The behaviour of a novel dynamically installed anchor during deployment – insights from field tests

Jalilvand, Soroosh; Gavin, Kenneth; Doherty, Paul; Gilbert, Robert B.; Vinayagamoothy, Siva; Bradshaw, Aaron

Publication date
2016

Document Version
Final published version

Published in
Proceedings of Civil Engineering Research in Ireland 2016

The behaviour of a novel dynamically installed anchor during deployment – insights from field tests

Soroosh Jalilvand[1], Kenneth Gavin[2], Paul Doherty[3], Robert B. Gilbert[4], Vinayagamoothy Sivakumar[5], Aaron Bradshaw[6]

[1]School of Civil, Structural and Environmental Engineering, University College Dublin, Dublin4, Ireland
[2] Faculty of Civil Engineering and Geosciences, TU Delft, Netherlands (formerly UCD)
[3]Gavin & Doherty Geosolutions, Dublin, Ireland (formerly UCD)
[4]Department of Civil, Architectural and Environnemental Engineering, The University of Texas at Austin, Austin, TX 78712, United States
[5]School of Planning, Architecture and Civil Engineering, Queen's University Belfast, University Rd, Belfast, BT7 1NN, Northern Ireland
[6]Department of Civil & Environmental Engineering, University of Rhode Island, Kingston, RI 02881, United States

Emails: soroosh.jalilvand@ucdconnect.ie, k.g.gavin@tudelft.nl, pdoherty@gdgeo.com, bob_gilbert@mail.utexas.edu, v.sivakumar@qub.ac.uk, bradshaw@egr.uri.edu

ABSTRACT: Offshore wind developments are moving towards deep water where the energy is abundant and visual and sound interference is minimised. However, construction in deep water poses several challenges to developers, among which are the high cost of operation and material transport. The current study addresses the behaviour of a novel foundation system (pending US patent) that aims at minimising the cost of deployment for emerging offshore wind facilities. To this end, the preliminary results of an offshore field test on the small scale dynamically installed anchor are presented and the testing methodologies are briefly outlined. The results provide insights into the behaviour of the anchor as it is released into the water column, impacts with the seabed, and finally, achieves it maximum penetration depth. This is enabled through a detailed study of the data obtained from an accelerometer built into the anchor, which tracks the anchor motion over the course of its deployment. Overall, the findings in this research contribute to an enhanced understanding of the behaviour of dynamically installed anchors as perceived through field tests.

KEY WORDS: Dynamically installed anchor; Offshore test.

1 INTRODUCTION

A major challenge in developing offshore wind developments is the high cost and risk involved in the construction of platforms to host such facilities. Floating platforms are the most viable options for emerging offshore wind turbines in deep water (>60m). Therefore, the development of efficient foundation solutions to serve the next generation of offshore wind turbines is critical to the sustainable growth of wind energy sources. The Flying Wing Anchor (pending US patent) is a novel foundation concept in the form of a plate anchor that addresses this issue through its enhanced deployment technique and efficient functionality. The anchor has a fluke in the form of a steel plate that is hinged to a freely rotating shank. The shank is initially fixed to the fluke, allowing for the anchor to be installed dynamically under its own weight. This results in significant gains in terms of operational time and resource commitment, while contributing to the performance of the anchor by proving an initial embedment. Once the anchor settles into the seabed at the end of its free fall, the line attached to the anchor is loaded resulting in opening-up of the shank. From this point onward, the anchor behaves like a drag embedment anchor, meaning that it can build up penetration (and as a result, bearing capacity) with increased dragging. The dual performance of the Flying Wing Anchor enables quick installation and optimized bearing capacity, previously unattainable using the torpedo or drag embedment anchors alone.

To date, numerous investigations have been performed on the behaviour of dynamically installed anchors, among which are the comprehensive studies conducted on torpedo anchors[1–4], Dynamically embedded plate anchors (DEPLAs) [5,6], and Omni-Max anchors [7–9]. Building upon this rich platform, a set of offshore anchor trials were conducted to assess the behaviour of the Flying Wing Anchor during deployment. The following sections provide a brief overview of the testing methodology and the quantitative findings obtained from the analysis of the anchor motion during the penetration phase of deployment.

2 METHODOLOGY

2.1 *Vessel*

The cruise was undertaken from 1th to 10th December 2015 on board the Irish Marine Institute's Celtic Voyager. The vessel accommodated a group of 13 crew members, technicians and scientists who participated in the various stages of anchor deployment and site investigation. Figure 1 shows a deck view of the Celtic Voyager, where the A-frame and the pulleys, together with the deck-mounted winches, were used to deploy the anchor and perform the site investigation operations.

2.2 *Test site*

The offshore testing program was performed in a relatively sheltered area off the coast of Scotland (see Figure 2) where the sediment has been broadly categorized as Muddy Sand [10] according to the BGS classification, which is a slight modification of the Folk classes [11]. The water depth at the location of the test is approximately 50m, which provided adequate drop height for the investigations performed in these anchor trials. The target area was approximately 1500m x 500m and was chosen to provide close proximity to local ports while causing no interference with the underwater features and the marine traffic.

Figure 1. Anchor deployment on board the Marine Institute's Celtic Voyager.

Figure 2. The test site was located in a relatively sheltered area off the coast of Scotland.

2.3 Model Anchor

The model scale anchor investigated in this study is a small scale Flying Wing Anchor with a characteristic size of 700mm that consists of two planar parts (flukes) connected using a central beam, which is hinged to a rotating shank (see *Figure 3*). The shank is initially restrained in position relative to the fluke, but it can open up once the anchor is loaded. This will cause the anchor to embed deeper into the seabed beyond the penetration obtained as a result of the free fall. This behaviour is similar to conventional drag-in-plate systems [12]. The anchor continues embedment until the load in the mooring line reaches the anchor ultimate capacity. Further loading at this stage will not result in significant gains in either anchor embedment or anchor capacity.

2.4 Deployment strategy

The anchor deployment involved:

- attaching the mooring line (dashed-line in Figure 3) and the installation line (solid line in Figure 3) to the anchor,
- lowering the anchor using the installation line and a deck-mounted winch to the specified drop height
- releasing the anchor by triggering a quick release shackle on the deck, and
- loading the anchor using the installation line.

At the end of loading, the anchor was retrieved using the mooring line connected to the tail of the anchor. This would allow for the mobilization of minimum anchor capacity during the retrieval process.

2.5 Operational Challenges

The presence of multiple lines during the anchor deployment resulted in complication of the offshore operations. In addition, the bad weather condition and the relatively small size of the Celtic Voyager posed serious challenges to the station-keeping of the vessel, resulting in frequent cancelations of the operations. The deployment challenges were mostly overcome through a close collaboration and communication among the scientists on board and the experienced crew members of the research vessel.

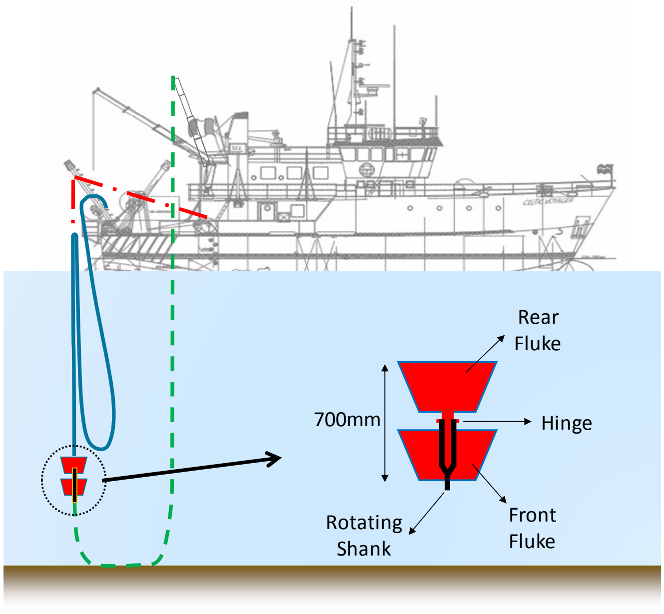

Figure 3. Schematic of the anchor deployment strategy.

3 RESULTS AND DISCUSSION

The anchor motion was monitored using an accelerometer that was packaged in a water-tight unit together with batteries and a data logger, and mounted on the anchor. In order to obtain the anchor velocity and displacement during the free fall and penetration phases, numerical integration was performed on the data obtained from the accelerometer. In the following sections the results of the anchor monitoring during a typical deployment process are presented and the trends in displacement, velocity and acceleration are discussed.

3.1 Anchor velocity

Figure 4 shows the variation of anchor velocity with time from the point of release of the anchor to the end of penetration. It can be observed that the anchor builds up speed upon triggering of the quick release shackle. The velocity increases gradually until it reaches an upper limit known as the terminal velocity. At this point, the amount of drag resistance balances out the gravitational force applied on the anchor. The terminal velocity obtained by the anchor during the demonstrated drop was approximately 4 m/s, which is lower than the range of velocities required for successful penetration [6]. This hints at the need for further streamlining of the anchor for future trials.

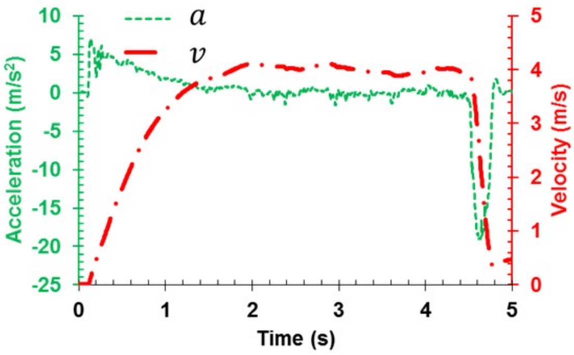

Figure 4. The variation in velocity and acceleration and of the anchor as it undergoes free fall and subsequently comes to a stop after impact with the seabed.

3.2 Anchor acceleration

The acceleration of the anchor along the vertical axis (direction of the anchor travel) for the sample trial is shown in Figure 4. As it can be observed, the anchor acceleration is zero at the initiation of the drop and it increases rapidly upon the release of the anchor. The peak acceleration reached by the anchor is 7.0 m/s^2. The results of similar trials on torpedo anchors have reportedly demonstrated a peak velocity of 8.9 m/s^2 immediately after the release of the anchor [6]. As the anchor gradually builds up speed, the value of the drag force applied on the anchor increases and as a result the anchor acceleration diminishes. Starting at t=2.2 sec, the resultant drag and gravitational forces converge to zero causing the anchor to experience a constant terminal velocity of 4m/s, which corresponds to zero acceleration. The anchor continues to fall at the terminal velocity until it impacts with the seabed at 4.4 sec, resulting in a peak deceleration of -19 m/s^2. The resulting deceleration, caused by the seabed bearing, viscosity and drag forces, brings the anchor to a complete rest within 0.5 sec.

3.3 Anchor displacement

The anchor displacement throughout the free-fall and penetration phase was derived by numerical double integration of the acceleration data. Figure 5 shows the displacement of the anchor during the sample trial. The drop height is approximately 15m. The anchor penetration into the seabed as a result of the free fall is estimated as 660mm, which is approximately one anchor length. The point of impact is obtained by the study of acceleration of the anchor where the impact time is associated with the initiation of a steep descent in acceleration values.

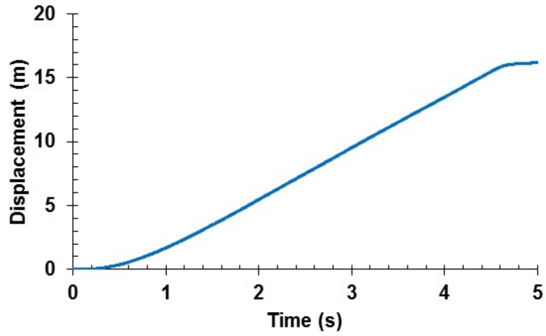

Figure 5.Anchor displacement calculated using accelerometer data.

3.4 Lateral stability

In order to assess the lateral stability of the anchor during free-fall and as a result of the impact with the seabed, the longitudinal (direction of anchor travel) and lateral accelerations of the anchor are investigated in Figure 6. According to the graph, the value of anchor lateral acceleration is negligible at the start of the free fall and throughout the anchors movement through the water column. As the anchor impacts the seabed, a sudden peak can be identified in both lateral and longitudinal accelerometer data. However, the surge in the former is considerably (about 90%) lower than the longitudinal acceleration peak, suggesting that the anchor was close to vertical at the time of release and maintained its orientation throughout the drop. Finally, the anchor landed almost vertically into the seabed. A closer examination of lateral stability can be performed by incorporating the data from gyroscopes in addition to accelerometer. This is beyond the scope of current study.

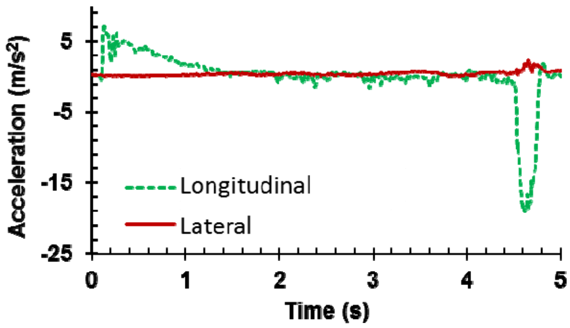

Figure 6. The lateral stability of the anchor under impact.

4 CONCLUSIONS

The current study presents the preliminary results from a set of offshore anchor trials that assessed the behaviour of a novel anchor system during deployment in the offshore environment. The anchor concept (Flying Wing Anchor) was designed to combine the best attributes of torpedo anchors and drag-in-plate anchors to provide an efficient installation technique and optimum capacity per material usage. The trials were conducted on board the Celtic Voyager in December 2015, where a group of 13 crew members, technicians and scientists worked together to accomplish the various tasks involved in the deployment of the anchor and relevant site investigations.

The deployment strategy involved (1) equipping the anchor with instrumentation package, a mooring line and an installation line, (1) lowering the anchor using the installation line to the required drop height, (2) dropping the anchor by triggering a quick release shackle, and (3) loading the anchor using the equipped mooring line. The deployment required simultaneous operation with both mooring and installation lines connected to the anchor, which resulted in operational difficulties.

Throughout the deployment process, the anchor motion was monitored using a built-in accelerometer. This enabled the tracking of the anchor as it underwent free fall in the water column and, subsequently, impacted with the seabed came to a complete halt. The performance of the anchor instrumentation is demonstrated through the results of a sample anchor trial, which is performed from a drop height of 15m. The results showed the variation of acceleration and velocity during the free fall and penetration. It was demonstrated that the anchor terminal velocity quickly mobilized upon the release of the anchor, pointing at the presence of a large drag resistance compared to the weight of the small scale anchor. The terminal velocity obtained by the anchor was approximately 4 m/s, which could be enhanced in future trials by further streamlining the anchor. Double integration of measured accelerations allowed for measurement of anchor displacement across the various phases of installation. The penetration depth was then calculated by extracting the amount of anchor displacement occurring between the time of impact and the time when the anchor velocity converged to zero. The time of impact was calculated with a close investigation of changes in anchor acceleration. The results showed a penetration depth of approximately one anchor length for the sample trial presented in this study. Finally, it was concluded that the anchor remained vertically stable throughout the free fall and impact with the seabed as no significant variation in the lateral acceleration of the anchor is observed during these stages.

ACKNOWLEDGMENTS

This research was conducted with the financial support of Science Foundation Ireland under the US-Ireland R&D Partnership Program Grant Number SFI/12/US/E2479. This research survey is supported by the Marine Institute, and is funded under the Marine Research Programme by the Irish Government

REFERENCES

[1] M. S. Raie and J. L. Tassoulas, “Installation of torpedo anchors: Numerical modeling,” *J. Geotech. Geoenvironmental Eng.*, vol. 135, no. 12, pp. 1805–1813, 2009.

[2] M. S. Hossain, Y. Kim, and D. Wang, “Physical and Numerical Modelling of Installation and Pull-Out of Dynamically Penetrating Anchors in Clay and Silt,” in *ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering*, 2013, pp. V006T10A019–V006T10A019.

[3] C. D. O’Loughlin, M. D. Richardson, M. F. Randolph, and C. Gaudin, “Penetration of dynamically installed anchors in clay,” *Geotechnique*, vol. 63, no. 11, pp. 909–919, 2013.

[4] H. Sabetamal, M. Nazem, J. P. Carter, and S. W. Sloan, “Large deformation dynamic analysis of saturated porous media with applications to penetration problems,” *Comput. Geotech.*, vol. 55, no. 0, pp. 117–131, Jan. 2014.

[5] D. Wang and C. D. O’Loughlin, “Numerical study of pull-out capacities of dynamically embedded plate anchors,” *Can. Geotech. J.*, vol. 51, no. 11, pp. 1263–1272, 2014.

[6] A. P. Blake and C. O’Loughlin, “Installation of dynamically embedded plate anchors as assessed through field tests,” *Can. Geotech. J.*, no. ja, 2015.

[7] J. T. Shelton, “OMNI-Maxtrade anchor development and technology,” in *OCEANS 2007*, 2007, pp. 1–10.

[8] E. H. Zimmerman, M. Smith, and J. T. Shelton, “Efficient gravity installed anchor for deepwater mooring,” in *Offshore Technology Conference*, 2009.

[9] J. Liu, L. Lu, and Y. Hu, “Keying behavior of gravity installed plate anchor in clay,” *Ocean Eng.*, vol. 114, pp. 10–24, 2016.

[10] D. Evans, “Clyde (Sheet 55N 06W), Sea bed Sediment and Quternary Geology,(1: 250,000 Offshore Map Series),” *Br. Geol. Surv.*, 1985.

[11] S. J. Blott and K. Pye, “Particle size scales and classification of sediment types based on particle size distributions: Review and recommended procedures,” *Sedimentology*, vol. 59, no. 7, pp. 2071–2096, 2012.

[12] C. P. Aubeny and C. Chi, “Mechanics of Drag Embedment Anchors in a Soft Seabed,” *J. Geotech. Geoenvironmental Eng.*, vol. 136, no. 1, pp. 57–68, Jan. 2010.