain moorings may also cause physical abrasion, creating a circular scar pattern around where they are anchored to the seabed (Collins *et al*., 2010). The physical disturbance caused by anchoring and mooring can also has a negative effect on benthic species abundance and diversity.

In soft sediments, moorings may lead to localised changes in sediment composition, resulting in an increase in the proportion of coarser sediment through suspension and winnowing (Herbert *et al*., 2009). These sediments are less cohesive, contain less organic matter, and are associated with lower infauna species richness. On hard substrates, anchoring can decrease habitat complexity and cause fragmentation, also leading to a decrease in species richness (Smith, 1988).

Impacts are likely to be greater on species and habitats that are fragile and intolerant of physical abrasion, such as shellfish beds, soft corals, maerl, and seagrass. Effects will be greater when the recovery time of organisms or ecosystems is longer and/or when there is frequent disturbance.

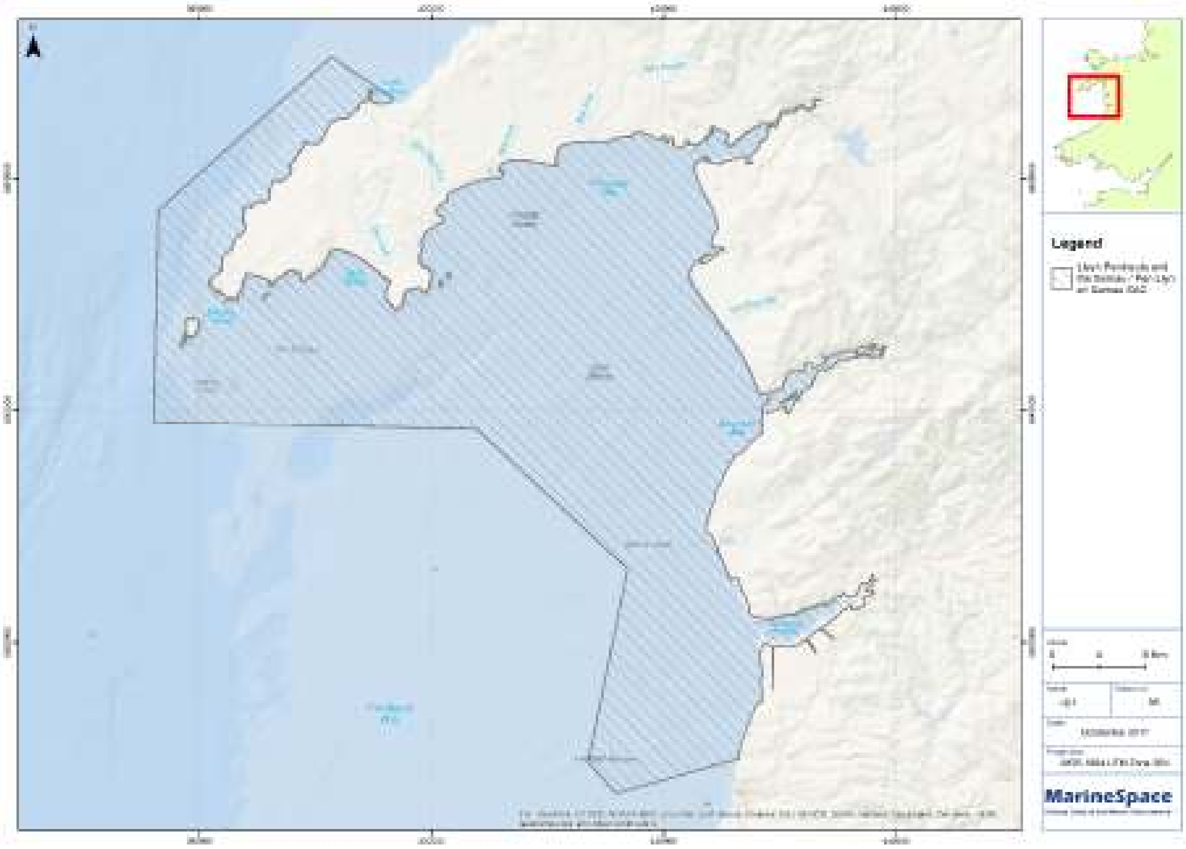
The impacts of anchoring and mooring need to be considered both spatially and temporally and across the tidal range. The impacts of one anchor may only have a small impact and cause damage to only a small area of seabed. However, if multiple vessels anchor within the same area on a daily basis, the impacts may be more significant.

# 2. Background

## 2.1. Pen Llŷn a'r Sarnau (PLAS) Special Area of Conservation (SAC)

The Pen Llŷn a'r Sarnau (PLAS) Special Area of Conservation (SAC) is located on the northwest Welsh coast.

**Figure 2.1: Location of the Pen Llŷn a'r Sarnau (PLAS) Special Area of Conservation (SAC).**




The site was designated due to the presence of a number of marine habitat types and associated wildlife (Habitats Directive Annex I habitat types) and mammal species (Habitats Directive Annex II species). The Annex I habitats that are a primary reason for the selection of this site are:

- Reefs;
- Large shallow inlets and bays;
- Sandbanks which are slightly covered by seawater all the time;
- Estuaries; and
- Coastal lagoons.

Annex I habitats that are present as a qualifying feature but not a primary reason for selection of the site are:

- Mudflats and sandflats not covered by seawater at low tide;

- Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*);
- Salicornia and other annuals colonising mud and sand; and
- Submerged or partially submerged sea caves.

Annex II species that are present as a qualifying feature but not a primary reason for selection of the site are:

- Grey seal - *Halichoerus grypus*;
- Bottlenose dolphin - Tursiops truncatus; and
- Otter - *Lutra lutra*.

## 2.2. Porthdinllaen seagrass beds

Seagrasses are the only truly marine flowering plants found subtidally in the UK. In the UK, three species of seagrass occur: *Zostera marina*, *Zostera noltii* and *Zostera angustifoli*.

The seagrass bed at Porthdinllaen falls within the Pen Llŷn a'r Sarnau SAC and is one of the largest seabeds in North Wales, present within the inner and outer harbour, spanning an area up to 1km in length and around 650 metres wide in places (Stamp and Morris, 2012). As part of the Welsh Assembly Government's targets to halt the rate of habitat loss and bring designated conservation sites into favourable management, action to safeguard the seagrass bed at Porthdinllaen and reduce the likelihood of impact from mooring and anchoring has been identified as one of the key management actions for the SAC.

Within Porthdinllaen, the moorings are split between two discreet areas: the outer harbour and the inner harbour. The inner harbour moorings house typically smaller vessels of approximately less than 5 metres, while the outer harbour moors larger vessels and yachts over 5 metres (Stamp and Morris, 2013). Installed by the National Trust, the inner harbour moorings are intertidal and were fixed landward of the old breakwater in the bay. Currently there are 35 moorings in the inner harbour area, consisting of either a concrete block poured into a fish box mould or more recently a 600 mm x 600 mm x 400 mm mould with a short length of connector chain and a 5-7 metres long 22 mm 4-strand polysteel rope riser. The 40 moorings in the outer harbour are subtidal and are installed seaward of the old breakwater in the bay by a contractor with a boat, with no moorings present more than 600 metres from shore (Stamp and Morris, 2013). Although the inner moorings have a capped mooring number of 50, the outer harbour does not have a restriction (Egerton, 2011). Subsequently, the outer harbour moorings have resulted in haloes of damaged seagrass surrounding the moorings due to the abrasive effect of the chain components.

# 3. Previous studies

## 3.1. Seagrass surveys

In 2008 and 2009, volunteer dive surveys were conducted to ground-truth potential seagrass patches, identified by aerial photography in both Porthdinllaen and Milford Haven. The method examined five of the fixed moorings, to provide an estimate of the current level of 'scar' created by each mooring on the seagrass bed. Results were collected through an underwater transect design, with quadrat counts taken every 5 metres from a central point (each mooring) for up to 30 metres. The results of the 2008 survey found that seagrass was absent in 83% and 86% of the quadrats at the base of, and 5m from, the moorings respectively; absent in 39% of quadrats 10m from the base; and absent in 20-25% of quadrats at distances greater than 10m from the base of the moorings (Morris, 2008).

One of the recommendations of the 2008 survey report was:

*Consider the use of more 'seagrass friendly' fixed mooring systems (e.g.: cyclone moorings and or 'Seaflex' moorings currently being trialled at Lundy Island Marine Nature Reserve).*

## 3.2. Eco-mooring reviews

Previous literature reviews have examined the alternative methods that can be used for mooring, which may result in a reduction of impact on the seagrass beds (Egerton, 2011; SEACAMS, 2015). A summary of the seagrass friendly mooring options identified are provided below.

### 3.2.1. Anchoring systems

#### 3.2.1.1. Traditional block anchor

The system currently used in the Porthdinllaen inner harbour is traditional block anchors, which are heavy weights that rest on the seabed. This may be clumps of chains, cement filled tyres, or train wheels. These are cheap and easily deployed. They have a large footprint and are regularly received and replaced causing greater disturbance to seagrass.

#### 3.2.1.2. Mantra ray and duckbill anchors

Manta ray anchors are installed using an underwater jackhammer and is driven into the sea floor, the anchor is then pulled upward, which opens it and locks it into place. Duckbill anchors work on the same principle, but rather than having a solid pole a cable is attached to the anchoring unit. Holding capacities range from 50-90kN for various sandy substrates and the maximum holding capacity is 100kN. In addition, they have a 120-year lifespan.

#### 3.2.1.3. Helix anchor

Helix anchors are popular for seagrass beds. In the intertidal region a 400 mm anchor is suggested, if sediment depth is sufficient a 600 mm anchor may be used. These are a cheap anchor option.

#### 3.2.1.4. Helical screw

The helical screw system is suggested for areas with dense root growth. Little information is available on the performance of these anchors.

#### 3.2.1.5. Mushroom block

Mushroom block anchors are not considered suitable for use at Porthdinllaen. These anchors are designed for silt and mud substrates.

#### 3.2.1.6. Trot moorings

Trot moorings have previously been in place in the inner harbour of Porthdinllaen, that comprised several moorings attached to a ground chain tensioned between two anchors. These moorings are not considered beneficial to seagrass as similar, cyclone moorings, have been shown to have a higher impact than other moorings. At Porthdinllaen they have since been replaced by concrete blocks.

#### 3.2.1.7. Drilled and bonded anchor for hard substrate

Drilled and bonded anchor for hard substrate are designed for installation on rock or coral reef and therefore are not suitable for sandy environments such as Porthdinllaen.

### 3.2.2. Mooring systems

#### 3.2.2.1. Halas system

The Halas System consists of a single pin or anchor unit embedded into the seabed and uses a commercial 18-inch diameter buoy. This system uses a three-part rope system instead of one continuous rope. This allows ropes to be replaced if required, reducing maintenance costs. A weight is placed 3ft down from the surface on the anchor line to avoid slack rope floating.

#### 3.2.2.2. Ezyrider

The Ezyrider has a displacement buoy that moves up and down a stainless steel shaft attached to a down-line chain at one end and a surface line at the other. When a vessel is attached it forces the buoy to move up the shaft, and with sufficient force it will become submerged. When the force is decreased the rubber connections at the base of the buoy contract and the buoy returns to its beutral vertical position. Exyrider claims it can reduce the swing of a vessel up to 50%. This has been extensively trialled in Australia.

#### 3.2.2.3. Seaflex

Seaflex is an elastic mooring system where a mooring is attached to the buoy through a stainless shackle and a rope is attached to the buoy. This can be used with any anchoring type. The crucial part of the system is the rubber hawser, which gives a progressive resistance reducing movements in the water column. Seaflex acts as a shock absorber. This system claims that less swinging space is required than conventional methods.

#### 3.2.2.4. Seagrass friendly mooring

Seagrass-friendly mooring is installed with a helix screw into the seabed that has minimal environmental damage. The system has a pivoting raised arm that is attached to a fixed anchor with a 360° rotating head attached, which allows movement of a shock absorber. When it is fixed to a rope and surface buoy the buoyancy keeps the shock absorber elevated from the seabed even at low tide.

#### 3.2.2.5. Eco-mooring rode

The Eco-Rode system is an elasticated rope and it can be attached to a variety of anchor types, although a Helix anchor is suggested. The standard Eco-Rode is 12ft will stretch up to 19ft and buoys can be added to help float longer systems.

#### 3.2.2.6. Hazelett elastic mooring rode

Similar to the Eco-Rode, the Hazelett system is made of an elastic material that can stretch to four times its unloaded strength and can also tolerate twisting. The system uses a spar buoy instead of the conventional rounded buoy. The extension acts to keep the boat pointed into the wind rather than yawing.

#### 3.2.2.7. Harmony system

The Harmony System has an intermediate floater, keeping the line permanently taut in open water, and when not in use the anchor line does not have contact with the seabed. At the surface the line is attached to a mooring buoy. At the head of the anchor the line is fastened to a shackle. A variety of anchors can be used, with spring shaped anchors of Helix anchors suggested. This system is widely used in the Mediterranean.

#### 3.2.2.8. Traditional style with subsurface buoy and high tensile rope

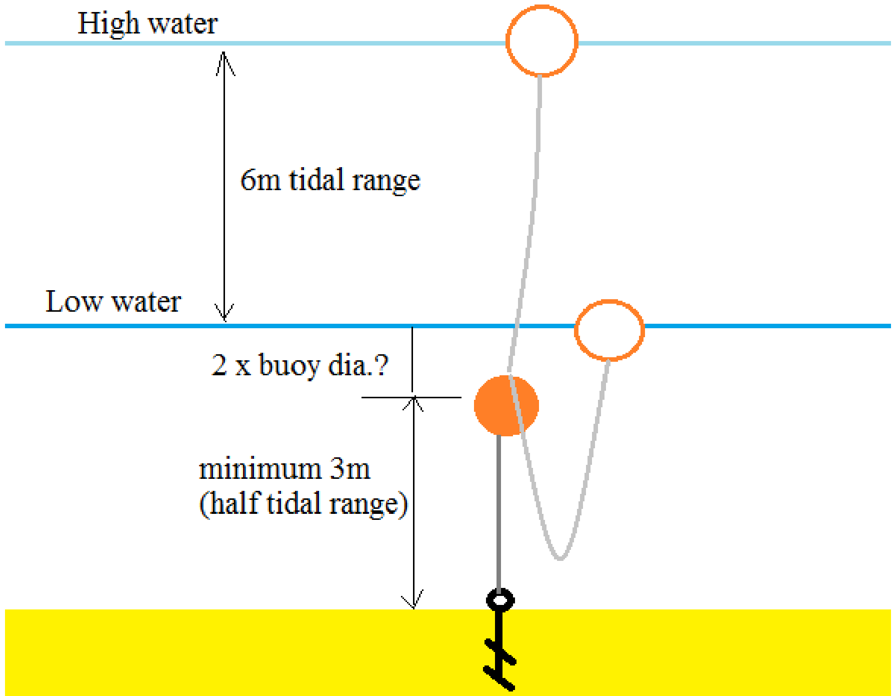
A suggested option would be to use high tensile rope rather than steel chain attached to a weight – such as a train wheel. To ensure the rope does not drag on the seabed a subsurface buoy would be attached. The installation of this is cheaper than the options listed previously.

#### 3.2.2.9. Retro-fitting of sub-surface floats

The cheapest option suggested by Egerton (2011) is to retro-fit a sub-surface float to the existing mooring chain or use an existing anchor with new chain/rope and a sub-surface buoy. Several considerations would need to be made for this system, including appropriate depths, changes to required anchor weights, and potential for tangling. An example of how this system may look is shown in

Figure 3.1.

**Figure 3.1: Conceptual schematic of a sub-surface buoy attached to a mooring (moorings at Porthdinllaen have more than one anchor point)**




### 3.2.3. Previous recommendations

The original review of the seagrass moorings presented several possibilities and recommended that the best way forward would be to conduct a trial of the recommended systems in a small area of the bed and also a trial of a voluntary no-anchoring zone. The recommended suitable systems were: the eco-rode mooring system; and a low cost and simple system suggested by Dr Ken Collins (using a train wheel, subsurface buoy and high tensile rope) (Egerton, 2011).

It was suggested that moorings with negligible impact to seagrass features and traditional ones could be put in unscarred areas of seagrass and then the differences in the subsequent amount of scarring could be tested. To test the effects of a voluntary no anchoring zone the area could be surveyed prior to the zone being implemented and then surveyed again following a designated period. In addition, a zone in the intertidal area could be designated on the beach for launching of vessels (Egerton, 2011).

*Inner harbour*

The SEACAMS (2015) review recommended that modifying the mooring design would not work well due to the intertidal or shallow sub-tidal location of the moorings. It was recommended that new moorings should be constructed using neutrally buoyant polypropylene rope, as this will roll over the seagrass without damaging it. It was also suggested that helical anchors should replace the block moorings, however this would be expensive due to the need to do an initial survey of the seabed (SEACAMS, 2015).

*Outer harbour*

The SEACAMS (2015) report recommended the use of duckbill anchors in the outer harbour. It was noted that the previously suggested installation of trot moorings would not be a suitable alternative to the current anchors, as they can negatively affect the seagrass through ground chain disturbance and installation disturbance. The majority of the current moorings in the outer harbour are removed over the winter. The lifespan of duckbill moorings is greater than 100 years and so are unlikely to need removing during the winter. For future projects, it was recommended that some of the shallow subtidal moorings could be replaced with elastic rodes, if the angle at which the rode can make with the seabed at low tide whilst not impacting the seabed is established.

As is recommended for the inner harbour further work should be conducted to test the benefit of elastic rodes on seagrass in regions of high tidal range (SEACAMS, 2015).

# 4. Review of additional options

In addition to the information summarised in Section 3, a further review of current literature and additional mooring options has been conducted.

## 4.1. Eco-friendly mooring

### 4.1.1. Rubber roller

It is suggested that a system that will allow the mooring fixtures to roll over the seagrass bed be used rather than drag/abrade as is observed with chain-based moorings. Therefore, a system that uses a foam roller and a synthetic rope is suggested.

This is based upon information provided on a similar system that has been successfully implemented for several years in an area in northern France where there is muddy and sandy sediment and a high tidal range (Alison Palmer Hargrave pers. comms., 2017). An example of the system used in France can be seen in Figure 4.1.

The materials used for this system are currently unknown and commercially sensitive, therefore some consideration would need to be given to the exact specification for this mooring option in Porthdinllaen.

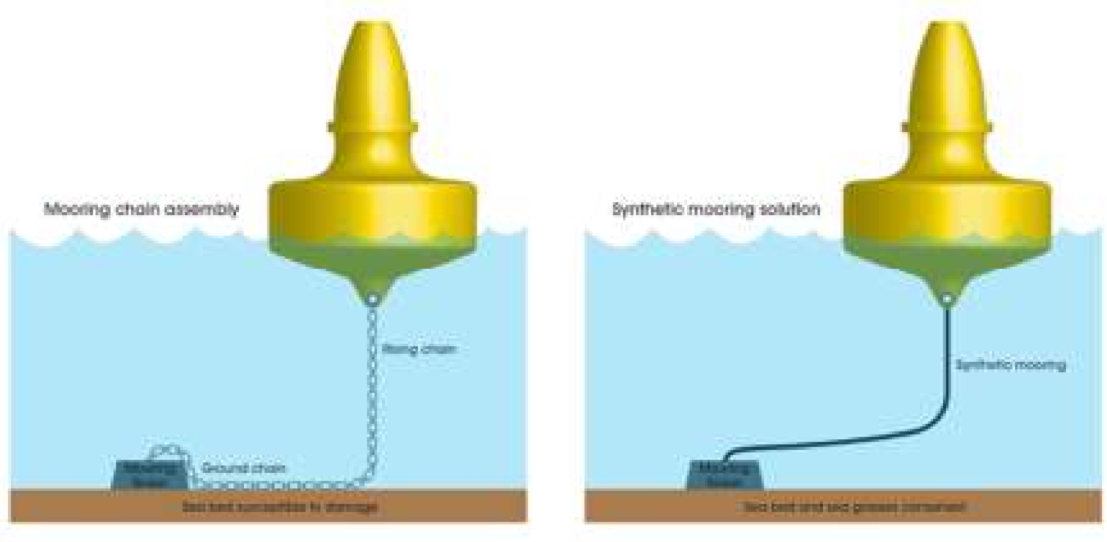
**Figure 4.1: Environmentally friendly mooring option used in northern France**

**Approximate cost per mooring**: £150

#### 4.1.2. Sealite

Sealite synthetic mooring solutions provide a lightweight and environmentally sensitive alternative to traditional mooring chain and are ideal for many marine mooring applications. Due to the lack of chain, the synthetic mooring reduces the damage on the seabed. It is also constructed from a nylon core, which absorbs shock loads in the wave and tidal conditions found in marine environments.

Sealite mooring can be used as a replacement for chain, and can be used with mooring buoys.




Chris Newell at Sealite has recommended that the specifications that should be used at Porthdinllaen is a maximum Synthetic Mooring Strop, 20T, 28mm Galv. Thimble. The full specification for the Sealite system can be seen in Appendix A.

**Approximate cost per mooring**: £572 (plus VAT)

#### 4.1.3. Retro-fitting sub-surface floats

The cheapest option for existing moorings would simply be to retro-fit a sub-surface riser float to the existing mooring chain or use an existing anchor with new chain/rope and a sub-surface buoy. Such a technique was suggested in a previous review of alternative mooring options by Dr Ken Collins of NOC (Egerton 2011). The previous review suggested that to prevent interference between the sub-surface riser float and the mooring buoy, a certain distance will be required between the height of the sub-surface float and lowest astronomical tide (LAT). It is suggested that this is likely to be about two buoy diameters. An estimate of a minimum depth of 4m LAT is suggested. This is about the same depth as the deepest moorings that need to be considered at Porthdinllaen (Egerton, 2011).

Concern might be given to the potential for tangling between the two sections of chain and the sub surface buoy. The line used could be polypropylene rope or chain, depending on boat size. Chain is preferred because the weight will mean slack chain will sink towards the seabed better than polypropylene rope under low tide and slack current conditions and hence will reduce both the radius of swing and potential for tangling (Egerton, 2011). The mooring currently in place at

Porthdinllaen is chain and therefore can be used to retro-fit the buoys. Anchor weight should also be considered since traditionally the mooring chain provides some anchoring force: typically for swing anchors mooring length to depth is around 3:1. The addition of a subsurface buoy will result in the initial section of the chain being close to vertical and hence consideration will need to be given to mooring strength (Egerton, 2011).

**Approximate cost per mooring**: £40

## 4.2. Suggested systems to model

Based on the review of the potential mooring options, considering both the performance of the system (in terms of mooring integrity and potential mitigation of damage to seagrass), and the potential cost, the following methods were recommended for the modelling study to determine the relative performance for conditions similar to Porthdinllaen:

- Rubber roller system;
- Retro-fitting of sub-surface floats; and
- Sealite mooring.

<u>The modelling undertaken within this project provides a comparative assessment of the performance of different possible mooring options and adaptations within the harbour. This is to inform recommendations for the 'best option' to progress to field trials.</u>

# 5. Modelling parameters

All modelling was undertaken by Orcades Marine Ltd (2017).

The modelling tested each option at different representative depths, comprising approximate LWST and HWST in the inner and outer harbour, using the same environmental conditions throughout. The environmental conditions, vessel, mooring options properties are described in detail in the following sections. The models were not based on specific locations within Porthdinllaen.

## 5.1. Environmental conditions

The modelling conducted by Orcades Marine Ltd examined each mooring option at four simulated water depths (1.5 m, 4.3 m, 7.5 m, and 10 m) agreed with the Gwynedd Council Project Officer with the same sea state applied to each depth.

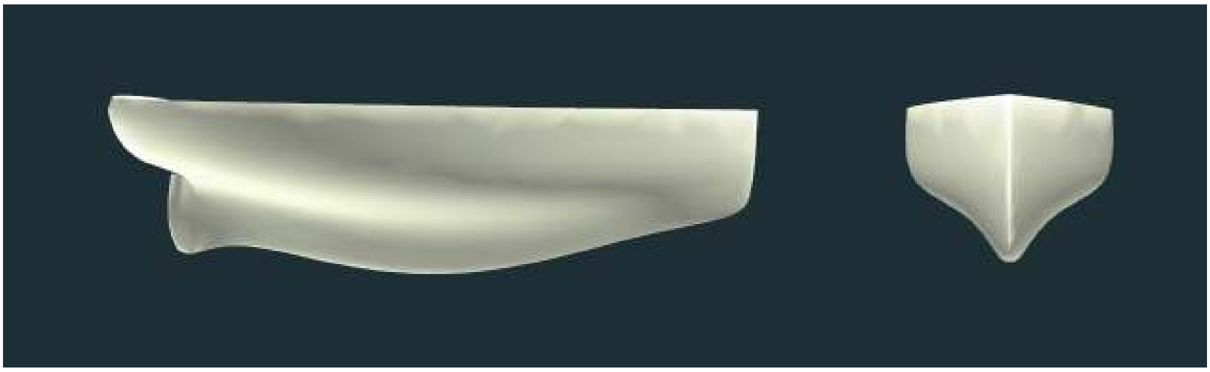
A steady state sensitivity study was completed using only a mean speed of 12 m/s. A fully dynamic model was then completed using a wind spectrum that applied gusting, as well as a JONSWAP (Joint North Sea Wave Project) spectrum wave state, the results of which built on earlier work to model the effect of wind fetch and wave climates. This model is used extensively for simulating wave climates.

The waves were made up of a significant wave height of 0.7 m and a peak period of 3 seconds (Orcades Marine Ltd, 2017).

## 5.2. Vessel model

The same surface vessel hull shape was used throughout each mooring option. A generic small boat hull was used that had a length of 12m and displacement of 8000 kg. A representative image of the hull shape used can be seen in Figure 5.1.

**Figure 5.1: Hull shape used for the surface vessel in the modelling**



## 5.3. Model properties

Each of the mooring options considered used a different combination of mooring components. A summary of each of the options is described in Table 5.1.

**Table 5.1: Specifications and properties of the mooring options considered in the modelling (information from discussion with mooring manufacturers and based on expert judgement of Orcades Marine)**

| Specification | Baseline | Mooring Options | | |
|---|---|---|---|---|
| | | 1.Rubber Roller | 2.Sub-surface buoy | 3.Sealite Mooring |
| **Total length of riser** | 22 m | 15 m | 15 m | 15 m |
| **Material and composition of riser** | 22 m Studless short link chain | 14m x Polymide Rope<br>1m x Stiff rubber roller | 15 m Studless short link chain | 15 m Rubber sheathed nylon |
| **Minimum breaking load** | 240 Kn MBL | Approx. 240 Kn MBL | 240 Kn MBL | 20 te MBL (196 Kn) |
| **Diameter and characteristics of riser** | 22 mm open link galvanized chain | 34 mm polymide 3 or 8 strand | 22 mm open link galvanized chain | Internal core 36mm<br>Outer rubber sheathing approx. 10 mm (total dia 46 mm) |
| **Weight per unit length (in air)** | 9.8 kg/m | 0.715 kg/m | 9.8 kg/m | 1.2 Kg/m |
| **Other** | | | A3 polyform* buoy attached at:<br>a) 2 m for water depths 1.5 m and 7.5 m<br>b) 4 m for water depths 4.3 and 10 m | |

*Attached at position from sinker - A3 Polyform Buoy: Diameter (Width) 460mm (DIA) Height 575mm Rope Hole Diameter 28mm, Weight 3.10 kg, Gross Buoyancy 52.0 kg

The numerical modelling exercise was carried out on a comparative basis between the options agreed, on the performance of the riser only, which assumes that the riser is attached to a fixed point on the sea bed. This is sufficient to inform selection of a mooring adaptation to take forward to field trials.

# 6. Results of modelling

The three new mooring options were modelled at four different depths: 1.5 m, 4.3 m, 7.5 m, and 10 m. This represented approximate LWST and HWST at two different mooring points, with 1.5 m and 7.5 m being low and high tide respectively at the inner harbour, and 4.3 m and 10 m being low and high tides respectively at the outer harbour. The baseline mooring system (i.e. the current system in place) was modelled at 10 m. The depths were approximate and were not based on specific locations with Porthdinllaen.

During the modelling of the different mooring options, a constant wind was applied to each option to gain an understanding of the steady state displacement, or watch circle, in these environmental conditions. Once a steady state analysis was completed, dynamic waves were introduced to the modelling (Orcades Marine Ltd, 2017).

During the dynamic response modelling in extreme conditions snap loads were common. This occurs when there is a slack event followed by a high-tension spike. Snap loads can lead to anchor uplift as well as mooring failure from very large line loads. This can mostly be observed in the relatively high anchor reaction loads at the 1.5 m water depth. As water depth increased, the reaction loads also increased, but a mean tension was often sustained (Orcades Marine Ltd, 2017).

## 6.1. Baseline

The baseline conditions were tested at a depth of 10 m, in order to compare to the new proposed options. The anchor reaction load, which is the load put on the anchor by the boat, is 2 kN. This anchor reaction load is the lowest across all the systems at a 10 m depth.

The length of chain touching the seabed (the grounded mooring length) for the baseline is 7 m and this was the only system that has any length of chain touching the seabed at 10 m depth.

**Table 6.1: Results of modelling for the baseline mooring system**

| Water depth | 1.5m | 4.3m | 7.5m | 10m |
|---|---|---|---|---|
| **Steady state response** | | | | |
| **Surface vessel watch circle** | | - | - | 23 m |
| **Grounded mooring length** | - | - | - | 7 m |
| **Dynamic loading response** | | | | |
| **Peak anchor reaction load** | - | - | - | 2kN |

## 6.2. Rubber roller

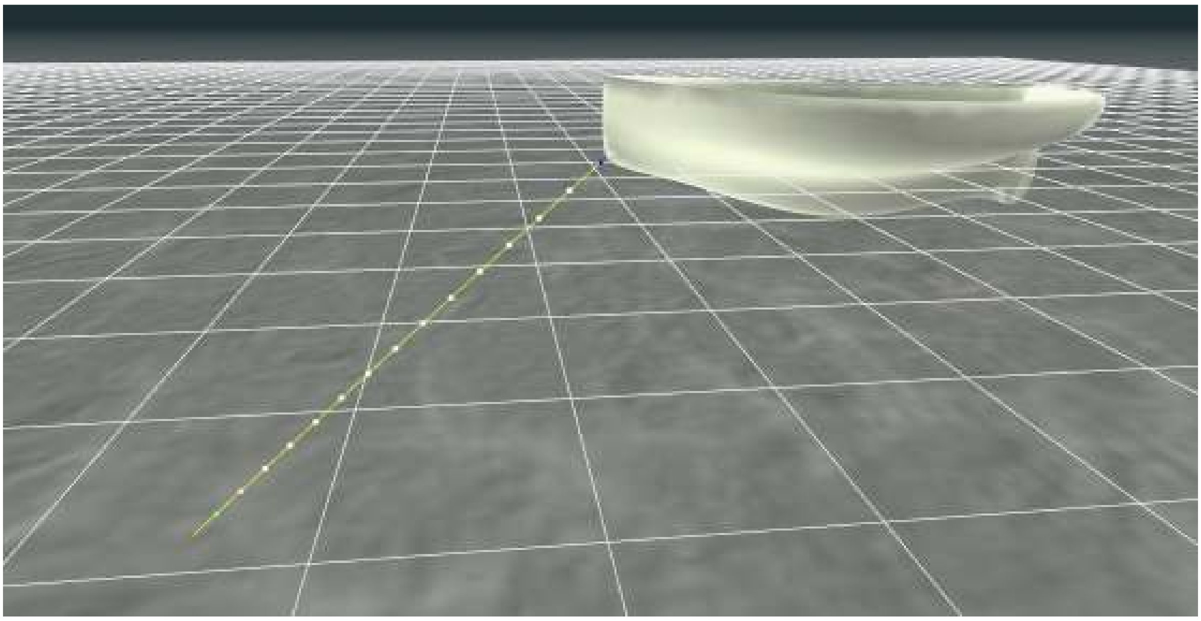
At a water depth of 1.5m, the rubber roller mooring system was pulled taut. This creates a mooring that does not contact the seabed. However, there is then minimal compliance in the system to absorb wave-induced boat motions and it risks damaging the moored vessel.

At a water depth of 10 m, the rubber roller option continued to show a taut mooring. This resulted in zero grounded mooring length. When compared to the baseline case, with a 7m length of grounded chain, the reduction in mooring line length resulted in a reduction in grounded mooring line length.

**Table 6.2: Results of modelling for the rubber roller mooring system**

| Water depth | 1.5m | 4.3m | 7.5m | 10m |
|---|---|---|---|---|
| **Steady state response** | | | | |
| **Surface vessel watch circle** | 21 m | - | - | 17 m |
| **Grounded mooring length** | 0 m | - | - | 0 m |
| **Dynamic loading response** | | | | |
| **Peak anchor reaction load** | 23 kN | 8 kN | 10 kN | 14 kN |

**Figure 6.1: Illustration of the rubber roller mooring option modelled (From: Orcades Marine Ltd, 2017)**



## 6.3. Retro-fitting of sub-surface floats

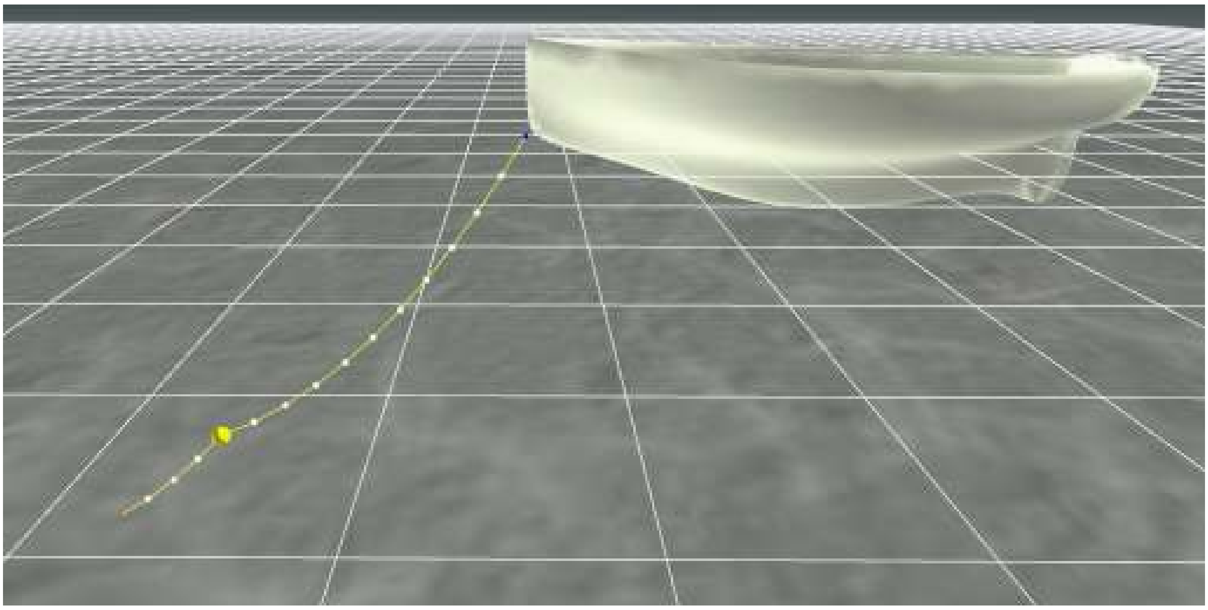
At a water depth of 10 m, the sub-surface buoy option showed a taut mooring. This resulted in zero grounded mooring length. When compared to the baseline case, with a 7m length of grounded chain, the reduction in mooring line length resulted in a reduction in grounded mooring line length.

For the sub-surface buoy mooring option, the 4.3 m and 7.5 m depths showed relatively small anchor reaction loads compared with the other systems. At the shallowest depth of 1.5 m, the anchor reaction load is very high for this system. This was due to the mid-span float adding compliance (elasticity or cushioning) to the system as well as the weight of the chain in the water column applying a constant tension. Both of these features help to alleviate snap loads that are observed in the synthetic mooring systems and risk damaging the moored vessel.

**Table 6.3: Results of modelling for the sub-surface floats mooring system**

| Water depth | 1.5m | 4.3m | 7.5m | 10m |
|---|---|---|---|---|
| **Steady state response** | | | | |
| **Surface vessel watch circle** | 20.5 m | - | - | 17 m |
| **Grounded mooring length** | 7 m | - | - | 0 m |
| **Dynamic loading response** | | | | |
| **Peak anchor reaction load** | 240kN | 3kN | 3kN | 18kN |

**Figure 6.2: Illustration of the sub-surface buoy mooring option modelled (From: Orcades Marine Ltd, 2017)**



## 6.4. Sealite mooring

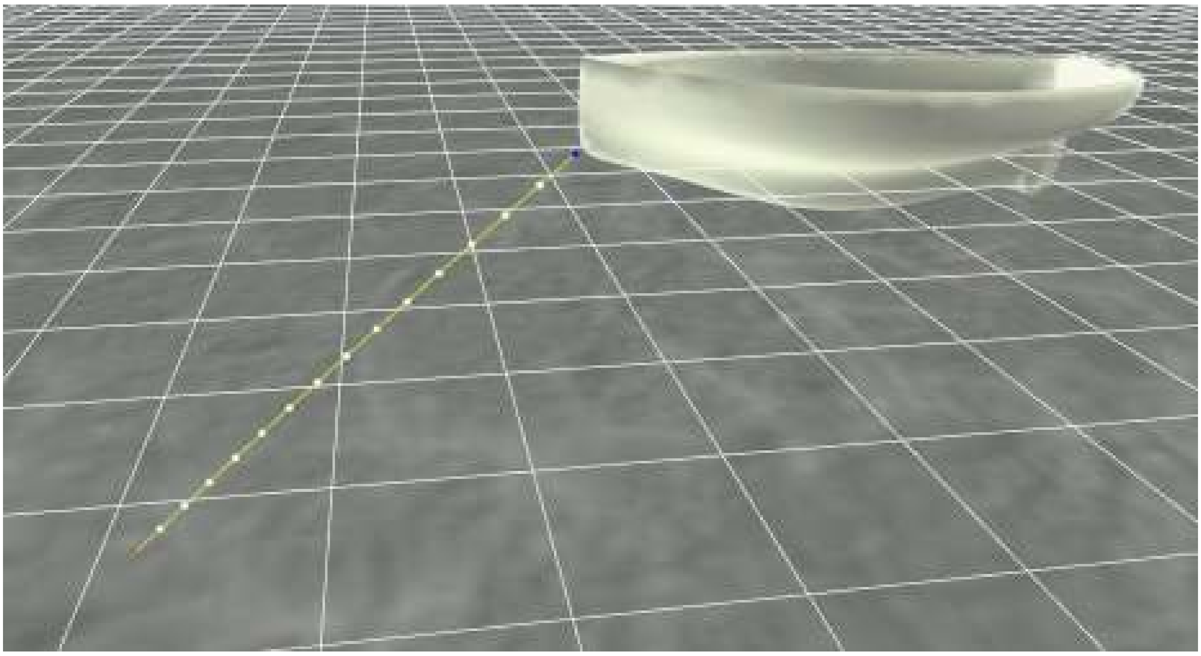
At a water depth of 1.5m, the Sealite mooring system was pulled taut. This creates a mooring that does not contact the seabed. However, there is minimal compliance (elasticity) in the system to absorb wave induced boat motions.

At a water depth of 10 m, the Sealite option continued to show a taut mooring. This resulted in zero grounded mooring length. When compared to the baseline case, with a 7m length of grounded chain, the reduction in mooring line length resulted in a reduction in grounded mooring line length.

**Table 6.4: Results of modelling for the Sealite mooring system**

| Water depth | 1.5m | 4.3m | 7.5m | 10m |
|---|---|---|---|---|
| **Steady state response** | | | | |
| **Surface vessel watch circle** | 21 m | - | - | 17 m |
| **Grounded mooring length** | 0 m | - | - | 0 m |
| **Dynamic loading response** | | | | |
| **Peak anchor reaction load** | 56kN | 9kN | 15kN | 15kN |

**Figure 6.3: Illustration of the Sealite mooring option modelled (From: Orcades Marine Ltd, 2017)**



# 7. Conclusions and recommendations

The modelling completed by Orcades Marine Ltd (2017) compared the behaviour of the three proposed mooring options with the baseline mooring, all under the same steady state and dynamic environmental loading.

The results of the modelling showed that the two synthetic mooring options (Sealite mooring and rubber roller) have the tendency to be pulled taut even at the shallowest water depth of 1.5 m. As the water depth increased to 10 m the synthetic mooring options remained taut and the sub-surface buoy option also became taut enough to remove most of the compliance in the system.

The watch circle of the surface vessel (the diameter which the boat can swing around the anchor point) varies from 17 m to roughly 21 m at the highest and lowest tides respectively for each of the three new mooring options tested. The baseline mooring system had a watch circle of 23 m at the highest tide modelled.

The sub-surface mooring option showed grounded length of 7 m at the 1.5 m water depth, at the deepest depth of 10 m there was no grounded length of chain. This suggests that at shallower depths the system would not successfully mitigate abrasion to surrounding seagrass beds.

The modelling of the baseline mooring option, that was made up of 22 mm chain, found that the additional length and mass from the chain was sufficient in preventing the system from going taut even at 10m water depth. However, a significant length of chain was in contact with the seabed at the deepest depth of 10 m.

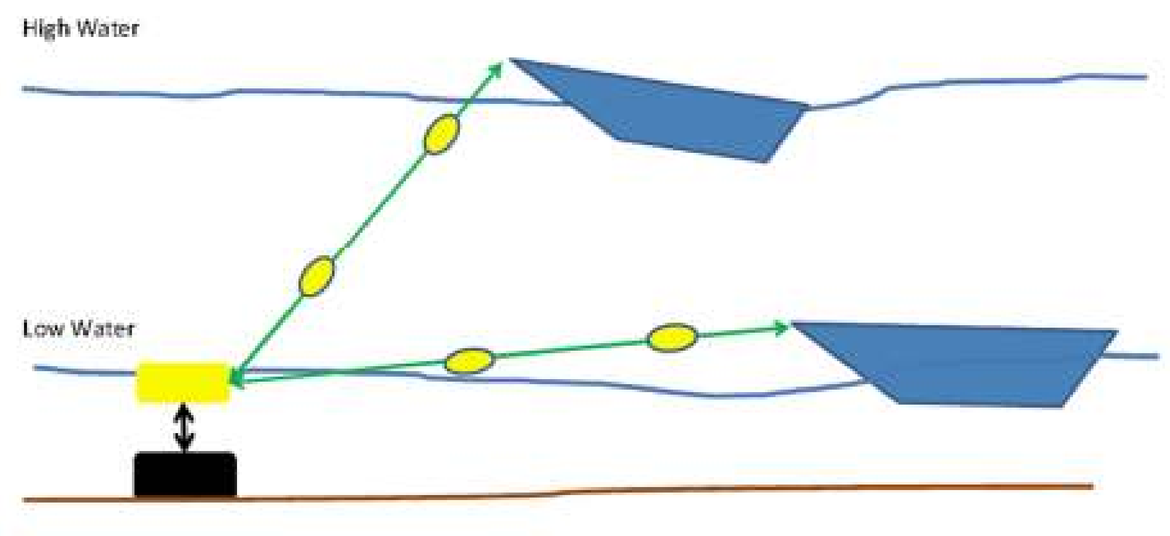
As dynamic waves were applied to the model, differing reaction loads were observed at the anchor point. The highest anchor reaction load was observed at the depth of 1.5 m for the sub-surface buoy mooring option. Snap loads were observed through each of the mooring options, particularly at the 1.5 m depth.

MarineSpace Ltd and Orcades Marine Ltd recommend that the sub-surface buoy mooring option has the potential to be the most viable option in terms of maintaining mooring integrity and in mitigating some of the damage to surrounding seagrass beds. It is also one of the most cost-effective and easy to apply mooring modifications at £40 per mooring. At the 4.3 m and 7.5 m depths, the sub-surface option showed minimal reaction loads as well as a reduced grounded length in comparison to the baseline case. Therefore, this system could be used for the deepest moorings at Porthdinllaen. It is suggested that careful design of the mooring components, buoy size, and anchor type should be considered during trials in order to investigate the possibility of a successful design at shallower water depths.

A similar trial of environmentally friendly mooring was recently conducted at Cawsands and Salcombe in Devon by the National Marine Aquarium (NMA). This system used a slightly different configuration to that used within the harbour at Porthdinllaen. The system included the use of a 500 kg sinker block, rather than chains on the seabed held in place by anchors. An illustration of the system used in Devon can be seen in Figure 7.1.

Following discussions with Mark Parry at the NMA, it was suggested that the sub-surface buoy system could work even better with a sinker as the load from the vessel is taken by the sinker in this situation, rather than the chain. Though in some instances, this system could be considered for shallower moorings – although at a significantly higher cost of £600 per mooring (Mark Parry pers. comms, 2017) – discussion with local fishermen suggested that the use of sinkers in shallower regions of the outer harbour would not be sufficient to cope with the wave conditions at Porthdinllaen. This is because the chains on the seabed are required to have a suspension system to prevent waves breaking over the bow of the moored fishing boats.

**Figure 7.1: Illustration of mooring system used at trials in Devon (From: Mark Parry pers. Comms, 2017)**




<ins>It is important to note that this study was a comparative sensitivity analysis intended to understand the relative behaviour of each mooring option in a modelled system similar to Porthdinllaen.</ins> Further design analysis of the mooring options could be completed before deployment of any of the anchor system.

It is recommended that the next step for this study before any widespread modifications is to conduct trials of the moorings *in situ* at Porthdinllaen. The addition of sub-surface buoys as described here could be trialled at the deeper moorings, as the modelling has suggested that this will work with the existing anchor system without affecting the integrity of the mooring system. However, at the shallower moorings the placement of the sub-surface buoys should be considered further, and additional/replacement materials may be required.

Moving forward, it will be critical to trial sub-surface buoys with multiple-point anchor systems. Whilst it was not possible to model these this as part of the current exercise due to the additional variables and complexity, the feasibly and performance of any sub-surface buoy system will be dependent upon the type of anchor points used and the distance between anchor points and multiple buoys which will necessarily vary with depth and location within the site. These trails should be informed by discussions with users of the site in order to predict and circumvent any potential problems with combinations of anchorings and moorings before the trial stage.

The trial moorings should be monitored over a period of several months and should involve an assessment of the seagrass surrounding each mooring. It is suggested that mooring trials should be conducted at various depths within Porthdinllaen.

# 8. References

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# Appendices

# Appendix A. Sealite Mooring Specification

# Appendix B. Orcades Marine Modelling Report