International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 27, No. 1, March 2017, pp. 44–53; https://doi.org/10.17736/ijope.2017.jc673

http://www.isope.org/publications/publications.htm

Recent Advances in Anchor Design for Floating Structures†

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This paper describes advances in offshore anchoring technology made possible through research undertaken recently at the Centre for Offshore Foundation Systems at the University of Western Australia. The paper focuses on the behavior and performance of statically and dynamically installed anchors for floating structures, addressing issues associated with anchor installation and anchor capacity under monotonic, sustained, and cyclic loading. The role of centrifuge modeling, numerical modeling using large deformation analysis, and analytical modeling based on plasticity analysis in advancing anchor technology is presented. This modeling has led to tools that can assist anchor design to reduce uncertainty and optimize performance.

INTRODUCTION

The role of offshore anchors is to keep a floating facility on station. These facilities include oil and gas structures in deep water (e.g., floating production, storage, and off-loading platforms) and renewable structures in shallow water (e.g., wave energy converters). They can be located either directly on the seabed (e.g., gravity anchors) or deep within the seabed (e.g., plate anchors, torpedo anchors, suction caissons, and piles), with the choice of anchor reflecting the mooring requirements and the type of seabed sediments (Randolph and Gourvenec, 2011). Driven by both economic and technological considerations, the last three decades has seen the evolution of anchor technology and the emergence of new anchoring solutions to comply with

- changing seabed conditions encountered in frontier regions;
- changes in mooring configurations, operating water depths, and sea states;
- increased holding capacity requirements associated with larger facilities; and
- different loading conditions associated with offshore renewable energy devices.

Notable examples of new anchor configurations, as shown in Fig. 1 and concentrated on in this paper, include (i) vertically loaded anchors (VLAs) that penetrate into the seabed by being dragged over a distance of 50–150 m, (ii) suction embedded plate anchors (SEPLAs) that are installed in the soil to a targeted depth using a follower (typically a suction caisson), (iii) dynamically installed anchors that penetrate into the seabed by falling freely through the water column from a targeted height, and (iv) helical anchors that are "screwed" into the seabed. These complement the traditional pile and (more recently) the suction caisson, which have been commonly used for permanent deep offshore floating facilities.

The mooring lines of anchors are installed either in a catenary configuration (e.g., for floating production storage and off-loading) in which a significant horizontal load is applied to the anchor or in a taut or semitaut configuration with lines at > 40° from the seabed (e.g., tension leg platform, some wave energy converters, and wind turbines) that requires anchors to hold predominantly vertical loads. In both cases, resistance is provided by a combination of bearing capacity of the soil and friction resistance, depending on the soil and mechanism involved. Both aspects of the resistance have been investigated thoroughly, for both clay and sand and for undrained and drained conditions, which are prevalent for each type of soil, respectively.

In design codes, anchor capacity is typically addressed using Terzaghi's bearing capacity theory. Research performed over the last decade has refined this concept and provided an accurate estimate of anchor capacity using bearing capacity factors N_c for clay and N_γ for sand. N_c depends essentially on the embedment and geometry of the anchor. For a given geometry, N_c increases with increasing embedment of the anchor, up to a transition depth ranging from 3 to 5 times the anchor primary dimension, from which a deep failure mechanism is generated and a constant value is adopted. N_γ depends on the embedment and geometry of the anchor but also on the mechanical properties of the sand (including its friction and dilation angles), which affects the failure mechanism and the volume of sand involved in the resistance. Sands with high dilation angle generate a larger failure mechanism and exhibit N_γ values higher than sand with low dilation angles. At

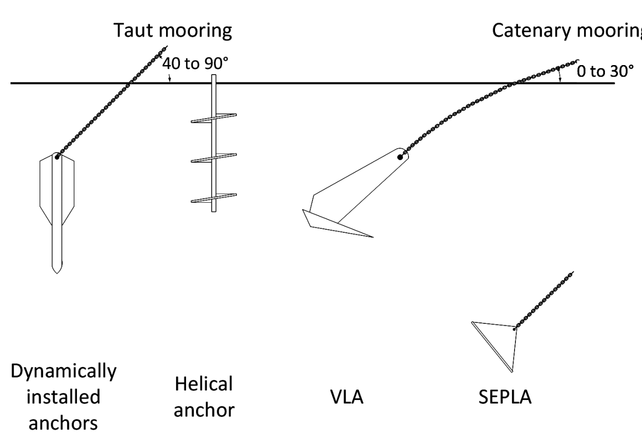

Fig. 1 Embedded anchors for offshore applications. Note that piles and suction caissons, also commonly used offshore, are not discussed in this paper.

† Keynote paper.

Received May 20, 2016; updated and further revised manuscript received by the editors September 28, 2016. The original version (prior to the final revised manuscript) was presented at the Twelfth ISOPE Pacific-Asia Offshore Mechanics Symposium (PACOMS-2016), Gold Coast, Australia, October 4–7, 2016.

KEY WORDS: Anchor, physical modeling, numerical modeling, floating structures, monotonic loading, cyclic loading, soil behavior.