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Keying of Plate Anchors in NC Clay Under Inclined Loading

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Plate anchors are commonly used in the offshore industry to anchor floating facilities. They are installed vertically using a follower and subsequently rotated, through a process called keying, to exhibit their maximum area normal to the loading direction. This paper describes a series of centrifuge tests performed in order to investigate the influence of the keying on the overall performance of the anchor. Tests were conducted against a Perspex window in plane strain chambers containing normally consolidated clay. Particle Image Velocimetry (PIV) provided insights into the different failure mechanisms generated during keying, and information about the load inclination and load eccentricity minimising the loss of embedment and hence maximising the anchor performance. The loss of embedment after keying for different load inclinations and different load eccentricities was also quantified.

INTRODUCTION

The gradual exhaustion of hydrocarbon reserves in shallow waters has forced the offshore oil and gas industry into water depths now approaching 2000 m (Aubeny et al., 2001; Ehlers et al., 2004). This transition to deep water and ultradeep water has necessitated the replacement of fixed platforms by floating facilities that are anchored to the seabed by vertical tethers or relatively taut mooring lines, both of which require anchoring systems designed to withstand significant vertical components of load.

One such anchoring system is the Suction Embedded Plate Anchor (SEPLA, Dove et al., 1998). It has been conceived to combine the advantages of suction caissons (known penetration depth and geographical location) and vertically loaded plate anchors (geotechnical efficiency and low cost) (Wilde et al., 2001). The SEPLA uses a suction caisson to embed a plate anchor that is slotted vertically into its base. The caisson is lowered to the seabed, where it is allowed to penetrate under self-weight. Water is then pumped from the interior of the caisson to allow the system to reach the design embedment depth. The plate anchor mooring line is then disengaged from the caisson and the pump flow is reversed, water being forced back into the caisson, causing it to move upwards whilst leaving the plate anchor in place at the required depth. At this stage the plate anchor and the mooring line are embedded vertically in the seabed. The mooring line attached to the plate anchor is then tensioned, causing the plate anchor to rotate or *key* to an orientation that is perpendicular to the direction of loading. In this way, the maximum projected area is presented to the direction of loading, maximising the bearing resistance of the anchor. The installation and keying processes are summarised schematically in Fig. 1.

The anchor keying process gives rise to 2 effects. First, the anchor embedment depth will reduce as the plate rotates; second, the soil in the immediate vicinity of the plate will exhibit some remoulding (Randolph et al., 2005) in addition to that resulting from the installation process (Gaudin et al., 2006; Song et al., 2007). The reduction in soil strength due to the latter effect may be recovered eventually due to consolidation, but the loss of embedment is crucial. As offshore clay deposits are typically characterised by an increasing strength profile with depth, any loss in embedment will correspond to a nonrecoverable loss in potential anchor capacity. U.S. Naval Civil Engineering Laboratory guidelines (NCEL, 1985) proposed that this loss of embedment is twice the anchor height in cohesive soils. However, SEPLA field tests reported by Wilde et al. (2001) indicated a smaller though wider range of vertical displacement during anchor keying: 0.5 to 1.7 times the plate height. More recently, numerical analyses indicated a loss of embedment in uniform strength clay of 0.6 times the anchor height for a vertical pullout (Song et al., 2005). This result was confirmed by centrifuge tests conducted on plate anchors installed and keyed in a transparent synthetic clay (Song et al., 2006). The authors also showed numerically that the loss of embedment reduces to 0.25 times the anchor height for a 45° pullout.

The overall range of embedment loss from the work quoted above, 0.25 to 2.5 times the plate height, is disconcertingly wide, equating to a high degree of uncertainty in the ultimate holding capacity. At an installation depth of 5 times the anchor height, a loss of embedment of 0.25 times the plate height is equivalent to 5% lost anchor capacity, increasing to 50% lost anchor

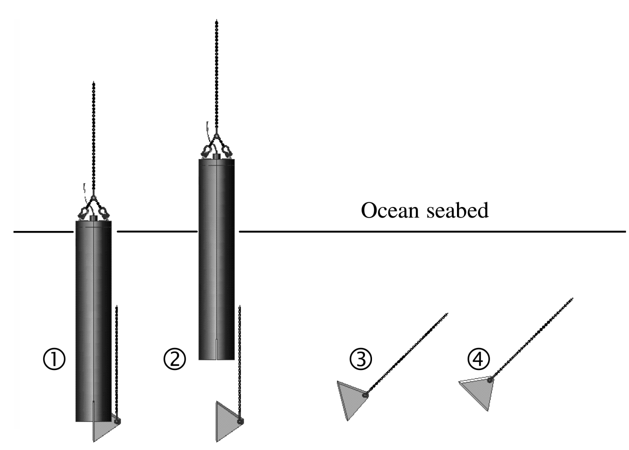

Fig. 1 SEPLA concept: ① suction installation, ② caisson retrieval, ③ anchor keying, ④ mobilised anchor

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KEY WORDS: Centrifuge modelling, clay, plate anchor, SEPLA, keying, failure mechanism, PIV (particle image velocimetry).