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Research Paper

Analytical model for vertically loaded anchor performance with a bridle shank

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ABSTRACT

Vertically loaded anchors offer an attractive alternative for mooring systems because of their relatively high efficiency and low cost. The bridle shank is an important feature of these anchors because its reconfiguration significantly affects their performance. A plasticity model considering a bridle shank is introduced to investigate the mechanism of the system. Model-based parametric studies on the effects of the bridle length, drag distance and anchor line angle are also conducted. These studies establish a new, more rational analytical model for these anchors, as well as contribute to the understanding of the mechanism of them in research and practice.

1. Introduction

Oil and gas exploration has moved extensively into deep waters as shallow water oil and gas fields are gradually being exhausted. This recent trend led to the introduction of taut mooring systems (TMS), in which the anchor is subjected to significant uplift loads. Several types of anchors are capable of resisting uplift loads, such as suction anchors [1], suction-embedded plate anchors (SEPLAs) [2–6], dynamically installed anchors [7] and vertically loaded anchors (VLAs) [8,9].

Vertically loaded anchors are an attractive alternative for taut mooring systems because of their relatively high efficiency as well as their low material and installation cost [8,10]. They can be placed and installed in much the same way as conventional drag embedment anchors (DEAs) [11–13]. Nevertheless, after installation to the required position, the shank (see Fig. 1) of the vertically loaded anchor can be reconfigured so that the anchor line forms a right pull angle to the fluke, thus significantly increases the pull-out capacity. The bridle shank [20] (see Fig. 1(b)) can be reconfigured even during the installation process. Therefore, the shank has a decisive influence on the performance. Aubeny and Chi [8] presented an analytical model and a parametric study on the behavior of the vertically loaded anchor with a rigid bar shank [19] (see Fig. 1(a)), with a focus on the load capacity and the ductility characteristics of the anchor. However, the analytical treatment of the bridle shank has received little attention to date. In this paper, we attempt to address this problem using a plasticity approach.

The plasticity approach allows a simple design calculation and sensitivity study to be efficiently performed, so it is increasing being used to predict the load-displacement behavior of offshore infrastructure, such as spudcan foundations [14], drag embedment anchors [11,12,15], suction-embedded plate anchors [2–4], vertically loaded anchors [8], pipelines [16,17] and caissons [18]. Rigid plasticity is assumed in the plasticity approach, allowing the kinematics of the anchor to be determined solely using a yield surface and an associated flow rule. The analytical model proposed in this paper is based on these assumptions, with additional consideration for the anchor line and the bridle shank.

An idealized rectangular fluke, as shown in Figs. 2 and 3, is used in this study. Although the real fluke is not rectangular, the conclusions drawn should still be applicable. A method to determine the configuration of the bridle shank is proposed, and the anchor capacity and kinematics are then studied. A prediction algorithm is established to simulate the following double-line installation and loading processes [20]:

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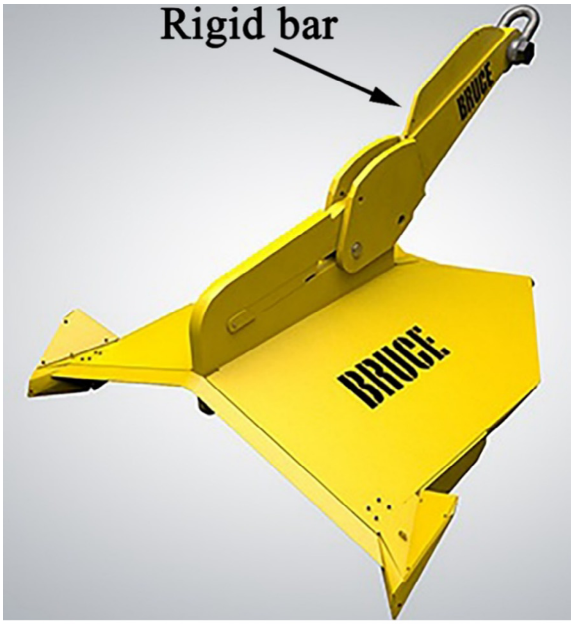
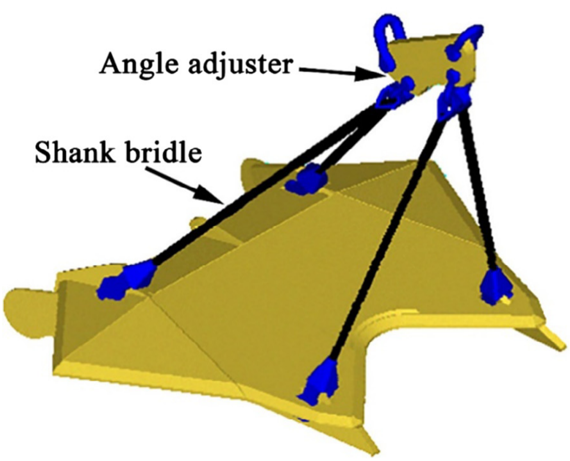


(a) Dennla MK3 (rigid bar shank)



(b) Vryhof Stevmanta (bridle shank)

Fig. 1. Types of vertically loaded anchors.

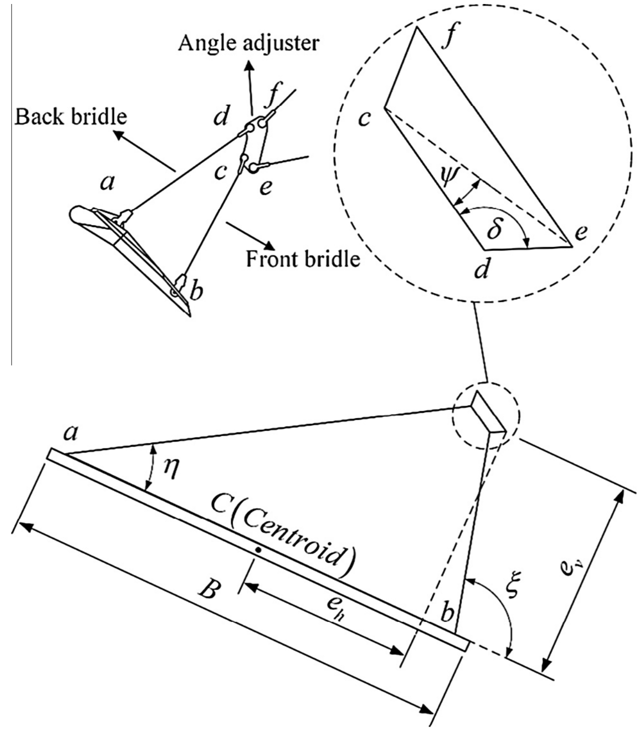


Fig. 3. Sketch of the anchor.

1. Installation process - the front anchor line (installation line) is tensioned, so that the anchor will be embedded into the seabed (see Fig. 4(a)).
2. Loading process - the back anchor line (mooring line) is tensioned, so that the shank will be reconfigured to increase the pull-out capacity (see Fig. 4(b)).

Based on the simulation results, the typical behaviors of vertically loaded anchors are discussed, and a parametric study is presented to investigate the effects of the following factors: (i) the ratio of front shank bridle length to back shank bridle length; (ii) the installation drag distance before loading process; and (iii) the anchor line angle at the mudline during the loading process. A convergence test and comparison with centrifuge experiments results are also provided to verify and validate the simulations.

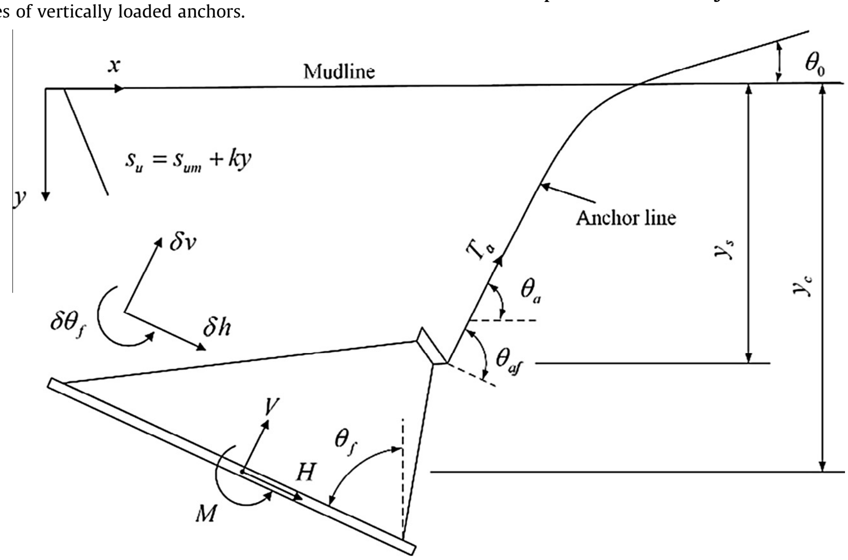


Fig. 2. Sketch of the anchor system.