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The drag effects on the penetration behavior of drag anchors during installation

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ABSTRACT

The penetration behavior of drag anchors in the seabed is directly controlled by the anchor handling vessel (AHV) and the installation line. However, the drag effects produced by the AHV and the installation line are difficult to investigate by either theoretical or experimental methods. In the present work, a large deformation numerical analysis employing the coupled Eulerian–Lagrangian technique is performed to investigate the effects of the drag velocity of AHV, the uplift angle of installation line, the diameter of installation line, and the length of installation line. It is demonstrated that the movement direction and the drag angle at the shackle of the anchor are not influenced by drag effects, while the drag effects on the anchor trajectory and the drag force are significant. Findings of the present study also yield a relation between drag velocity and drag force and the knowledge of the ultimate embedment depth of anchor and the critical length of installation line, which are beneficial to fully understanding the drag embedment problems and to enhancing the installation techniques for drag anchors.

1. Introduction

Reliable anchor performance is important for mooring floating offshore platforms. Anchor failure may result in the platform going adrift and colliding with other offshore structures and hence result in unexpected hazards. Because of better performance both in pullout capacity and deepwater installation, drag anchors are widely utilized in mooring systems for offshore applications, such as the conventional drag anchor in the catenary mooring system and the vertically loaded plate anchor in the taut-wire mooring system. When the drag anchor is lowered on the seabed and sufficient installation line has been paid out, the anchor handling vessel (AHV) starts moving along a certain direction. The anchor will gradually penetrate into the soil due to the drag force transmitted from the installation line, as illustrated in Fig. 1(a) (Liu et al., 2010b). Apparently, the AHV, the installation line and the anchor interact with each other as an installation system during dragging. The penetration behavior of the anchor is directly controlled by the AHV and the installation line. Factors produced by the AHV and the installation line, such as the drag velocity of AHV, the uplift angle of installation line, the diameter of installation line and the length of installation line, will affect the installation of drag anchors. Correctly understanding the drag effects on the penetration behavior of drag anchors in the seabed is important to improving the drag embedment performance, predicting the anchor trajectory, and accurately positioning the anchor in offshore applications.

The penetration behavior of drag anchors, such as the movement direction of the anchor (Dunnavant and Kwan, 1993; O'Neill et al., 1997, 2003; O'Neill and Randolph, 2001; Liu et al., 2012b), the drag force (Reese, 1973; Gault and William, 1974; Vivatrat et al., 1982; Degenkamp and Dutta, 1989; Neubecker and Randolph, 1995; Bang et al., 1996; Bang and Taylor, 1997; Zhang et al., 2014) and drag angle (θ_a) (Neubecker and Randolph, 1996; O'Neill et al., 1997, 2003; O'Neill and Randolph, 2001; Elkhatib and Randolph, 2005; Aubeny et al., 2008; Zhang et al., 2014) at the shackle, and the trajectory (Murff et al., 2005; Aubeny et al., 2008; Aubeny and Chi, 2010; Liu et al., 2012a, 2013) and the ultimate embedment depth (UED) (Neubecker and Randolph, 1996; O'Neill et al., 1997; O'Neill and Randolph, 2001; Ruinen and Degenkamp, 2001; Liu et al., 2010a) of the anchor, as illustrated in Fig. 1(b), have been investigated by numerous researchers through theoretical and experimental methods. Recently, a large deformation finite element (FE) analysis using the coupled Eulerian–Lagrangian (CEL) method was carried out to simulate the installation process and to investigate the penetration behavior of drag anchors in seabed soils (Liu and Zhao, 2014; Zhao and Liu, 2014). However, few researchers performed a systematic investigation of the drag

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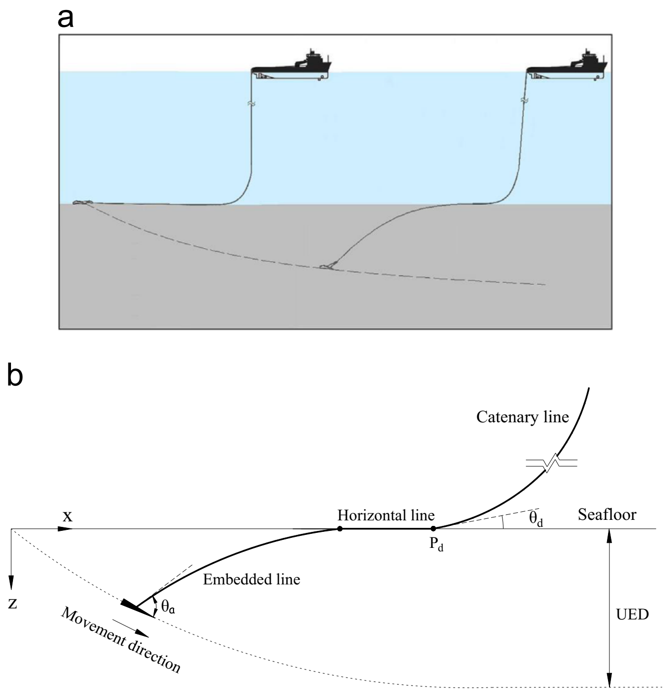

Fig. 1. Description of the drag anchor installation. (a) Drag anchor installation (Liu et al., 2010b). (b) Key parameters in the anchor installation.

effects produced by the AHV and the installation line on the penetration behavior of drag anchors.

During drag anchor installation, the anchor will be gradually penetrated into the soil with the moving AHV. It seems obvious that the movement velocity of AHV, or the drag velocity, will affect the anchor installation, such as the installation load or the drag force transmitted by the installation line. In the large scale model tests of Dennla and Stevmanta VLAs (30–40% of prototype size), Dahlberg and Strom (1999) demonstrated that a reduction in the drag velocity resulted in an immediate drop in installation line tension amounting to about 15–20% per log-cycle change in speed. Aubeny et al. (2011) found in a small scale (1:10) model test that the drag velocity increasing from 0.13 to 0.19 m/s resulted in a slight increase in drag force at the shackle of 1–8 lbs. It was also proved by Zhao and Liu (2014) that the drag force decreased with decreasing value of drag velocity in the FE simulation of drag anchor installation. Meanwhile, Dahlberg and Strom (1999), Aubeny et al. (2011) and Zhao and Liu (2014) all concluded that the drag velocity had almost no impact on the final penetration depth of the anchor. However, a quantitative relationship between the drag velocity and the drag force was not tried in earlier studies. Is there a relationship between the drag velocity and the drag force? And does the drag velocity affect any other behavior of the anchor in seabed soils? These questions are interesting and necessary to be clarified because of their importance to the installation of drag anchors.

As a part of the installation system, the installation line generally affects the anchor behavior through two ways, i.e., the drag force at the anchor shackle transmitted from the line and the configuration of the line embedded in seabed soils. The two ways are all closely relevant to the property of the line, such as the diameter and length of the line (including the length of line lying on seafloor) and the drag angle (θ_d) at the drag point (P_d) (see Fig. 1(b)).

The installation line attached to the shackle of the anchor will embed together with the anchor during installation. The anchor trajectory is significantly affected by the type (wire or chain) and the size of installation line (DNV, 2012). It has been demonstrated by previous researchers that an anchor penetrating with a wire will reach a larger depth than with a chain at the same drag distance (Murff et al., 2005; Aubeny et al., 2008; Liu et al., 2012a, 2013), because the soil cutting resistance is less for a wire than for a chain. The effect of the type of installation line on the penetration behavior of the anchor can be equivalently analyzed by investigating the effect of the diameter of installation line due to that the nominal diameters for wire and chain are different.

DNV (2012) stated that the anchor trajectory is affected by the uplift angle of installation line. If the uplift angle becomes excessive during installation, the anchor penetration depth will be reduced. It suggested that the uplift angle at the seabed level exceeding 10° should not be expected during installation. In this situation, there is always not a horizontal line, which is the segment of the installation line that lies on the seabed (see Fig. 1(b)), and the uplift angle is just identical with the drag angle at the drag point. To enhance the installation technique and accurately predict the anchor behavior in seabed soils, further study on the uplift angle of installation line is a work that should not be avoided.

In the theoretical analysis of the anchor trajectory (Murff et al., 2005; Aubeny et al., 2008; Liu et al., 2012a, 2013), a generally accepted assumption is that the length of installation line is long enough so that there is always a horizontal line thus the anchor can reach the UED under the drag force of AHV. However, the UED can hardly be obtained in the practical engineering owing to restrictions of the drag distance or the length of installation line. The UED was observed by O'Neill et al. (1997) and Liu et al. (2010a) during the model tests in clay and sand, respectively. Due to the limitation of the model flume size, the values of UED were not more than 2.5B and 1.3B in clay and sand, respectively, where B denotes the fluke width. Formulas were also proposed by Neubecker and Randolph (1996), Ruinen and Degenkamp (2001) and Liu et al. (2010a) to predict the UED of drag anchors, in which the effect of the length of installation line was not taken into consideration. In other words, the length of installation line was assumed to be long enough in their studies. However, the UED will be obviously affected by the length of installation line. If the line length is shorter than the "theoretical UED" predicted by the formulas of previous researchers (Neubecker and Randolph, 1996; Ruinen and Degenkamp, 2001; Liu et al., 2010a), it is hard to think that the anchor can reach the UED. Note that a plastic limit analysis was performed by Aubeny and Chi (2010), in which the effect of uplift of the anchor line in the water column was considered due to a finite installation line length. It was demonstrated that a shorter length of installation line will induce a larger uplift of the anchor line and a shallower penetration depth, and hence the anchor performance such as the bearing capacity of the anchor will be limited. Therefore, three problems need to be clarified through further efforts, i.e., whether the UED of the anchor exists, how the length of installation line affects the anchor behavior in the seabed especially the UED, and what is the optimal length of installation line to make the anchor achieve the best performance.

A survey of current researches reveals that few of researchers performed a systematic investigation on the drag effects produced by the AHV and the installation line, which is attributed to the limitations of the theoretical analysis, model tests and practical applications. These limitations include: (a) the effects of the drag velocity and the length of installation line are difficult to consider in earlier analytical methods; (b) the UED of the anchor is hard to reach with restriction of the model flume size in model tests; and (c) the high cost of drag anchor installation in practical applications.

The CEL method is a large deformation FE technique, which is able to deal with the contact problems and the mesh distortion appearing in the classical FE codes, and well suited to simulate the installation process of drag anchors involving large deformation of