Falmouth Harbour Advanced Mooring System (AMS) Trial Report

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Project funded by TEVI

Executive summary

This report details the output of a trial of a specifically designed Advanced Mooring System (AMS) installed within Falmouth Harbour waters (see fig 1). The objective of an AMS is to reduce the impact of leisure moorings on fragile estuarine and riverbed ecosystems, specifically on Seagrass beds.

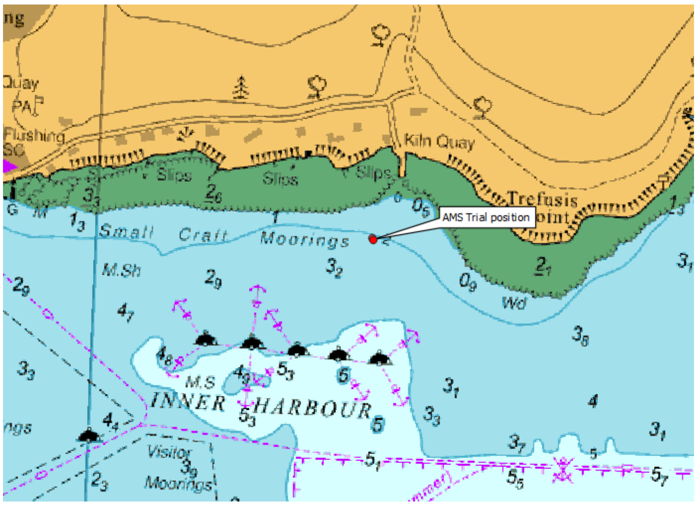

Fig 1: Chart showing location of AMS trial © UKHO. Not for Navigation

This project aims to build on understanding and previous modelling completed within Cornish harbours[1] commissioned by Tevi and completed by Morek[2] and contribute to the development around the potential use of AMS within Falmouth and other harbours.

The mooring was designed by Morek considering Falmouth Harbour aims to utilise materials & equipment already in use to minimise costs and maximise use.

Once the mooring design had been finalised the mooring was made up and deployed by the Falmouth Harbour Maintenance team.

During the trial various tests were carried out to measure maximum cleat forces and vessel excursion which differ as a direct result of changing the design of a traditional mooring. It was hoped that this data could be used to assess and improve the modelling software accuracy and provide information to Falmouth and other harbours on how these moorings work and could potentially be used in the future.

The AMS was deployed at the end of July 2022. Testing was carried out in September in addition to underwater monitoring of the AMS whilst in situ. The boat was removed from the mooring on 5th November 2022 and the mooring itself removed in February 2023.

The AMS performed well to support the 6.71 metres long, 2.44 metres beam and 1.07 metres draught vessel during all weather conditions (up to force 8) the over three-month period the mooring was deployed with a vessel attached. The results of the tests indicated the modelling was successful in designing a mooring capable of securing the vessel within expected parameters. However, the tests conducted were not conclusive due to conditions and equipment.

There are some concerns around the navigational risk of using this design more widely within the harbour due to the proximity of floats and chain to the surface of the water, particularly at low tide. This would need to be overcome to be able to use AMS in more open water alongside race marks and navigation buoys. Therefore, further trials are recommended to find a solution which minimises navigational risk.

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[1] https://tevi.co.uk/wp-content/uploads/2021/03/Tevi-Modelling-of-Advanced-Moorings-in-Cornish-Harbours.pdf

[2] Morek – Marine Engineering & Naval Architecture

Acknowledgements

This work would not have been possible without the interaction and contributions of several key individuals and organisations:

- Tevi[3] for raising this issue through their challenge network and providing funding to facilitate this trial.
- Bob, Jovie and Arthur of Morek
- The mooring maintenance team at Falmouth Harbour
- Support and encouragement from our board of commissioners and staff at Falmouth Harbour
- Support and understanding from Falmouth Harbour users

Thank you all for your time, expertise and enthusiasm for this project.

[3] Home page 2021 - Tevi

Contents

Introduction

Project background

Traditional swinging moorings have an impact on the seabed due to the abrasive movement of the heavy chain creating a scour patch (see fig 2). In Falmouth the impact of swinging moorings on infauna communities was studied in 2012 in the Fal and Helford Recreational Boating study[4]. The study found there was an impact on infauna communities within the vicinity of mooring infrastructure.

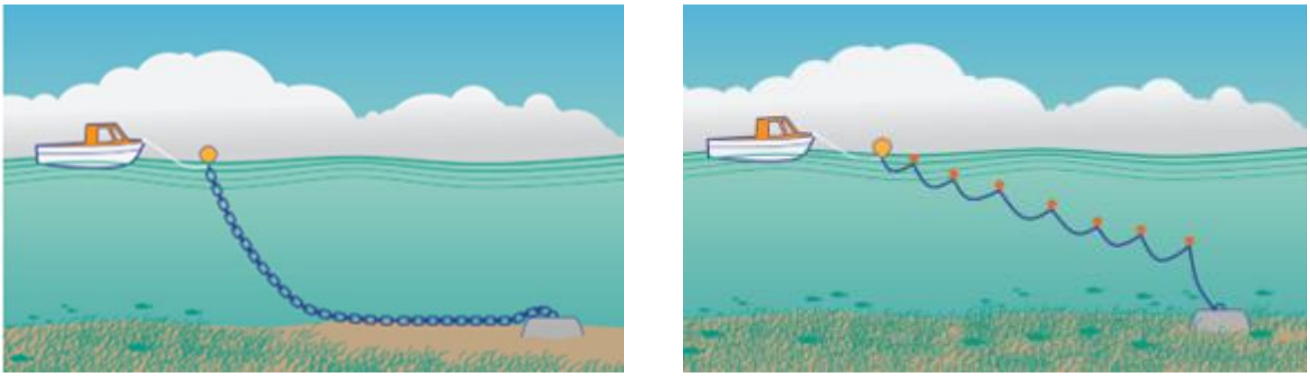

Fig 2: Image showing impacts of traditional swinging mooring vs Stirling Advanced Mooring System.

More recently further studies, specifically looking into the health of seagrass within Cornwall quantified the impacts of moorings on seagrass[5] in particular. the Tevi challenge network on Seagrass regrowth and boat moorings brought this issue and potential solutions to local harbour authorities' attention. This combined with increased understanding about the importance of seagrass and maerl as natural solutions to climate change and biodiversity loss has raised the issue further up the priority list for a number of harbours including Falmouth.

Falmouth Harbour owns and maintains over 600 deep water swinging moorings within the inner harbour. A number of these were found to have a localised impact on the Flushing Seagrass bed. In 2021 the harbour removed 11 swinging moorings from this area and set up a seagrass regeneration area[6]. However around 10 further moorings present in the area still have a localised impact on the seagrass.

Further removal of moorings is not financially viable without replacing these with another source of revenue so Falmouth Harbour would like to understand more about the potential of using Advanced Mooring Systems to be able to offer and charge for a mooring whilst not impacting important habitats below.

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[4] Latham, H., Sheehan, E., Foggo, A., Attrill, M., Hoskin, P. and Knowles, H. (2012). Fal and Helford Recreational Boating Study Chapter 1. Single block, sub-tidal, permanent moorings: Ecological impact on infaunal communities due to direct, physical disturbance from mooring infrastructure. Falmouth Harbour Commissioners, Falmouth, UK on behalf of the Fal and Helford Recreational Boating Study Project Partner

[5] Tevi-Advanced-Moorings-and-Seagrass-Report-compressed-1.pdf

[6] Seagrass Regeneration - Falmouth Harbour, Cornwall

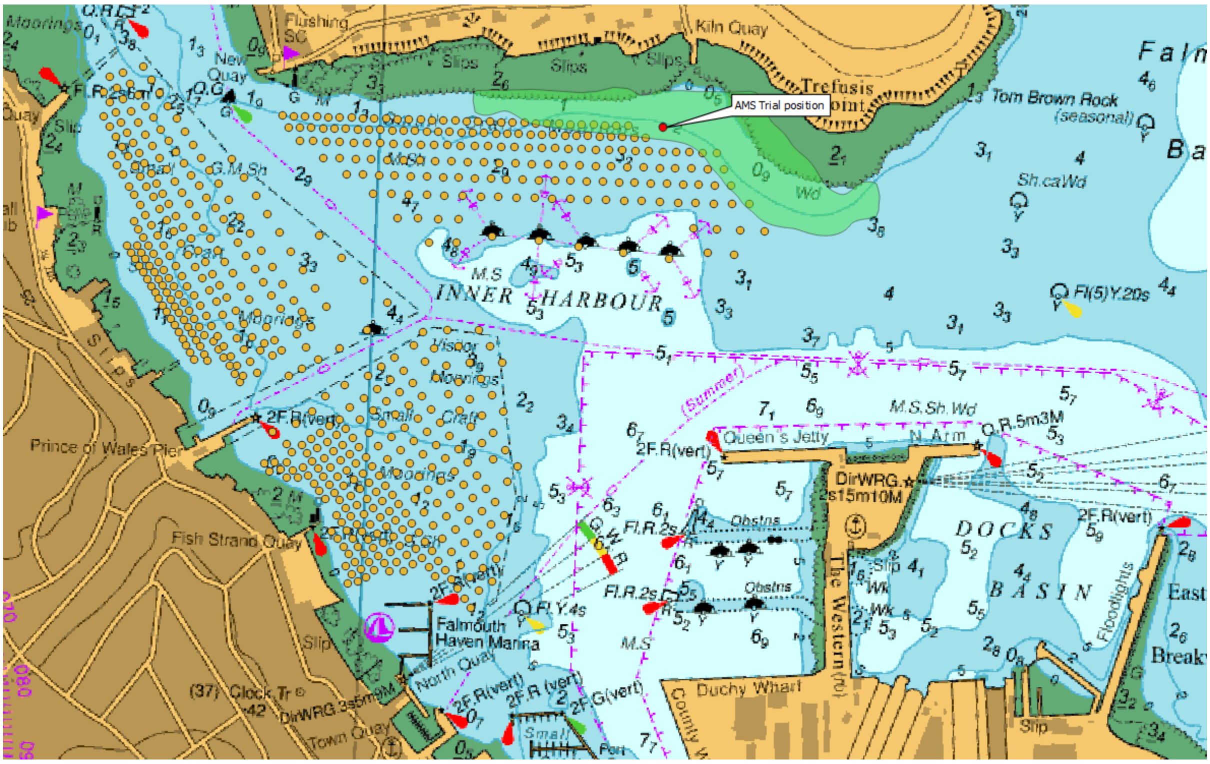


Fig 3. Showing moorings and seagrass areas in the inner harbour at Flushing © UKHO. Not for Navigation

Aims

There are no guidance materials currently available to harbour authorities wanting to implement AMS. This, perhaps prevents / delays adoption of this kind of mooring system. Understanding what works and what doesn't is essential for ensuring safe use of the harbour. Tevi contributed to this by commissioning Morek to model AMS behaviour in Cornish Harbours[7]. It is this study's hope to build on this work and develop the model further by feeding in real world findings from a practical trial.

The aims for this study are therefore:

- Design a stirling mooring system suitable to hold a typical leisure vessel for Falmouth waters made from materials already in use and readily deployable using current harbour infrastructure.
- Make up and deploy designed mooring and attach a vessel
- Monitor performance of mooring to understand how the designed mooring performs & feedback into the model
- Share learning with other ports and harbours to further understanding and development of similar systems.

[7] https://tevi.co.uk/wp-content/uploads/2021/03/Tevi-Modelling-of-Advanced-Moorings-in-Cornish-Harbours.pdf

Design of the AMS

Kick off

Design requirements were agreed with Morek as follows:

- Stirling style AMS
- Focus on use of existing block sizes and chain gauges already in use within the moorings maintained by the harbour
- Minimal contact of the mooring with the seabed
- To be designed for a 6.7m vessel (the dimensions of an end of life boat in the possession of Falmouth Harbour at the time of the trial)
- Reducing navigational hazards associated with typical Stirling designed moorings

Design

Morek commenced the design of the mooring by assessing 250 permutations of design using chain & block sizes already in use within the harbour using software designed to model the mooring design. The sensitivity study aimed to optimise the AMS spread to perform as well as, or better than the existing traditional block and chain moorings currently in use.

To perform the sensitivity study, three top-level variables were chosen:

1. Trawl buoyancy
2. Chain gauge
3. Number of trawls

Trawl buoyancy spacing has been determined by calculating the length of chain required for neutral buoyancy for each trawl size and chain gauge.

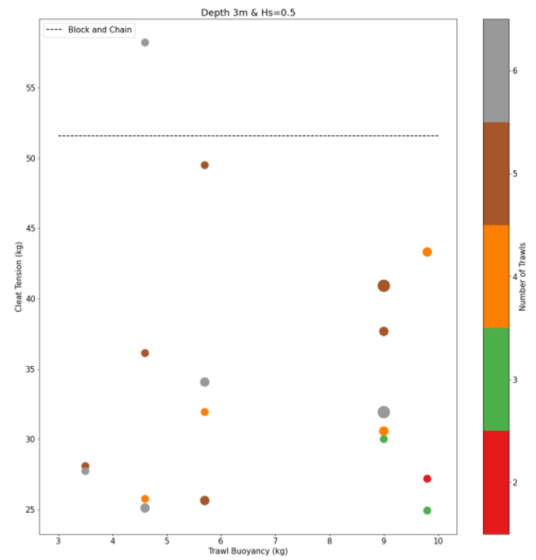
1st sensitivity study

A number of designs were trialled in the model. The 1st sensitivity study analysed 250 permutations with differing:

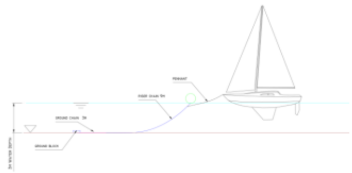
- Trawl float sizes
- No. of trawl floats along the chain
- Differing chain gauges
- Water depths representing high and low tide in the agreed test site area.

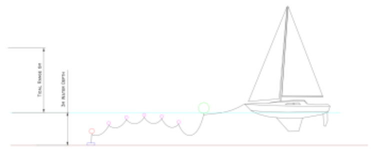
The trials measured

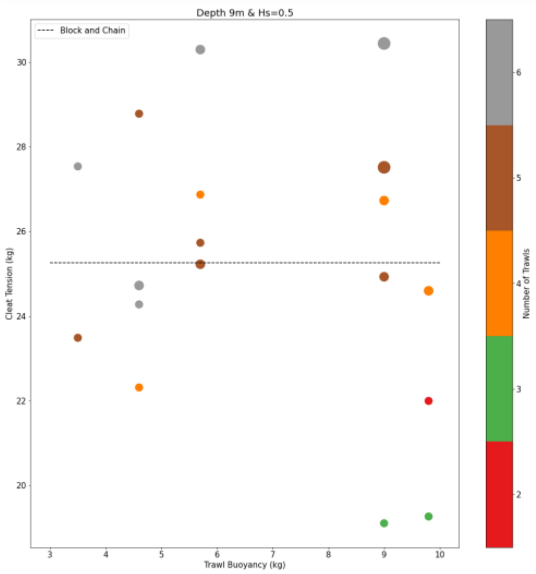
- Cleat tension at both depths (3 and 9m)
- Vessel excursion i.e. distance between the vessel and the mooring block



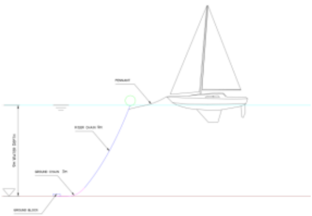
- This plot shows maximum tension at the boat's cleat for each AMS
- For a depth of 3m, 94.4% of the AMS's performed better than the Block and Chain system
- The bubble size represents chain gauge, for these systems the bubble ranges from 10mm to 16mm (all 19mm and 25mm chains failed at the PI check)

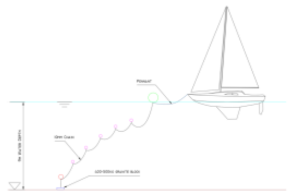


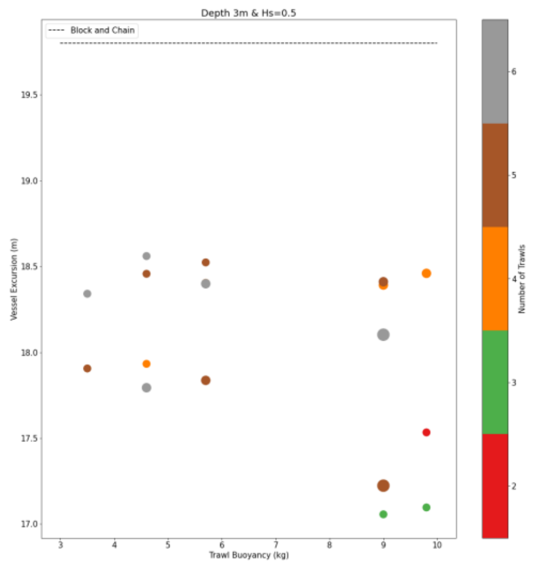




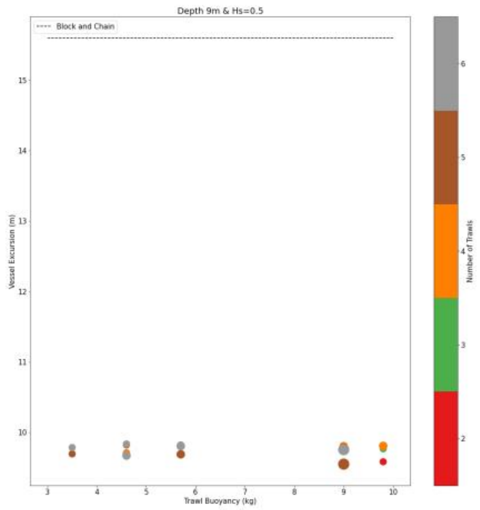
- For a depth of 9m, 55.5% of the AMS's performed better than the Block and Chain system
- From these graphs we can also begin to see that fewer trawls, higher buoyancy and smaller chain garage seems to be performing the best







- This plot shows maximum vessel excursion at the stern of a 5.1m boat for each AMS
- Here we can see that 100% the AMS's performed better than the Block and Chain system with respect to maximum vessel excursion



- For a depth of 9m, 100% of the AMS's performed better than the Block and Chain system
- A large difference between vessel excursion can be seen when on an AMS compared with the Block and Chain

2nd sensitivity study

15 AMS spreads were selected for the second sensitivity study based on their ability to perform better than the block and chain. This means each AMS selected had smaller vessel excursions and cleat tensions than the baseline block and chain for both water depths.

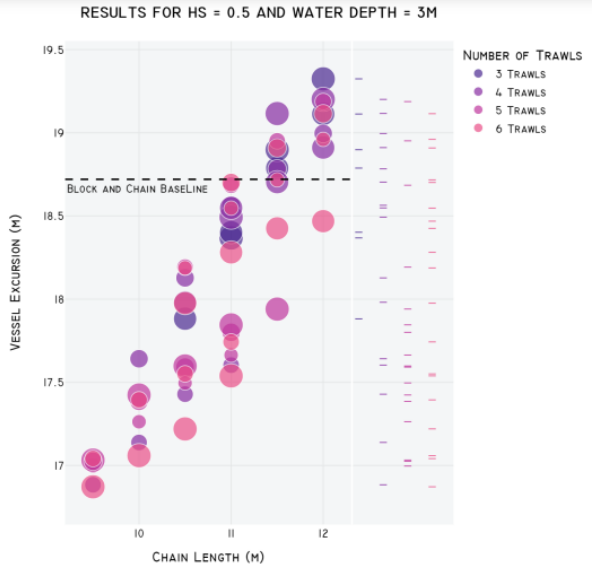
The 2nd sensitivity study were focused on varying total chain length. The purpose of this round is to optimise the AMS configurations with respect to maximum excursion by varying total chain length.

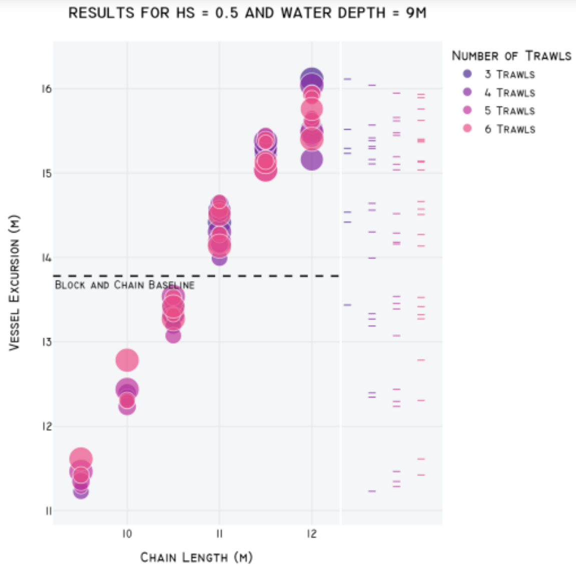
What's changing	What are the constants
5 different chain lengths	1st trawl size
15 AMS spreads	Vessel size
2 Water depths (3m and 9m)	Environmental conditions

The trials measured:

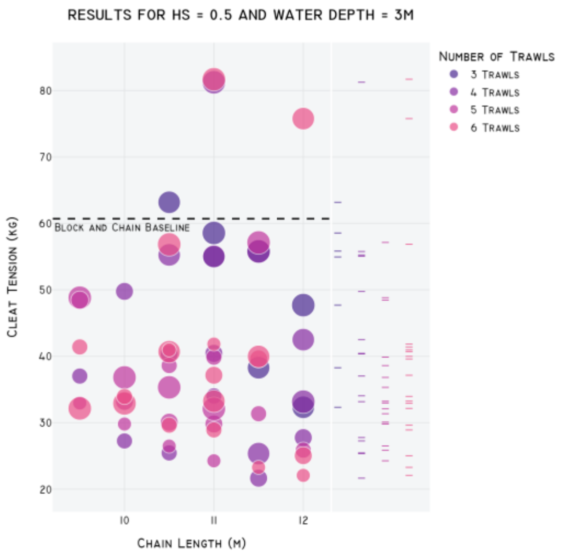
- Vessel excursion i.e. distance between the vessel and the mooring block
- Cleat tension at both depths (3 and 9m)
- Cleat tension against vessel excursion at both depths

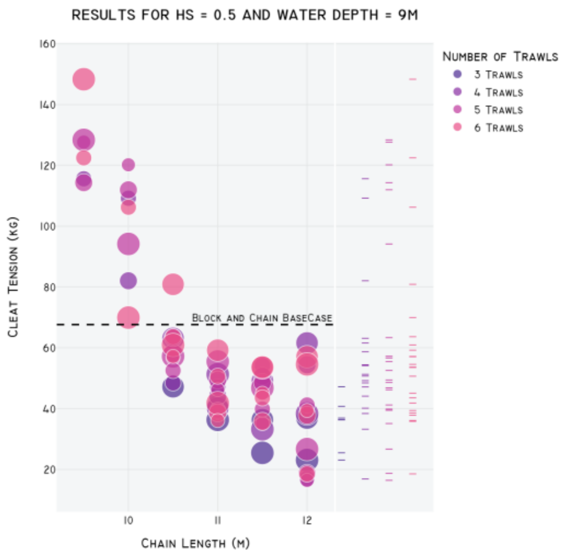
Vessel excursion



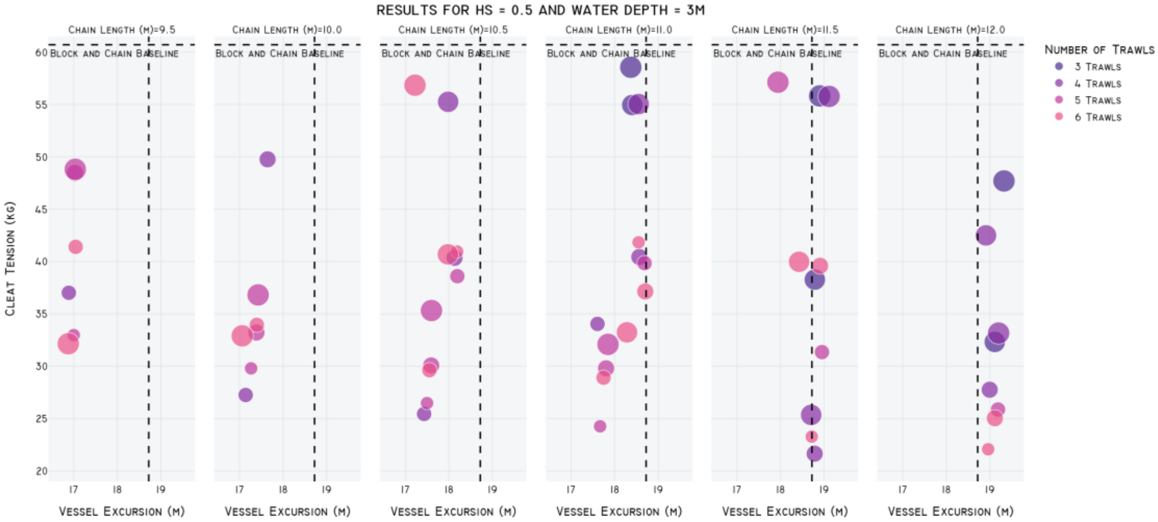


Cleat tensions

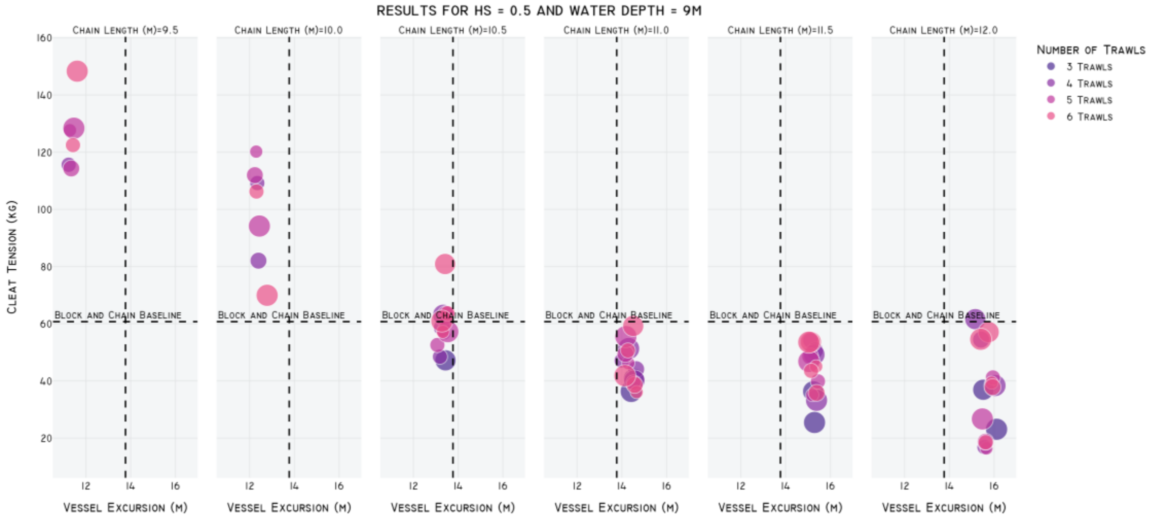




Cleat tension against vessel excursion at depth 3m



Cleat tension against vessel excursion at depth 9m



This allowed some design variations that didn't meet desired outcomes to be removed from further consideration. The lower values for cleat tension and vessel excursion, the higher the AMS scored in the decision matrix. This resulted in 3 AMS to be analysed in a final round.

3rd sensitivity study

The 3rd sensitivity study explored the effect of varying environmental conditions on maximum cleat tension and vessel excursion for the 3 best performing AMS.

What's changing	**What are the constants**
6 x Environmental conditions	Vessel size
3 x AMS spreads	
2 x water depths	

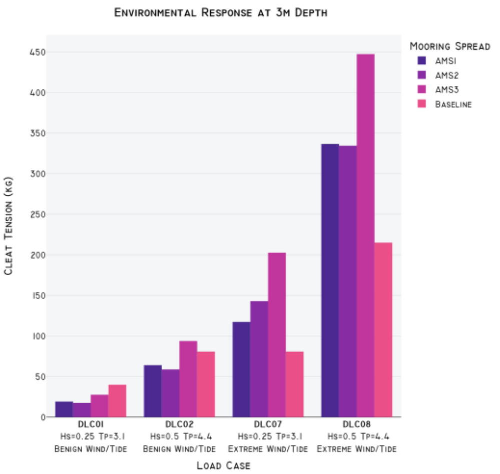
Environmental conditions – Wave height

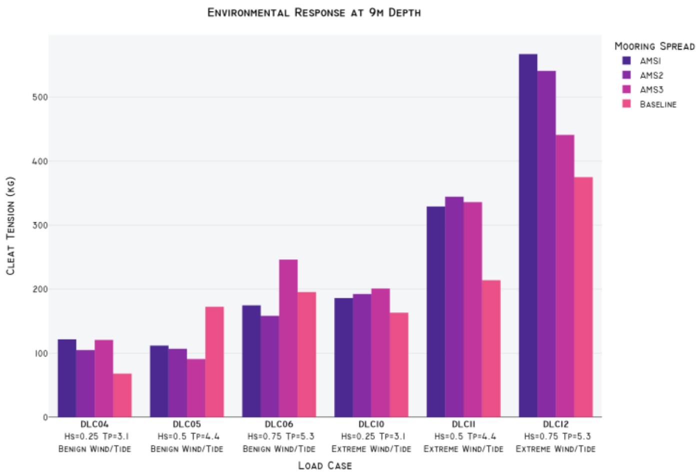
The following load cases were used as these represent a broad spectrum of seasonal environmental conditions.

Load Case	CD (m)	Tidal Elevation (m)	Wave Tp (s)	Wave Hs (m)	Gamma (-)	Current Speed (m/s)	Wind Speed (m/s)
DLC01	3	0	3.1	0.25	1.0	0.1	5.0
DLC02	3	0	4.4	0.50	1.0	0.1	5.0
DLC04	3	6	3.1	0.25	1.0	0.1	5.0
DLC05	3	6	4.4	0.50	1.0	0.1	5.0
DLC06	3	6	5.4	0.75	1.0	0.1	5.0
DLC07	3	0	3.1	0.25	1.0	0.5	18.5
DLC08	3	0	4.4	0.50	1.0	0.5	18.5
DLC10	3	6	3.1	0.25	1.0	0.5	18.5
DLC11	3	6	4.4	0.50	1.0	0.5	18.5
DLC12	3	6	5.4	0.75	1.0	0.5	18.5

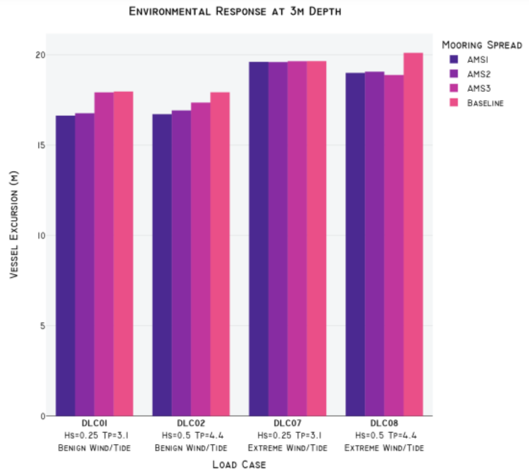
Basic wave theory dictates that cases with a Hs of 0.75m at a depth of 3m would cause a breaking wave. For this reason, DLC03 and DLC09 have not been included.

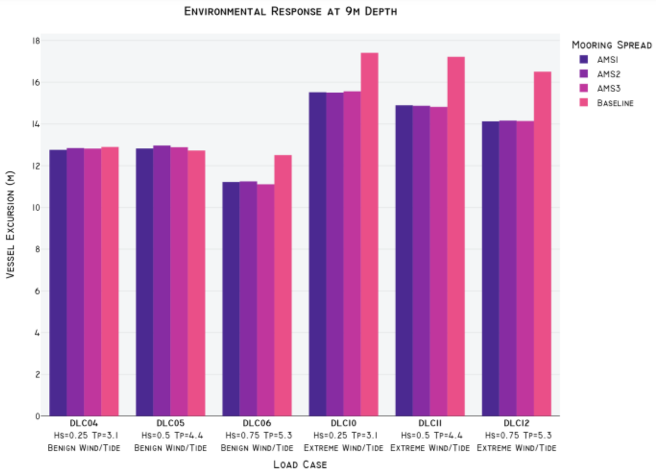
Round 3 Wave height - Cleat tensions





Round 3 Wave height - Vessel Excursions





Environmental Conditions – Wind sensitivity

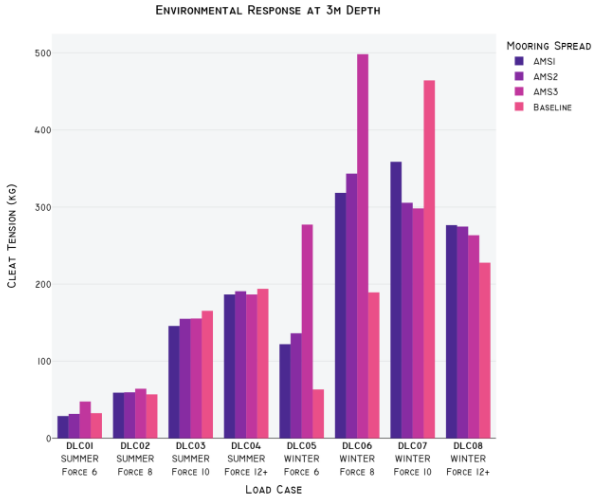
For both summer and winter conditions, wind speeds are increased from force 6 to force 12+.

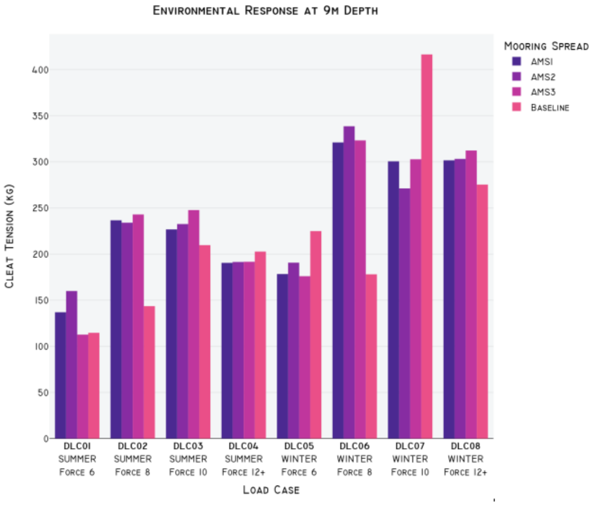
Load Case	CD (m)	Tidal Elevation (m)	Wave Tp (s)	Wave Hs (m)	Gamma (-)	Current Speed (m/s)	Wind Speed (m/s)
DLC01	3	0	3.1	0.25	1.0	0.1	12
DLC02	3	0	3.1	0.25	1.0	0.1	19
DLC03	3	0	3.1	0.25	1.0	0.1	27
DLC04	3	0	3.1	0.25	1.0	0.1	42.5
DLC05	3	0	4.4	0.50	1.0	0.5	12
DLC06	3	0	4.4	0.50	1.0	0.5	19
DLC07	3	0	4.4	0.50	1.0	0.5	27
DLC08	3	0	4.4	0.50	1.0	0.5	42.5

Hs = 0.25m and current 0.1m/s is seen as a summer condition.

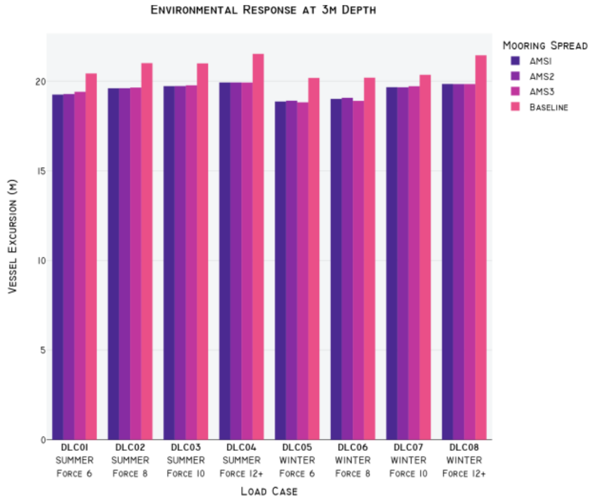
Hs = 0.5m and current 0.5m /s is seen as a winter condition.

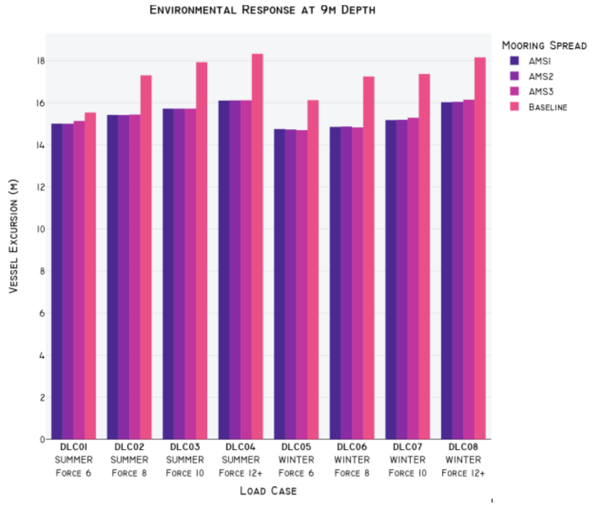
Round 3 Wind force – Cleat tensions





Round 3 Wind force – vessel excursion





Sensitivity study results

In the previous environmental study, the variables included a larger range of significant wave heights but only two wind speeds. This study includes two lower significant wave heights but a far larger range of wind speeds.

This would more likely represent conditions in Falmouth Harbour. The wind sensitivity study above that shows that maximum cleat tension and vessel excursion for each AMS is still below the maximums seen in the first environmental conditions study.

Large deviations in maximum cleat tensions within load groups can be seen in the plots above. In some mooring spreads, the maximum cleat tension is seen to be higher in lower wind condition cases than in high wind condition cases. This is due to excitation of resonant frequencies of the coupled system. The influence of wind as a static force varies with speed.

Three mooring spread options were provided as all providing the same performance. Falmouth Harbour chose the AMS spread – AMS 1. The reason for this choice was because it used the least number of trawl floats that were positioned lower down the chain in the hope that this would reduce the number of floats close to the surface and reduce the navigational risk associated with floats and chain close to the water's surface.

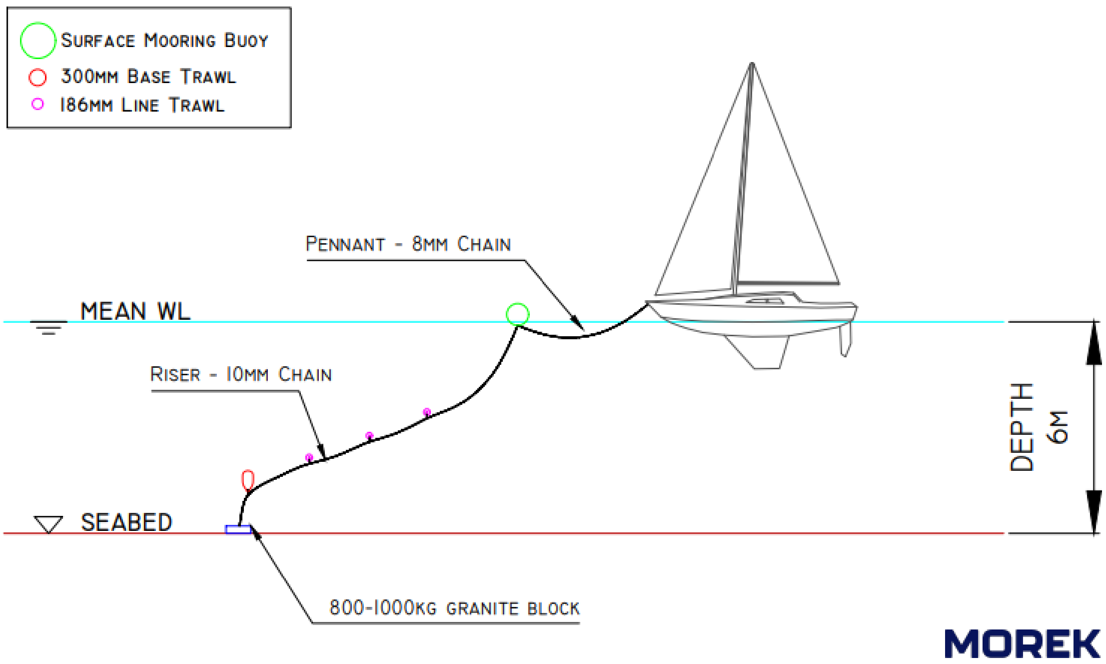


Fig 4. Chosen AMS design

Make up and deployment

The mooring was made up by the harbour maintenance team using the following materials:

- 1 tonne granite block with eyebolt
- Shackle onto 10.5m of 10mm chain
- A total of 4 trawl floats were placed along the length of chain at specific intervals defined by trawl size and chain intervals
- Surface marker buoy
- 3m chain pendant

The mooring was deployed on 27th July 2022 from Aberfal into a scour patch left by a previous traditional mooring.

Monitoring performance during the trial

Measuring cleat forces

During the trial we attempted to measure the maximum cleat forces that would be exerted by the mooring to the vessel. This was completed using Aberfal, (Falmouth Harbour's mooring maintenance vessel), and a load cell to measure the maximum force exerted through the mooring.

The maximum tension before block drags was calculated using a simplified method and therefore should be taken as reference only. Given load cells are accurate to +-1% collecting data at low tensions during the start of the pull test was limited.

The stiffness curve produced from OrcaFlex data is much steeper than that of collected data on site, the maximum excursion looked plausible at around 11.5-12m (measured from block to end of pendant on *cleat side).

The collected results do show a relationship between tension and excursion, with tension increasing with excursion. This increase does seem to be non-linear which indicates increasing stiffness as more load is applied.

*NOTE: As many errors were compounded into the collected data, the level of confidence in these results, thus ability to make meaningful interpretations and predictions is very limited.

Some of the likely errors have been highlighted above, however quantifying these and adjusting the data to correct for these errors is very difficult and greatly reduces confidence in the results. More accurate load cells are needed to measure smaller tensions present during the first stages of the pull test, this along with desired environmental conditions would greatly improve results.

This is not something we were able to provide in this trial but should a further trial be undertaken this requirement would be included in the trial set up.

Measuring excursion

During the test pull GPS was used to plot the position of the vessel against the known position of the block. This allowed the distance from the block to the vessel (excursion) to be measured.

The maximum excursion measured was not measured accurately enough to ensure a meaningful result. The data recorded however broadly concurred with that predicted by the OrcaFlex model.

During the test pull there was some adverse conditions which may mean the measurements weren't completely accurate and reliable however we are fairly confident that the findings are correct.

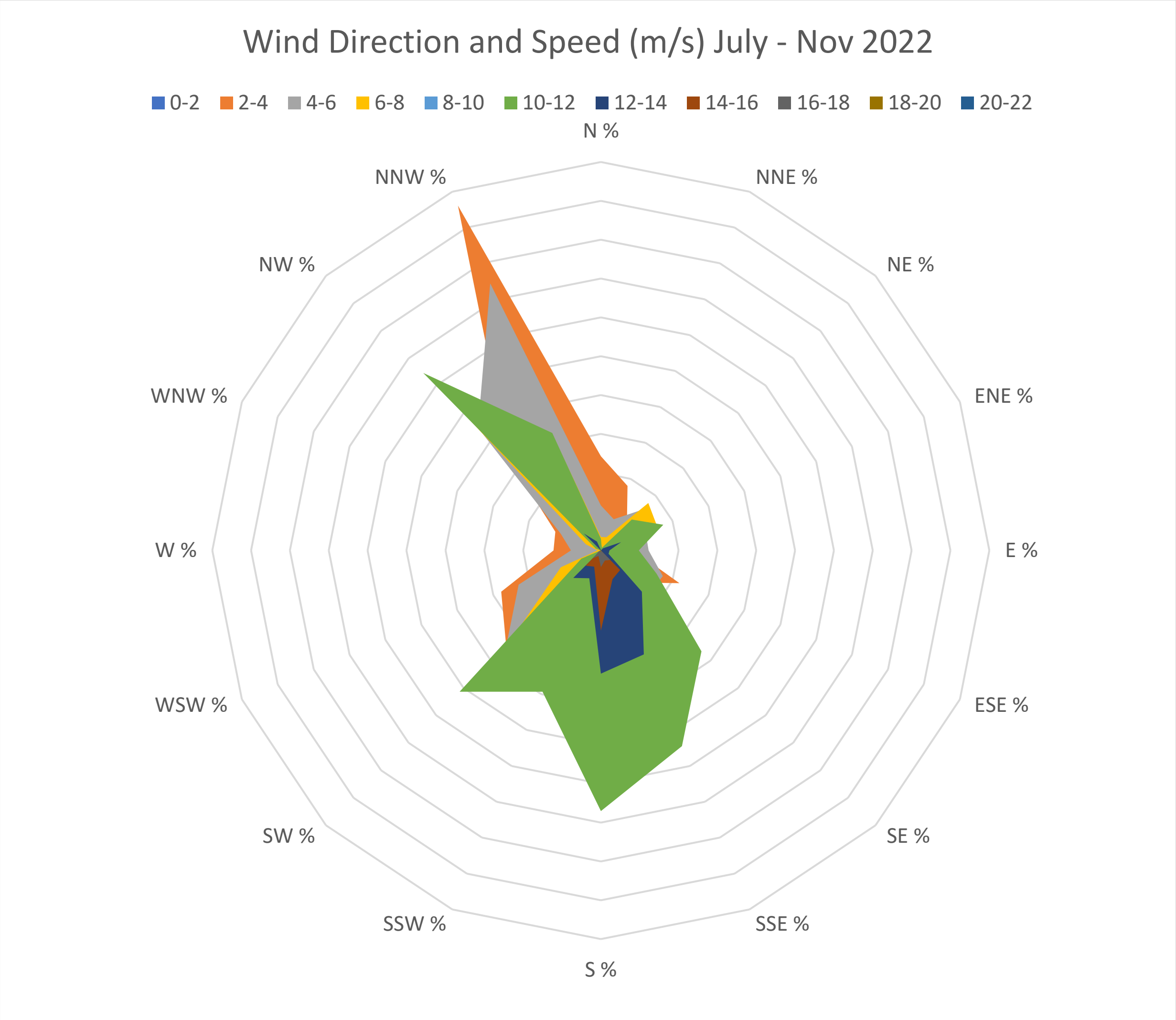
Measuring effectiveness of AMS to remove impact from the seabed.

The seabed within the known excursion of the vessel was surveyed and no visible signs of scour were found. This will hopefully be verified soon with the repeat of the seagrass regenerations measurement work around the seagrass scours.

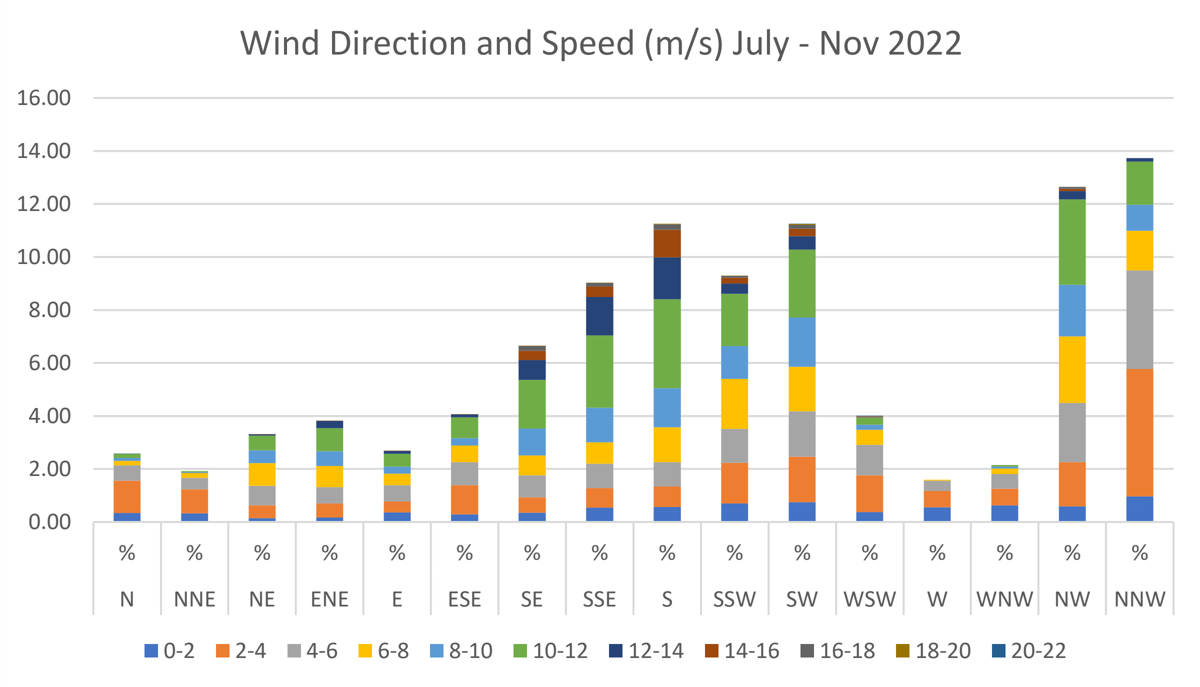
Weather conditions

The AMS was deployed from 27th July to 5th November. Over the deployment period the Black Rock weather buoy was used to monitor the weather. The maximum conditions experienced during the deployment period were as follows:

Wind data from Black Rock weather monitoring station[8] has been reviewed and summarised below. During the deployment period weather conditions were varied up to a maximum wind speed of 22 metres per second (force 9).



[8] https://www.falmouthharbour.co.uk/wind-speed/



The mooring was able to withstand some significant winds from varying directions. Flushing moorings are particularly sensitive to East or South Easterly wind so particularly relevant are the instances where Beaufort scale force 8 SE and E winds were experienced.

This demonstrates the designed AMS was able to withstand the forces and maintain the mooring within these conditions.

Winter weather and extreme weather events similar to that experienced within Falmouth on 20th October 2021 where NW winds of up to 80 knots were measured within the inner harbour will not be tested. Initially, at least, any AMS deployed will likely be restricted to summer months only.

Tidal range

The highest high tide during deployment was 5.5m and the lowest 0.1m on September 12th 2022.

Discussion

This section of the document will review the initial aims of the project to discuss findings. Each aim is discussed separately below

Design

Aim: Design a stirling mooring system suitable to hold a typical leisure vessel for Falmouth waters made from materials already in use and readily deployable using current harbour infrastructure.

This aim was met in full with the design proving it could hold the vessel it was designed for in place during the trial period. Particular discussion points identified during the trial around navigation, increased mooring costs, increased use of plastics and maintenance and these have been discussed below.

Navigational safety

Concern has been expressed from the harbour master team relating to the presence of the trawl floats and chain close to the surface of the water particularly at low tide as this could represent a hazard to navigation for vessels moving over the area of chain.

Over the three months of deployment at Flushing no incident reports have been received from harbour users. When the AMS was deployed a Harbour Notice was communicated to harbour users advising of the potential hazard[9].

To understand the depth at low tide, the distance between the trawl floats and the surface of the water was measured. The measurements at low tide for each float were around 50cm below the water line. This would represent a hazard to keel sail boats (needing 1.5m – 2m draft) and also to vessels with inboard or outboard engines navigating over the floats and chain.

Further work is required to understand whether the floats could be reconfigured / reduced in number to ensure a depth, below the waterline, of at least 1.5m is maintained for all floats and chain at all tides or some other potential solution to this issue whilst fulfilling the AMS purpose to lift the chain off the seabed.

Comparison of costs of traditional mooring with that of AMS

The design of this AMS resulted in an increased cost of £150.00 per mooring. This was due to a required increase in block size, compared to that used for a traditional mooring for the same size of vessel and additional purchase of 5 trawl floats to achieve the required buoyancy along the length of the chain.

[9] PORT-NOTICE-TO-MARINERS-1922-Advanced-Mooring-System-trial-at-Flushing.pdf (falmouthharbour.co.uk)

Increased use of plastics

The use of trawl floats along the length of the mooring chain to lift the chain off the seabed introduces more plastics as part of the mooring system. Unfortunately there is currently no solution available at the moment to reduce this.

However, there may be some solutions relating to implementation of circular economy thinking. Is there a recycled plastic product that can be used for this? This would be something Falmouth Harbour would hope to be able to explore further if an opportunity can be found.

Maintenance

The maintenance team serviced the mooring in August 2022 and removed it completely in February 2023.

There are additional requirements when maintaining this mooring as the floats can catch and cause issues when pulling the mooring over the back if the vessel. These issues will be considered as this will add time to the maintenance of moorings. This is ok when dealing with a small number as long as this is adequately risk assessed but may cause an issue if more moorings were added.

Monitor

Aim: Monitor performance of mooring to understand how the designed mooring performs & feedback into the model.

This was attempted but due to conditions the results could be improved. If future trials are possible further monitoring will be attempted as part of the trial.

Share

Aim: Share learning with other ports and harbours to further understanding and development of similar systems.

This report has been discussed with local partners attempting similar trials to communicate lessons learned and share knowledge. It will also be shared with the wider port and harbour community through Falmouth Harbour membership of Southwest Regional Ports Association (SWRPA) and British Ports Association (BPA).

Conclusions

The AMS performed well and kept the vessel in position, this validates the design and modelling software used by Morek. There are however operational issues that will have to be overcome to allow for further deployment and use of a similar design of AMS in other areas of the harbour.

It is hoped that this trial of an OrcaFlex modelled AMS demonstrates that the model can be trusted to find suitable designs although further design parameters such as chain and trawl float depth may need to be modelled to come up with a solution that does not compromise navigational safety.

Recommendations

- Further research or trials to understand how navigational risks associated with Stirling design of moorings can be overcome. Ensure these trials test the excursion and cleat forces through the mooring using accurate load cells and take account of lessons learned in this project.
- Consider trialling seaflex mooring or similar to understand whether these remove the navigational hazard and would perform as well or better than traditional and current AMS trial design.
- Research potential circular economy solutions for floats required to lift the chain.

References / further information

AMS impact report (including their benefits for seagrass, available solutions, and trials to date): https://tevi.co.uk/wp-content/uploads/2020/06/Tevi-Advanced-Moorings-and-Seagrass-Report-compressed-1.pdf

AMS behaviour modelling in Cornish Harbours: https://tevi.co.uk/wp-content/uploads/2021/03/Tevi-Modelling-of-Advanced-Moorings-in-Cornish-Harbours.pdf

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