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An innovative concept of booster for OMNI-Max anchor

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ABSTRACT

OMNI-Max anchors are newly developed dynamically installed anchors for deep water mooring systems. However, the final penetration depth of the anchor after its dynamic installation can be limited, especially in a strong soil seabed with high strength gradient, due to its limited release height in water and large contact areas between the anchor flukes and the adjacent soil. To increase the anchor final penetration depth in seabed, an innovative concept of anchor booster is proposed in this paper. The booster, comprised of a cylindrical shaft with three rear fins, is attached to the anchor tail during its dynamic installation and then is retrieved after installation for reuse. The boosters with three different sizes, hence different masses, are designed and tested. Three dimensional computational fluid dynamics (CFD) simulations were conducted to investigate the working efficiency of a booster on the final penetration depth of the OMNI-Max anchor in a strong soil seabed. Moreover, the entire process of the dynamic installation of the hybrid anchors (an OMNI-Max anchor with a booster) from water to seabed is predicted by a theoretical model. The results demonstrate that the booster is beneficial both in improving the directional stability and impact velocity for the OMNI-Max anchor during its free fall in water. Relative to the OMNI-Max anchor, the final penetration depth of a hybrid anchor increases significantly (from 23% to 115%) due to the addition of the booster, which helps the anchor to gain higher holding capacity. This preliminary study is only to prove effectiveness of the booster concept without a complete investigation of the booster. More detailed studies are planned in the pipeline.

1. Introduction

1.1. OMNI-Max anchors

Offshore oil and gas exploration adventures into deeper waters with harsher environments due to the depletion of oil/gas fields in shallow waters. As offshore exploration develops into waters deeper than 1000 m, floating platforms secured by anchoring systems are more favourable [1]. Among various anchor types, dynamically installed anchors (DIAs) are cost-effective and time-efficient [2]. Torpedo anchors and deep penetrating anchors (DPAs) are first emerged DIAs, and they both have cylindrical shafts with conical or ellipsoidal tips and four rear fins (see Fig. 1(a–b)). Under monotonic uplift loading, their capacity efficiency ratios (i.e. the ratio of the holding capacity to anchor dry weight) are relatively low, which are in the range of 3–5 as reported by O'Loughlin et al. [3]. To increase the capacity efficiency ratio, the OMNI-Max anchor is developed as shown in Fig. 1(c) [4]. The OMNI-Max anchor has two distinct features compared with DPAs and torpedo anchors: (1) Instead of four small rear fins on DPAs and torpedo anchors, the OMNI-Max is primarily comprised of three pairs of flukes, and each pair includes a smaller tip fluke and a larger top fluke; (2) The padeye of the OMNI-Max anchor is located at the upper tip of the loading arm, which is mounted between the tip and top flukes and can rotate freely around the anchor shaft. The first feature enables more contact areas between anchor flukes and the surrounding soil to increase its holding capacity. The second feature encourages the anchor to dive deeper into the seabed during keying and hence to gain additional holding capacity [5].

1.2. Dynamic installation and keying processes of OMNI-Max anchors

The installation process of an OMNI-Max anchor includes two stages: Stage 1 – anchor free fall in water; and Stage 2 – anchor dynamic penetration into seabed (Fig. 2(a)). In Stage 1, the anchor is released at a predetermined height, which is termed as the release height, H_e, above the seabed. After the release, the anchor falls freely in water and accelerates under its gravity. The fall velocity at the mudline is termed the impact velocity. In Stage 2, the anchor penetrates within the seabed by its total energy, including the potential energy from its self-weight and the kinetic energy from its impact velocity.

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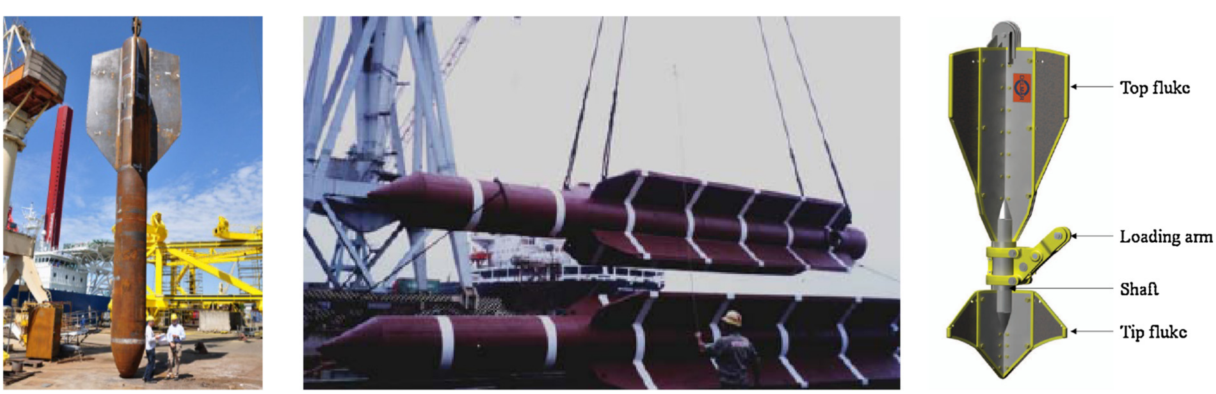
Notation

A_f	Anchor maximum projected area perpendicular to anchor shaft
B	Footing width
B_A	Fluke width of OMNI-Max anchor
C_D	Drag coefficient
C_m	Added mass factor
D_A	Ring diameter attached to the loading arm
D	Footing embedment depth
D_B	Booster diameter
D_i	Soil subdomain diameter in CFX
D_r	Rear ring diameter of the anchor booster
D_{rear}	Booster rear diameter
D_s	Soil domain diameter in CFX
F_D	Drag force
F_b	Soil buoyancy on the anchor
F_f	Soil frictional resistance on the OMNI-Max anchor or booster
F_s	Soil resistance on the anchor
F_t	Soil end bearing resistance on the OMNI-Max anchor or booster
H_w	Water domain height in CFX
H_e	Anchor release height
H_i	Soil subdomain height in CFX
H_s	Soil domain height in CFX
h_A	Anchor length
h_{A1}	Top fluke length
h_{A2}	Tip fluke length
h_B	Booster length
h_r	Top length of booster
k	Soil strength gradient
L_s	Sleeve length
L_t	Tip length of booster shaft
L_r	Height of the rear ring
l	Characteristic length
m^*	Added mass
m_A	Anchor mass
m_B	Booster mass
N_c	End bearing capacity factor
Re	Reynolds number
s_u	Soil undrained shear strength
s_{u0}	Soil undrained shear strength at seabed surface
$s_{u,ref}$	Soil reference undrained shear strength
S_z	Anchor free fall distance in the vertical direction
t	Time
t_A	Fluke thickness
t_r	Thickness of ring attached to the booster rear
v	Anchor velocity
v_0	Anchor impact velocity
V_s	Volume of soil displaced by the OMNI-Max anchor or hybrid anchors
v_T	Anchor terminal velocity
v_z	Anchor vertical velocity
W_s'	Anchor submerged weight in water
z	Penetration depth from soil surface
z_e	Anchor final penetration depth from anchor tip to soil surface
α	Friction coefficient
β	Strain-rate property factor
γ'	Soil effective unit weight
$\dot{\gamma}$	Shear strain rate
$\dot{\gamma}_{ref}$	Reference shear strain rate
δ	Tilt angle from anchor shaft to the vertical direction
δ_{rem}	Soil remoulding ratio
η	Viscous property factor
μ	Fluid dynamic viscosity
ξ	Soil cumulative plastic shear strain
ξ_{95}	Soil cumulative plastic shear strain for 95% remoulding
ρ_w	Water density
τ	Soil shear stress



(a) (b) (c)

Fig. 1. Dynamically installed anchors: (a) DPA (Deep Sea Anchors, www.deepseaanchors.com); (b) torpedo anchor (after de Araujo et al. [14]); (c) OMNI-Max anchor (www.delmarus.com).

After installation, the anchor is keyed to develop its holding capacity. The keying process is illustrated in Fig. 2(b). The mooring chain attached to the padeye at the tip of the loading arm is tensioned first. Then the anchor rotates (and dives hopefully) to a new position and orientation due to the padeye offset from the anchor centroid [6,7].

1.3. Advantages and limitations of the OMNI-Max anchor

By design, the OMNI-Max anchor has three advantages to increase its working efficiency: (1) high capacity efficiency ratio; (2) adjustability of the loading arm eliminating out-of-plane loading; and (3) potential to dive deeper with higher loading during operation (i.e. to keep its high holding capacity). During keying, the anchor is likely to rotate to an orientation more perpendicular to the uplift load at the