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Comparative study of reverse catenary properties of the installation line for drag anchors

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ABSTRACT

The penetration mechanism and kinematic behavior of the drag anchor are significantly influenced by the installation line especially the segment embedded in seabed soils. Full knowledge of the embedded installation line is important to improving the drag embedment performance, predicting the trajectory, and solving the positioning problem in engineering. However, the configuration of the embedded line is complex and cannot be observed in soils. Few of the researchers performed systematic experiments focusing on the embedded line. Utilizing specially developed measurement techniques, four important topics including the reverse catenary profile of the embedded line, the effective length of the installation line, the relation between the vertical position and the drag angle at the shackle of the anchor, and the equivalent length of the installation line, are experimentally investigated in a model flume. Comparative studies of these topics are also performed between experiments, theoretical analysis and numerical simulations. Clear knowledge is then obtained which is beneficial to fully understanding complex properties of the embedded installation line.

1. Introduction

Drag embedment plate anchors are increasingly applied in offshore engineering. It has been recognized that the penetration behavior and trajectory of the drag anchor in seabed soils are not only controlled by the properties of the anchor and soil, but also related to the installation line especially the segment embedded in soils. Unlike the catenary line in the seawater and the horizontal line on the seafloor, the configuration of the embedded line in soils is complex and cannot be observed, and the reverse catenary shape significantly influences the kinematic behavior of drag anchors besides transmitting the drag force. Correctly understanding and describing reverse catenary properties of the embedded line is important to improving the drag embedment performance, precisely predicting the anchor trajectory, and solving the positioning problem in offshore applications.

Previous analytical studies of the embedded installation line mainly focused on the tension and profile of the line. The investigation on reverse catenary problems [1–8] demonstrates that, except the theoretical models from Neubecker and Randolph [5] and Liu et al. [8], the tension and the reverse catenary shape of the embedded line have to be solved through numerical incremental methods. Due to the method with which this paper is especially concerned, experimental studies relevant to reverse catenary properties of the installation line are overviewed herein.

Degenkamp and Dutta [4] carried out pull-through tests on anchor pile chains in clay with a tank of 4.5 m × 1.25 m × 0.37 m. A number of laboratory tests with three different chain sizes and two different undrained shear strengths were performed. During the test, at regular intervals, the displacement, the projected length of embedded chain, the horizontal pulling force, and the horizontal and vertical lug forces were measured. However, the reverse catenary profile of the embedded chain was not measured in the experiments.

Heyerdahl and Eklund [9] performed onshore model tests on Position Installed Plate Anchors. The tests were extensively instrumented and performed in situ in typical normally consolidated clay. However, a manual measurement of the anchor line geometry was performed. The geometry of the anchor line was measured manually using thin wires connected along the anchor line with different distances from the pad eye. To measure the anchor line geometry, pulling in the anchor line was stopped, and the thin wires were tightened vertically. For each wire, the horizontal position from the anchor installation point was recorded as well as the depth to the anchor line. This stepwise procedure was once for each of the anchors.

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Bang et al. [10] performed geotechnical centrifuge tests on single segmented mooring lines. The model mooring line included a steel chain and a wire cable starting at various depths within the sandy seafloor soil. The mooring lines were loaded to preset tensions at the water surface under an elevated acceleration inside the centrifuge to simulate the field stress conditions that the prototype mooring lines were experiencing. The detailed trajectories of the mooring lines were measured from zero to the maximum deployment load. Developed tensions within the mooring lines at the anchor and at the seafloor surface were also measured. The mooring line inclination angles and geometry were recorded after the test container was removed from the centrifuge. The test container was laid on its side and the panel removed to expose the sand encasing the mooring line. The sand was carefully removed to expose the mooring line so the geometry could be recorded.

The overview of experimental studies on the embedded line demonstrates that, compared to the tension, the reverse catenary profile of the embedded line was not instrumentally measured. Either the method adopted by Heyerdahl and Eklund [9] or the method adopted by Bang et al. [10] belongs to a manual measurement and can only get the static profile of the embedded line at several stages of embedment. These methods are unable to capture the real-time reverse catenary profile of the embedded line during anchor penetration, and apparently do not allow sufficient measurement precision. These indicate that further experiments including advanced measurement techniques are still needed to explore complex properties of the embedded line, so that on the other hand theoretical models and numerical simulations of reverse catenary problems can be effectively calibrated by experiments.

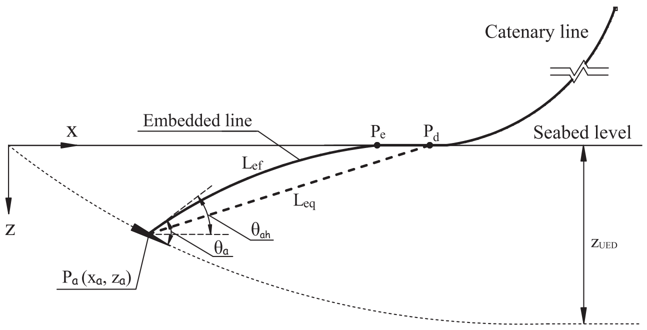


Fig. 1. Definition of the parameters.

In the present study, the techniques for investigating reverse catenary properties based on tilt transducers and photography are specially developed. Utilizing the measurement techniques, four important topics including the reverse catenary profile of the embedded line, the effective length of the installation line (L_{ef}), the relation between the vertical position (z_a) and the drag angles at the shackle (θ_{ah} and θ_a) of the anchor, and the equivalent length of the installation line (L_{eq}), as illustrated in Fig. 1, are experimentally investigated in a model flume. L_{ef} and L_{eq} are both important parameters to describe the reverse catenary properties. The former is defined as the length of the embedded line, i.e., the line length between the embedment point (P_e) and the anchor (P_a), and the latter is defined as the distance between the drag point (P_d) and the anchor. To fully understand complex properties of the embedded installation line, a systematic investigation on the four topics by different ways is required besides the experimental method. Therefore, comparative studies of these topics are also performed between experiments, theoretical analysis and numerical simulations.

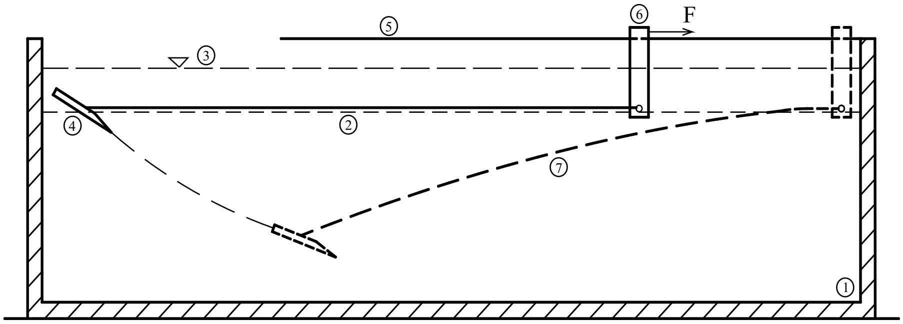
2. Measurement techniques

All experiments are conducted in a model experimental system, which was especially designed for drag embedment plate anchors. This system mainly consists of four parts, i.e., experimental flume, drag and retrieval system, measurement system, and drag-mooring conversion system, as illustrated in Fig. 2. Through the experimental system, dynamic and motion parameters of the anchor, including the trajectory, drag force, drag distance, drag angle at the shackle and pitch and roll of the anchor model, can be gathered and simulated simultaneously during dragging [11].

2.1. The technique for measuring the reverse catenary profile

In the experiments, a technique for measuring the reverse catenary shape based on tilt transducers is developed. These transducers were fabricated as small as possible (with size of 40 mm × 11 mm × 11 mm), and were bound on the embedded line nonuniformly but with sufficient density. By monitoring and measuring the instantaneous values of tilt transducers during anchor penetration, the instantaneous curvature of the embedded installation line can be precisely simulated through a circular arc recursive algorithm.

The recursive algorithm assumes a circular arc between two transducers whose measured angles are different and a straight line between two transducers whose measured angles are identical, and the two adjacent segments are tangent, as illustrated in Fig. 3. The coordinates of the $(i+1)$th transducer P_{i+1} can be derived from the



① Flume ② Soil surface ③ Water surface ④ Anchor model

⑤ Line track ⑥ Slide vehicle ⑦ Installation line

Fig. 2. Sketch of the model experimental system.