Physical measurement of a slow drag of a drag embedment anchor during sea trials

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Abstract

Anchor drag during operation of offshore structures could significantly alter the initial load design characteristics of a mooring system. Hence an estimation of anchor positions during operation is essential to identify whether slow or abrupt anchor motion occurs and might require the redeployment of an anchor.

During storm conditions, monitoring of mooring tensions and structure motions at the South West Mooring Test Facility (SWMTF) revealed the slow drift motion of one anchor. This facility is a surface buoy with a three-legged, compliant mooring system designed to investigate mooring system behaviour for Marine Renewable Energy (MRE) devices. This paper presents i) some methods to identify the deployment anchor positions: numerical model, acoustics diver survey, and towed sonar ii) the analyses procedure, and estimations of slow drift anchor motion.

The findings indicate that one drag embedment anchor moved slowly during a moderate but prolonged and isolated storm, before embedding again. The work demonstrates that anchor position can be accurately monitored and that anchor motion is not necessarily due to excessive peak loads.

Keywords: Anchor drag, large scale experiments, mooring, marine renewable energy

1. Introduction

Mooring designs for oil and gas industry applications have been extensively developed. However, the needs of Marine Renewable Energy (MRE devices) in term of moorings are specific because of their installation locations and load and motion requirements. Installation and operation standards for MRE moorings have to be developed using sea trials, in order to understand the loads involved and to improve design and thus reliability and cost effectiveness.

The practical limitations to anchor positioning accuracy add considerable uncertainty to a mooring system deployment relative to the design and modelling of the system. Anchors are installed when environmental conditions are favourable. However, because of currents, moving installation vessel and variable embedment conditions, the anchors may not be deployed exactly where they are intended but in a restrained area near their target deployment position. Several methods have been investigated to estimate the anchor positions at the South Western Mooring Test Facility (SWMTF), a unique mooring load and response test facility.

This facility has been built to conduct long term sea trials for moorings of MRE devices. The aim of this paper is a) to compare different methods to estimate anchor position; b) to discuss based on data collected from September 2010 to September 2011 an unexpected slow anchor drift and to evaluate accuracy of motion tracking from top end.

2. Description of the South West Mooring Test Facility

The South West Mooring Test Facility (SWMTF) research is led by the mooring and hydrodynamic group at the University of Exeter, working with the Peninsula Research Institute for Marine Renewable Energy (PRIMaRE). This facility is installed in Falmouth Bay, Cornwall, UK, as shown in Fig. 1. The location was chosen to provide a location near a port and with wave conditions with a 1/3rd scale to the Wave Hub site. Based on Froude scaling law this allows investigation suitable for a device with lengths a third of those used for a full scale device, whilst viscous effects are not directly scalable.

Figure 1: South West Mooring Test Facility location

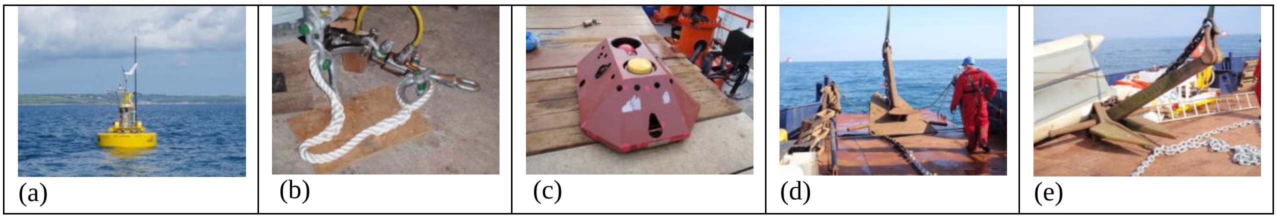


Figure2a-e: (a) Instrumented buoy, (b) A tri-axial(left) and an inline(right) loadcells, (c) ADCP and its frame, (d) Stevin anchor, (e) Danforth anchor

The facility is described in detail by Johanning [1] and in summary consists of:

- An instrumented buoy of 3250 kg and 2.9m float diameter (Fig. 2a), equipped with a DGPS (with a resolution of +/-1cm for the latitude and longitude and +/-2cm for the elevation) and six-degree of motion system, conventional in-line (axial) loadcells and specifically designed tri-axial loadcells with a 1kg resolution (Fig. 2b), and environmental instruments monitoring wind, salinity, etc. Data were recorded at 10 Hz for GPS and at 20Hz for loadcells. A three leg catenary mooring configuration was used (Fig. 4), where each leg was made of several elements, as shown in Fig. 3, and with the anchor described in Table 1.

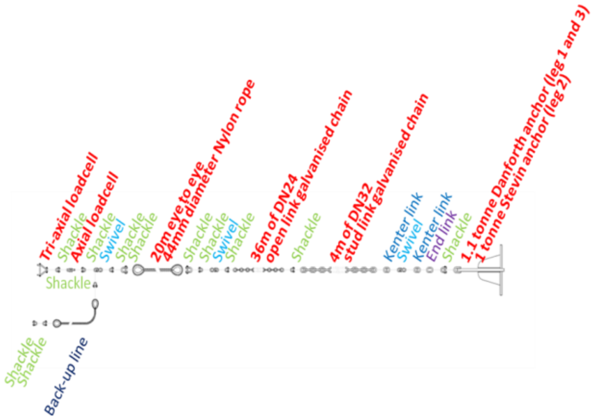


Figure 3: Components of a limb at South West Mooring Test Facility

Anchor 1	Anchor 2	Anchor 3
1.1 tonne Danforth	1 tonne Stevin	1.1 tonne Danforth
180kN holding capacity	219kN holding capacity	180kN holding capacity

Table 1: Anchor type and holding capacity at the South West Mooring Test Facility

- An Acoustic Current Doppler Profiler (ADCP) (Fig. 2c) to record wave and current data at 2Hz [2]. The ADCP is installed 25m towards the SE direction in respect to buoy equilibrium position (Fig. 4).

The mechanical elements of the system were designed based on a 1-year return period seastate with a significant wave height Hs of 3.5m. A design load of 7 tonnes (~69kN) was derived from a fully dynamic analysis in OrcaFlex [3]. Additionally, a target Factor Of Safety (FOS) of 3 was applied for the structural design to account for uncertainties. However, due to availability of anchors, 1,1 tonne Danfort Bruce anchor (Fig. 2d) and 1.0 tonne Stevin anchor (Fig. 2e) have respectively a slightly different FOS than the target one, because of the limited availability of anchors on the market. The anchors holding capacity was obtained from Fig. 5 [4,5].The FOS of anchor 1 and 3 is 2.61 and the FOS of anchor 2 is 3.17.

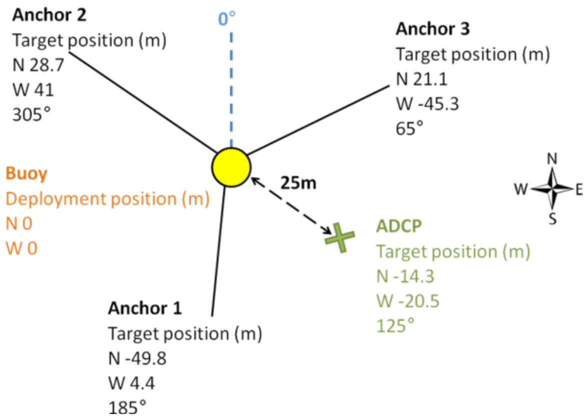


Figure4: South West Mooring Test Facility configuration

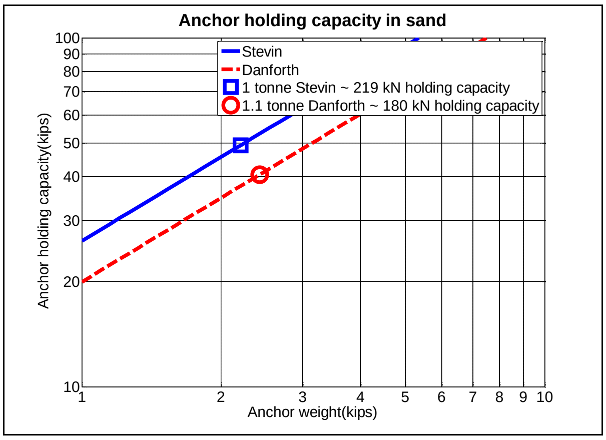


Figure 5: Anchor holding capacity in sand [4,5]
1kips~454kg~4.45kN

The position of the buoy is 50°04.75'N, 05°02.85'W, which was set as the point of origin (0,0) m. The targeted anchor positions were calculated based on an equal spread of 120degree and a horizontal radius of 50m. The buoy, anchor positions and that of the ADCP are summarised in Table 2 in term of latitude and longitude and in relation to the buoy origin in meter.

	In degree	In meter (N,W)
Buoy deployment position	50°04.75'N 05°02.85'W	(0,0)
ADCP position	50° 4.7423' N 05° 2.8328' W	(-14.3,-20.5)
Anchor 1 position	50° 4.7231' N 05° 2.8537' W	(-49.8,4.4)
Anchor 2 position	50° 4.7655' N 05° 2.8843' W	(28.7,41)
Anchor 3 position	50° 4.7614' N 05° 2.8121' W	(21.1,-45.3)

Table 2: Locations of the different elements of the South West Mooring Test Facility

3. Estimation of anchor position

METHODOLOGY

Several methods have been implemented investigating the anchor positions.

a)Numerical method: a static analysis has been conducted with Orcaflex: a model of a mooring limb has been built to identify the variation of static tension characteristics for different horizontal buoy positions and tide elevations. The tide elevations chosen were between the Lowest Astronomical Tide (LAT) of 27 meter and the Highest Astronomical Tide (HAT) of 32.4m. The anchor touchdown points are spread on a circle with a radius of 50m. An error of +/-5 m between the centre of the circle and the buoy position is allowed. The result of this analysis is shown in Fig. 6.

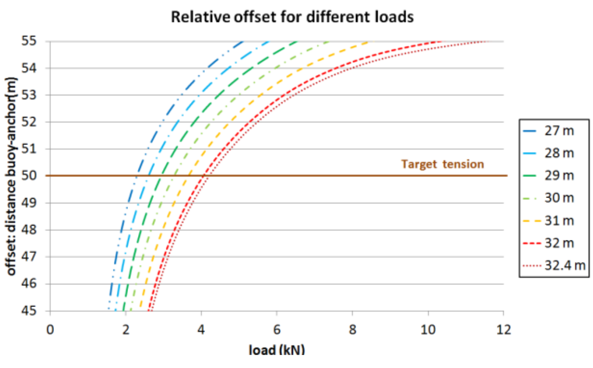


Figure 6: Calculated horizontal distance (offset) between the buoy and an anchor point for different mooring loads and water depth

The latitude and longitude measurements from the DGPS, the loads measurements from the axial and tri-axial loadcells and the depth measurements from the ADCP are used to derive the horizontal distance between the buoy and each anchor, using the results of the analysis presented in Fig. 6. By repeating this methodology for different time steps as indicated in Fig. 7, a horizontal time history was derived and plotted in Fig. 8 for 24 hours of a calm day. Anchor 2 was not installed at its target position but within acceptable limit due to operational error. Consequently, the calculation for anchor 2 was based on a range of different anchor positions. Fig. 8 shows that the distance between the anchor and the buoy can be predicted with an accuracy of 1m using this method. However, this method does not give the exact anchor position of the anchor but a range of possible value on an arc of circle. This method can easily be used, for example to double check another method.

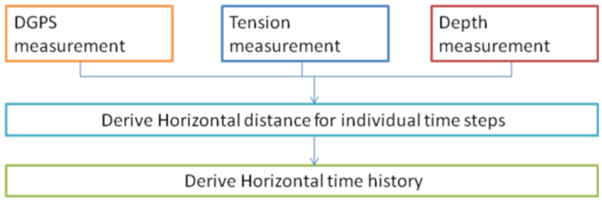


Figure 7: Methodology of the numerical method to estimate the anchor position

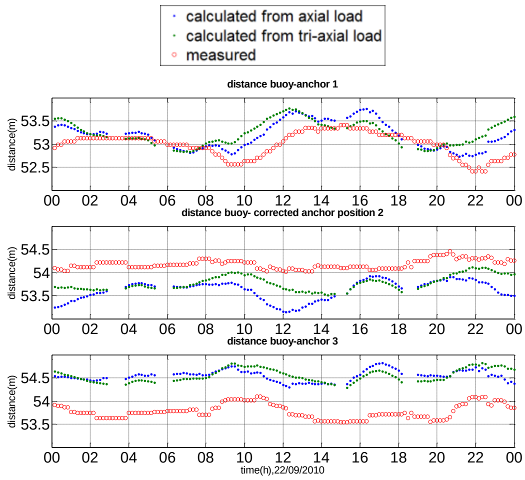


Figure 8: Comparison of calculated offset from the mooring loads and measured offset using target anchor position and buoy position

b)Acoustics diver survey method: An acoustic system, called Easytrack Ultra-Short BaseLine (USBL) positioning system from Applied Acoustics Engineering Ltd, has been used with a DGPS input from the survey vessel. This system is detailed by Parish [6]. Divers attached a beacon to the shackle of each anchor. The signal from the beacons was received on the boat, and several bursts of data were taken. The results of this survey are shown in Fig. 9. Some spurious data were removed before calculating an average anchor position. The mean value from these bursts was compared with the deployed anchor position. The acoustics method gives rather accurate results but is expensive because of the use of divers. This method could be improved by reducing magnetic interferences.

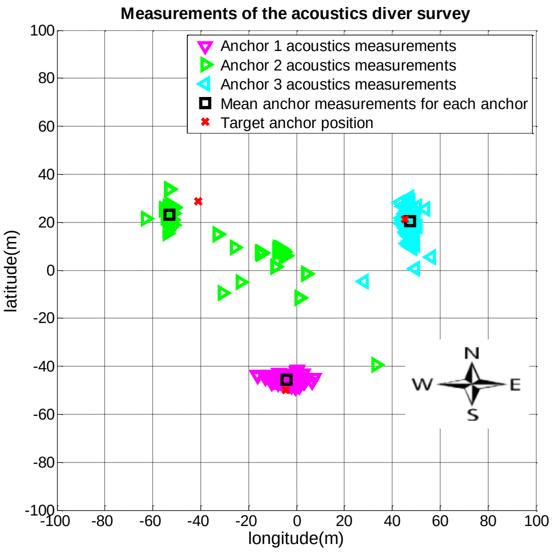


Figure 9: Summary of the diver measurements

c)Towed sonar method: a boat tows a sidescan towfish equipped with high resolution sonar operating at 675kHz over the anchor and mooring chains. The sonar establishes a map of the seabed features, based on the boat position and the relative towfish position to the boat.

Chains and scars left by chains uplift or drag can be detected on the map shown in Fig. 10. The anchors are assumed to be at the end of the scars. It should be noted that two possible values were available for anchor 1, because two scars which could correspond to the termination of a chain were detected by the sonar at this location.

This method gives fairly accurate values, which can be improved by knowing with more accuracy the position of the towfish. This method also allows investigating the whole seabed sedimentation at the mooring location.

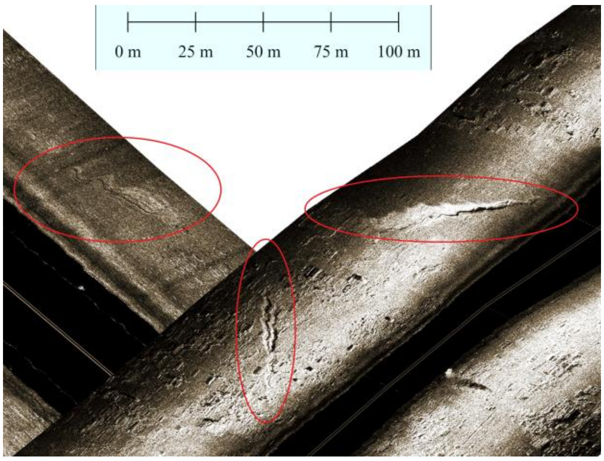


Figure 10: Seabed map obtained with a towed sonar (courtesy of Neill Wood)

DISCUSSION

The results of the different anchor estimation methods have been plotted in Fig. 11. It should be noted that the target anchor positions may have not been attained.

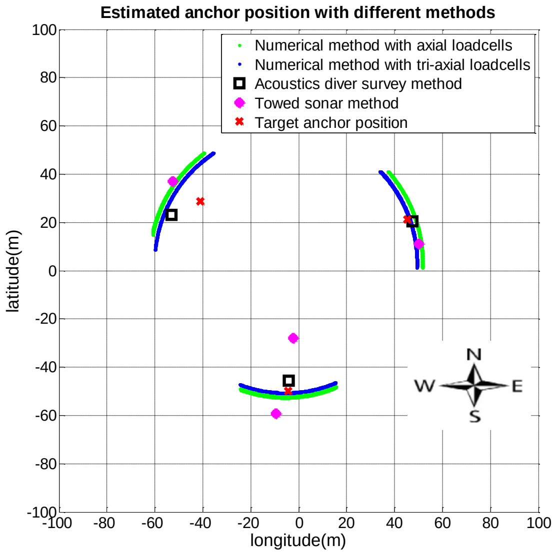


Figure 11: Estimated anchor position with different methods

Each method could fairly estimate the anchor position, except the numerical model which just gives a possible range of values. These methods could be combined to gain more confidence in the anchor position. From these results, it can be concluded that anchor 2 was deployed at approximately 10m from its target position. The other anchors seem to have achieved their target positions. The accuracy of the different methods is detailed in Table 3.

Method	**Accuracy**
a)Numerical method	1m for the distance between the buoy and the anchor
b)Acoustics diver survey method	10m for the anchor position
d)Towed sonar method	15m for the anchor position

Table 3: Accuracy of the different estimation methods

Line pulling is another method to estimate anchor position which also provides accurate results, as describe by Johanning[7,8].

4. Observation of a slow anchor drag and estimation of the new anchor position

A summary of the loads and positions data recorded at SWMTF are plotted in Fig. 12. A significant event can be observed: at the end of January, the mean loads are suddenly decreasing to attain permanently a new pre-tension in the mooring system and the buoy is moving to a new mean equilibrium position. This is the result of anchor 3 drag. Fig. 13 summarises the statistical wave climate parameters during the year and Table 4 during the day of this event. This drag event occurred during a storm of medium amplitude, heading in a NW direction. This is the first storm of this kind of amplitude since three storms with similar amplitude at the end of December 2010.

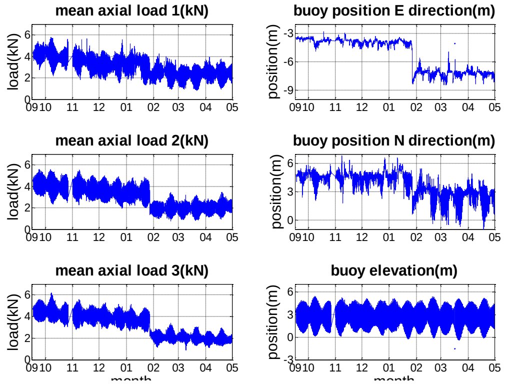


Figure 12: Summary of mean load and position at SWMTF from September 2010 to May 2011. A black-out occurred at end of October. Tide variations can be observed on mean loads and position.

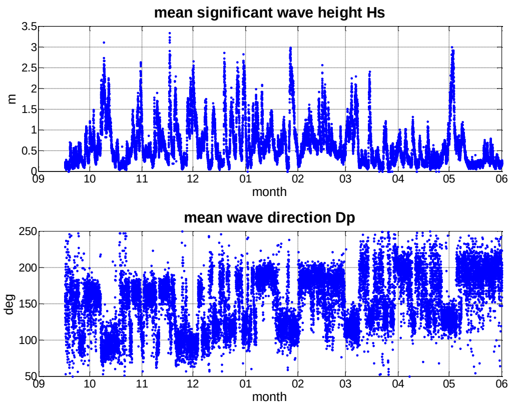


Figure 13: Summary of the environmental data at SWMTF from September 2010 to May 2011.

A closer look at the time series of loads and positions during this day is displayed in Fig. 14a. Data show high peak loads with a maximum load of 42kN on line 3.

The event can be divided in three steps:

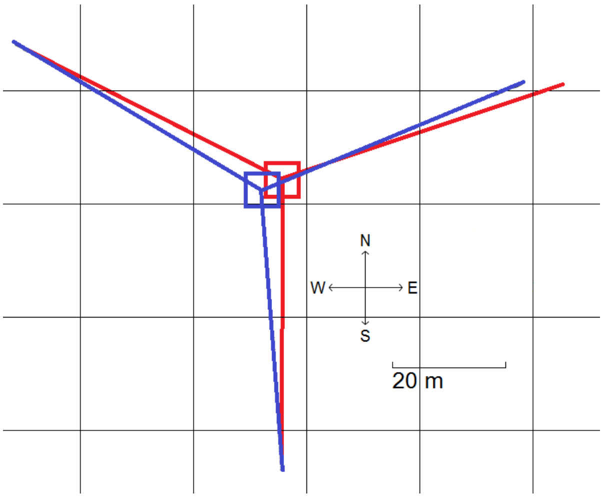
- Anchor break-out (Fig. 14b): A group of waves with a maximum wave height of 4.1 m created a large buoy motion with amplitude of 10.1m in the West direction and 1.7m in the South direction. This led to a peakload of 37kN on line 3, which triggered the anchor shift. The mean average position of the buoy is starting to change after this peakload.
- Anchor slow drag: The anchor position was slowly changing during 70 minutes.
- Anchor re-embedment (Fig. 14c): A group of waves induced a large motion of the buoy of 9.4m in the westerly direction and led to a peakload of 36kN on line 3. It suddenly shifted the anchor and re-embedded it. After this peakload, the mean buoy position attained its final value.

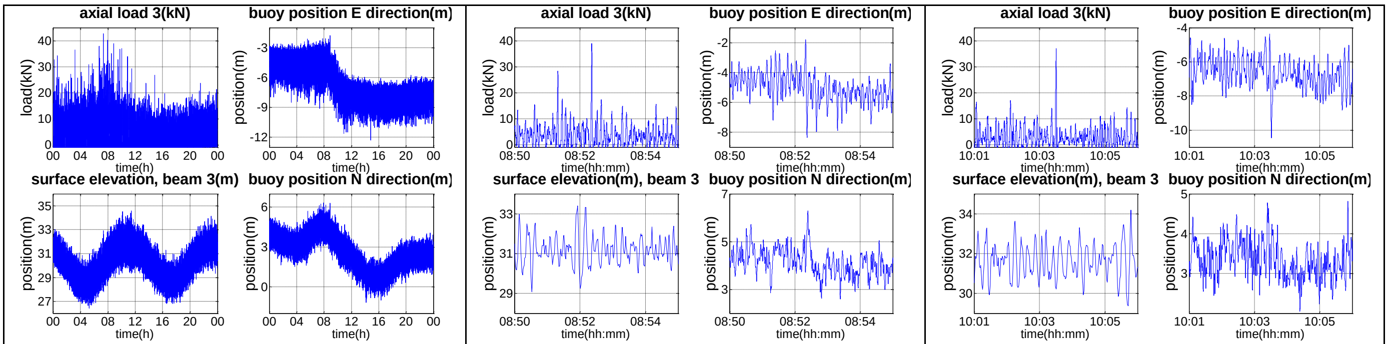
The new mean buoy position is 3.5m west and 1.5m south of the initial one. This means, according to an Orcaflex model, that anchor 3 shifted by approximately 7m, mainly in a westerly direction as shown in Fig. 15.

Summary 27/01/11, based on calculation for each ADCP sample (~17min)	
Mean significant wave height Hs	2.4m
Max significant wave height Hs	3m
Mean peak period Tp	7.3s
Max peak period Tp	7.7s
Mean wave direction Dp (0°is North, 90° is East)	122°

Table 4: Summary of environment on the 27/01/11

Figure 15: Static Orcaflex model before (red) and after (blue) anchor drag





(a)Overall anchor drag during the day	(b)Anchor break out	(c)Anchor re-embedment

Figure 14a-c: Anchor drag

(a)Anchor 1	(b)Anchor 2	(c)Anchor 3

Figure 16a-c Picture taken by a ROV of the different anchors of the South West Mooring Test Facility mooring system (courtesy of Neill Wood)

A further proof of anchor 3 movement is shown in Fig. 16a-c. A Remotely Operated underwater Vehicle (ROV) was sent to monitor the mooring line conditions and anchor embedment. The position of the ROV is deduced from its orientation and from the layout of chains. The results are as follow:

- Anchor 1(Fig. 16a) is surrounded by a local rocky seabed. That also explains why this anchor was difficult to install.
- Anchor 2(Fig. 16b) was correctly embedded. Several holes in the sediment caused by marine species are evident around the anchor which means the seabed has not been disturbed recently.
- Anchor 3(Fig. 16c) recently moved. The lack of holes in the close vicinity of the anchor shows that the seabed has recently been disturbed and marine life has not yet recreated holes

5. Conclusion

This paper has shown an example of the results that the South West Mooring Test Facility (SWMTF) can provide, such as mean loads and positions, and has highlighted the importance of understanding mooring systems for MRE devices. It has focused on the methods available to assess anchor positioning. Modern installation vessel, shallow water depth, silty seabed and calm environmental conditions could all increase the precision of the anchor positioning, which is critical for the mooring arrangement. Other methods can also be used such as line pulling

The results presented also demonstrate that the slow drift of a drag embedment anchor motion can occur to a mooring designed for a MRE device. Although this event is not as dramatic as a line failure, it may lead to the necessary recovery and redeployment of the moved anchor. Preventing and identifying this event is a key element of MRE sea trials.

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