Loading Performance of Fish and OMNI-Max Anchors in Crust-over-Soft Clays

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- Number of Words: 2700 (text only)
- Number of Tables: 2
- Number of Figures: 10

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ABSTRACT

This paper reports the results from three-dimensional dynamic finite element analysis undertaken to provide insight into the behaviour of the fish and OMNI-max dynamically installed anchors during loading in crust-over-soft clay sediments. Particular attention was focused on the situations where the anchor is embedded to a shallow depth during dynamic installation due to the strong crust layer. Large deformation finite element analyses were carried out using the coupled Eulerian-Lagrangian approach, incorporating the anchor chain effect. Parametric analyses were undertaken varying the initial embedment depth, anchor shape, loading angle, strength ratio between the top and bottom layers. The tracked anchor trajectory confirmed that the diving potential of the fish and OMNI-Max anchors were enhanced by the presence of the crust layer as that somewhat restricted the upward movement. This will be beneficial for many hydrocarbon active regions with layered seabed sediments where the anchor embedment depths during dynamic installation are expected to be low.

KEYWORDS: dynamically installed anchors; crust-over-soft clays; loading; numerical modelling; offshore engineering

INTRODUCTION

Dynamically installed anchors have been identified as the most cost effective and promising concept for mooring floating facilities in deep water clayey sediments. They are also being increasingly considered in shallow waters for temporary mooring of floating facilities, such as floating wind turbines and wave energy converters. The anchor is released from a specified height above the seabed. This allows the anchor to gain velocity as it falls freely through the water column before impacting the seafloor and embedding into the sediments.

Seabed sediments generally comprise discrete layers of different thicknesses and properties. A distinguished strong or crust layer (i.e. the clay is one to two orders of magnitude stronger than a virgin deposit) is commonly encountered in both shallow and deep waters in the West coast of Africa, the Sunda Shelf, offshore Malaysia, Australia's Bass Strait and North-West Shelf [1-5]. Kim et al. [6] provided a summary of site investigation data for layered seabed sediments with a surface or interbedded crust layer.

Most of the previous field trials are limited to single layer clayey sediments (offshore Brazil, the Gulf of Mexico, the North Sea; Brandão et al. [7]; Zimmerman et al. [8]) or a soft-over-stiff deposit in the North Sea (Lieng et al. [9]). No attempt has been taken to install dynamically installed anchors in layered soils with a crust layer. Recently, Kim et al. [6] assessed the embedment depth of a torpedo anchor in crust-over-soft clay deposits through numerical analyses. Their results showed that the anchor can penetrate through the crust layer with thickness $0.25L_A$ (where L_A is the length of the anchor) and strength ratio to the bottom soft layer > 15 . However, under a similar impact velocity, the anchor embedment in crust (with thickness $\leq 0.3L_A$)-over-soft clay deposits was significantly lower ($0.4\sim1.4L_A$) than that in single layer soft clay ($2\sim3L_A$).

The recently developed anchors, such as the OMNI-Max [10] and fish [11, 12], were designed by shifting the padeye towards its tip at around the 2/3 height of the anchor length. This lowered padeye position may allow the anchor to embed further (through diving) under operational loadings [8, 10, 11, 12]. Several studies have confirmed this diving potential in clay, identifying the critical factors for diving as (i) anchor embedment depth, (ii) padeye offset ratio (η ; definition is in Figure 1), (iii) loading angle at the mudline or soil surface [11-15].

This paper provides a first attempt towards quantifying the effect of presence of a crust layer on the keying and diving behaviours of the OMNI-Max and fish anchors. A series of integrated dynamic installation-monotonic loading large deformation finite element (LD FE) analyses have been carried out using the established numerical modelling techniques accounting for strain softening and strain rate dependency of the undrained shear strength and embedded chain profile. An extensive parametric investigation was undertaken, varying the relevant range of various parameters related to the initial embedment depth, anchor shape, loading angle, strength ratio between the top and bottom layers.

NUMERICAL ANALYSIS

Geometry and parameters

This study has considered two diveable anchors including (a) the OMNI-Max anchor [8, 10] and (b) the fish anchor [11, 12]. Both anchors are illustrated in Figure 1, with the dimensions given in Table 1. The OMNI-Max anchor features three large fins with intermittent discontinuity to accommodate a loading arm that transfers the padeye nearer to the head of the anchor (see Figure 1a). Nearly 160 OMNI-Max anchors have been installed across the Gulf of

Mexico for temporary mooring of mobile offshore drilling units in water depths ranging from 290 m to 1,160 m [8, 16]. More recently, the fish anchor was developed, adopting a geometry taken from nature [17]. The fish anchor features elliptical cross-sections of smoothly varying size for the anchor shaft, and with the widest part in the anchor middle. To increase the potential for diving upon loading, the shaft is shaped to be thicker near the head to lower the resistance centroid (see Figure 1b). The padeye is fitted on the widest part of the shaft to mobilise the maximum resistance area under operational loading. This study has considered padeye offset ratio $\eta = 0.35$ for the OMNI-Max anchor, and $\eta = 0.40$ for the fish anchor, respectively. These padeye offset ratios showed the best diving efficiency in single layer clay [12, 13, 15].

Figure 2 shows a schematic diagram of an anchor installed in a crust-over-clay deposit. The top crust layer of thickness H with uniform undrained shear strength s_{ut} is underlain by a clay layer of (nominally) infinite depth of non-uniform undrained shear strength $s_{ub} = s_{ubs} + k(z - H)$. The strength difference between the two distinct layers is characterised by the ratio of the top layer strength to the bottom layer surface strength s_{ut}/s_{ubs} . The values of s_{ut} were determined according to strength ratios $s_{ut}/s_{ubs} = 5 \sim 15$. The thickness of the crust layer was varied relative to the anchor length as $H/L_A = 0.25 \sim 0.3$.

Analysis details

3D LDFE analyses were carried out using the coupled Eulerian-Lagrangian (CEL) approach in the commercial finite element package ABAQUS/Explicit [18]. Extensive background information about installation modelling of anchors in two-layer clays can be found in Kim et al. [6], which are not repeated here.

Considering the symmetry of the problem, only a half anchor and soil domain were modelled. The lateral extension of the soil domain from the centre of the anchor (D_p is the anchor frontal projected area (A_p) equivalent diameter) was $55D_p$ in the loading direction and $17D_p$ in the opposite direction. A typical mesh is shown in Figure 3. As obtained from preliminary convergence studies [12, 15], the typical minimum soil element size along the trajectory of the anchor was selected as $0.18t_f$ (where t_f is the anchor fin thickness) for vertical installation (very fine mesh zone) and $0.5t_f$ for inclined loading (fine mesh zone). The anchor was simplified as a rigid body.

The simulation was fully integrated taking into account the disturbed soil conditions through installation of the anchor for the loading stage [19]. An inclined loading, instead of an inclined displacement, was applied at the anchor padeye (θ_a) to obtain apparent anchor trajectory. In the field, environmental and operational loadings are transferred to the anchor interacting with the seabed. Upon loading at an angle at the mudline (θ_0), the embedded chain profile, anchor orientation, and (hence) the loading angle at the padeye (θ_a) change. To simulate this change of θ_a , an anchor chain equation (Neubecker and Randolph, [20]) was introduced in the analysis by a user subroutine. More details about the anchor chain modelling can be found in Zhao et al. [14].

The loading of anchors in clay was completed under undrained conditions. The soil was thus modelled as an elasto-plastic material obeying a Tresca yield criterion, but extended to capture strain-rate and strain-softening effects, following the models of Einav-Randolph [21].

$$s_u = \left[1 + \lambda \log \left(\frac{\text{Max}(|\dot{\gamma}|, \dot{\gamma}_{\text{ref}})}{\dot{\gamma}_{\text{ref}}} \right) \right] \left[\delta_{\text{rem}} + (1 - \delta_{\text{rem}}) e^{-3\xi\zeta/95} \right] s_{u,\text{ref}} \quad (1)$$

The definitions are given under notation list, with the details reported by e.g. Hossain and Randolph [22], Zheng et al. [23] and Kim and Hossain [15]. The elastic behaviour was defined by a Poisson's ratio of 0.49 and Young's modulus of $500s_u$ throughout the soil profile. The soil-anchor interface was modelled as frictional contact with a limiting shear stress ($\tau_{\max}$) along the anchor-soil interface.

As discussed previously, there are no measured data (either from centrifuge tests or field trials) for dynamically installed anchors in layered clays with a crust layer. This has limited corresponding validation of the used numerical model. However, the model has previously been used in investigating the performance of the torpedo, OMNI-Max and fish anchors in single layer clay [6, 12, 14, 15, 19, 26]. The results have been validated against existing field data and centrifuge test data, confirming the capability and accuracy of the numerical model in assessing installation depth, keying and diving of the dynamic installed anchors.

LOADING BEHAVIOR

This study has focused mainly on the anchor trajectories during loading. An extensive parametric study was carried out varying (a) impact velocity ($v_i = 8 \sim 30$ m/s); (b) strength ratio of the crust layer ($s_{ut}/s_{ubs} = 5 \sim 15$); and (c) loading angle. The thickness of the upper layer was kept constant at $H = 2.7$ m, and the strength of the lower layer at $s_{ub} = (2.4 + 1.1H) + 1.1(z - H)$ kPa. For single layer clay (i.e. $H = 0$), $s_{ub} = 2.4 + 1.1z$ kPa was considered. The results from this parametric study, as assembled in Table 2, are discussed below. Parameters in terms of rate dependency and strain-softening were taken as $\lambda = 0.1$; $\dot{\gamma}_{ref} = 1.5\% \text{ h}^{-1}$; $\xi_{95} = 20$, as they provided good match in the previous validation exercise in single layer clay [12, 15].

Embedment depth

Generally, anchor embedment depth, $d_{e,t}$, is a function of impact velocity, anchor weight, projected area, total anchor–soil contact surface area, and undrained shear strength of the surrounding soil [24-26]. Figure 4 shows the effect of the strength ratio of the crust layer ($s_{ut}/s_{ubs} = 5 \sim 15$) and impact velocity ($v_i = 8 \sim 30$ m/s) on the final embedment depth ($d_{e,t}$) of the OMNI-Max and fish anchors (Groups I ~ IV in Table 2). Note, Figure 4 also includes the padeye penetration depths ($d_{e,p}$). As expected, the embedment depths of the anchors reduce as s_{ut}/s_{ubs} increases. The reverse trend is evident with increasing impact velocity. For a very high strength ratio of $s_{ut}/s_{ubs} = 15$ and low impact velocities, the anchor penetration terminates between the two layers (see insets (a) and (b) in Figure 4), meaning the anchor penetration energy dissipates quickly at a very shallow depth. During penetration in the seabed sediments, the bottom half of the fish anchor provides a low-angle bearing surface hence facilitating penetration; the upper half loses contact with the adjacent soil, reducing frictional resistance. As such (and as it is heavier), under an identical impact velocity, the fish anchor penetrates deeper than the OMNI-Max anchor (see insets (c) and (d) in Figure 4). For a direct comparison of the loading behaviour of these two diveable anchors, the embedment depth of the padeye ($d_{e,p}$) should be identical. Therefore, based on the penetration results, a similar set of $d_{e,p}$ was selected (adjusting the impact velocity) for subsequent explorations (see Table 2).

Effect of embedment depth on diving potential

For a strong thin crust layer, the diving potential of the anchors was assessed varying embedment depth. As summarised in Table 2 (in Groups II and III), the strength ratio ($s_{ut}/s_{ubs} = 15$) and loading angle at the mudline ($\theta_0 = 0^\circ$) were kept constant.

Figures 5 and 6 depict the trajectories and corresponding failure mechanisms of the OMNI-Max and fish anchors, respectively, while loaded from similar initial padeye embedment depths ($d_{e,p} \approx 3.1$ and 13 m). The trajectories can be divided into two main stages: (a) keying; and (b) diving (Figures 5a and 6a) – consistent with single layer clay [8, 12-15]. At the beginning of the keying process, the soil adjacent to the anchor tip moves significantly and faster, while the soils around the tail fins move marginally (Figures 5c and 6c). This indicates that the anchor rotates or keying occurs at this stage and thus results in a loss of embedment. At the end of the keying process, more mobilisation of soil movement can be seen around the tail fins, indicating transition of the anchor with minor rotation. In the middle of diving stage (see inset figures), the anchor keeps diving into deeper soil with a constant angle, which means translation plays the dominant role at this stage.

Interestingly, shallower embedment depth ($d_{e,p} \approx 3.1$ m) results in a greater diving angle. Due to the presence of the strong crust layer just above the padeye, the initial loss of embedment during the keying process is very small compared to the deep embedment depth ($d_{e,p} \approx 13$ m). This allows an earlier transition from keying to diving with smaller rotation of the anchor (see Figures 5b and 6b). As such, although the embedment depth is not deep enough, the anchor can dive if there is a strong crust layer above the padeye. Note, with this embedment depth in a single layer clay, the anchor pulls out of the seabed without diving [12].

The OMNI-Max and fish anchors show a similar trajectory regardless of the embedment depth. However, the diving efficiency of the fish anchor is greater than the OMNI-Max anchor. For both embedment depths ($d_{e,p} \approx 3.1$ and 13 m), the fish anchor dives earlier with steeper anchor travelling angle (defined as ϕ ; see Figure 7). One of the key reasons is the relative lower location of the centroid mass of the fish anchor ($0.44L_A$ from the tip), compared to that of the OMNI-Max anchor ($0.52L_A$ from the tip) (see Figure 1).

Effect of loading angle

Figure 8 shows anchor trajectories for various loading angles at the padeye, $\theta_a = 15^\circ \sim 55^\circ$ (in Groups II and III, Table 2). Note, θ_a was kept constant during loading to explore corresponding effect. Overall, the stabilised centroid traveling angle φ decreases with reducing the loading angle (including negative values). This trend is consistent with that in single layer clay (Kim and Hossain, [15]; Group V in Table 2), which are also plotted together for comparison.

For shallow embedment depth of $d_{e,p} \approx 3.1$ m (i.e. the padeye is within the crust layer), the diving potential is very limited with the loading angle at the padeye (θ_a) and anchor geometry (see Figure 8a). For example, for $\theta_a = 30^\circ$, the fish anchor dives, while the OMNI-Max anchor pulls out of the soil. Again, due to the thicker head part and lower centroid mass, the rotation of the fish anchor during keying is much greater than that of the OMNI-Max anchor (see location (b) in Figure 8a).

For deep embedment depth of $d_{e,p} \approx 13$ m, due to the strong top layer, the anchors show a smaller loss of embedment, leading to an earlier transition from keying to diving, compared to that in a single layer clay under an identical loading angle (e.g. $\theta_a = 30^\circ$; see Figure 8b). Interestingly, for $\theta_a = 45^\circ$, the anchors dive in spite of the larger loss of embedment depth. As shown in the insets in Figure 8b, in the initial loading phase, the anchor pulls out with a stiff travelling angle (location (A)). When the anchor tail fins touch the crust layer (locations (b) and (c)), the anchor rotates quickly and transits to diving (location (d)). More interestingly, for $\theta_a = 55^\circ$, the anchor does not dive but travels a long distance under and along the strong crust layer (see insets). Although the anchor may eventually be pulled out, the trend is gradual.

This contrasts the previous studies for single layer clay or silt soil [13, 15], which concluded that the anchor pulls out of the soil for $\theta_a \geq 45^\circ$.

Effect of strength ratio

In the results presented so far, the soil strength ratio s_{ut}/s_{ubs} was kept constant at 15. This section focuses on the effect of s_{ut}/s_{ubs} on the anchor trajectory. Additional analyses were carried out considering $s_{ut}/s_{ubs} = 5$ and 10 (Group IV; Table 2). For a direct comparison, the embedment depth of the padeye was adjusted to be similar ($d_{e,p} \approx 13$ m) by changing impact velocity (v_i). Figure 9 plots the trajectories of the OMNI-Max anchor for $\theta_a = 30^\circ$. The result for single layer clay (with the strength gradient identical to that of the bottom layer of the layered deposits) is also included for comparison (Group V; Table 2). Interestingly, the loss of embedment of the anchor during the keying process reduces (leading to earlier transition to dive) as s_{ut}/s_{ubs} increases.

A design chart in terms of stabilised centroid travelling angle (φ) and padeye offset ratio (η) has been established in Figure 10 to be used in practice. $\varphi < 0$ indicates that the anchor will dive deeper, and $\varphi > 0$ signifies that the anchor will pull out of the soil. All the results for a similar embedment depth ($d_{e,p} \approx 13$ m) in crust-over-soft clay deposits ($s_{ut}/s_{ubs} = 5\sim 15$) are plotted along with the trajectories for single layer clay. It confirms clearly that, regardless of θ_a , (i) the crust layer enhances the diving potential if the anchor can penetrate through that layer during installation, and (ii) the diving potential of the fish anchor is significantly higher compared to that of the OMNI-Max anchor, and that increases with reducing θ_a .

CONCLUDING REMARKS

The loading performances of the dynamically installed OMNI-Max and fish anchors in crust-over-soft clay deposits have been explored through three-dimensional dynamic large deformation finite element analyses. The following key conclusions can be drawn from the results presented in the paper.

1. The embedment depths of the anchors reduced with increasing crust layer strength, and decreasing impact velocity. For very high strength ratio of $s_{ut}/s_{ubs} = 15$ and low impact velocities, the anchor penetration terminated between the two layers. The fish anchor penetrated deeper than the OMNI-Max anchor under identical impact velocity.
2. Even for a shallow embedment depth of $d_{e,p} \approx 3.1$ m with the padeye in the crust layer ($s_{ut}/s_{ubs} = 15$), both the fish and OMNI-Max anchors were able to dive. The fish anchor dived for the loading angle at the padeye $\theta_a \leq 30^\circ$, and the OMNI-Max anchor for $\theta_a \leq 20^\circ$. These are beneficial where the achieved embedment depths are significantly low due to the presence of the strong crust layer.
3. Even for a deeper embedment depth of $d_{e,p} \approx 13$ m with the full anchor length in the lower soft layer ($s_{ut}/s_{ubs} = 15$), the diving potential was enhanced by the presence of the crust layer. Both anchors dived for $\theta_a \leq 45^\circ$ in crust-over-soft clay deposits, whilst pulled out of the seabed for $\theta_a = 45^\circ$ in single layer soft clay. For $\theta_a = 55^\circ$ in crust-over-soft clay ($s_{ut}/s_{ubs} = 15$), the fish anchor travelled for a long distance along and under the crust layer before pulling out.
4. The loss of embedment of the anchors during the keying process reduced with increasing s_{ut}/s_{ubs} , leading to earlier transition to dive.

5. A design chart for the anchors travelling trajectory under operational monotonic loading was proposed to be used in practice. For at least $\theta_a \leq 45^\circ$, (i) the diving potential of the anchors was enhanced by the presence of the crust layer so long the anchor can penetrate through that layer during installation, and (ii) the diving potential of the fish anchor was significantly higher compared to that of the OMNI-Max anchor.

ACKNOWLEDGEMENTS

The research presented here was undertaken with support from the Australian Research Council through the Discover Early Career Researcher Award DE140100903. The work forms part of the activities of the Centre for Offshore Foundation Systems (COFS), currently supported as a node of the Australian Research Council Centre of Excellence for Geotechnical Science and Engineering, through Centre of Excellence funding from the State Government of Western Australia and in partnership with The Lloyd's Register Foundation. This support is gratefully acknowledged.

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Figure Caption (no. of Figures: 10)

Figure 1. Geometries of diveable dynamically installed anchors: (a) OMNI-Max anchor;
(b) Fish anchor

Figure 2. Schematic diagram of installed anchor in layered clays

Figure 3. Typical mesh used in finite element analysis: (a) Side view; (b) OMNI-Max
anchor modelling; (c) Fish anchor modelling

Figure 4. Anchor embedment depths in crust-over-soft clay deposits (Groups I~IV, Table
2)

Figure 5. Anchor trajectories and corresponding soil failure mechanisms: OMNI-Max
anchor (in Groups II and III, Table 2)

Figure 6. Anchor trajectories and corresponding soil failure mechanisms: fish anchor (in
Groups II and III, Table 2)

Figure 7. Effect of embedment depth on anchor trajectories (in Groups II and III, Table 2)

Figure 8. Effect of loading angle on behaviour of anchors (in Group II, III and V, Table
2): (a) At shallow embedment depth ($d_{e,p} \approx 3.1$ m); (b) At deep embedment
depth ($d_{e,p} \approx 13$ m)

Figure 9. Effect of strength ratio, s_{ut}/s_{ubs} (Groups III ~ V, Table 2)

Figure 10. Design chart for anchor travelling trajectory (Groups III ~ V, Table 2)

Figure 1. Geometries of diveable anchors: (a) OMNI-Max anchor; (b) Fish anchor

Figure 2. Schematic diagram of installed anchor in crust-over-soft clay

Figure 3. Typical mesh used in 3D LDFE analysis: (a) Side view; (b) OMNI-Max anchor modelling; (c) Fish anchor modelling

Figure 4. Anchor embedment depths on crust-over-soft clays (Groups I~IV, Table 2)

Figure 5. Anchor trajectories and corresponding soil failure mechanisms: OMNI-Max anchor (in Groups II and III, Table 2)

Figure 6. Anchor trajectories and corresponding soil failure mechanisms: fish anchor (in Groups II and III, Table 2)

Figure 7. Effect of initial embedment depth on anchor trajectories (in Groups II and III, Table 2)

(a) At shallow embedment depth ($d_{e,p} \approx 3.1$ m)

(b) At deep embedment depth ($d_{e,p} \approx 13$ m)

Figure 8. Effect of loading angle on diving potential and anchor trajectory (in Groups II, III and V; Table 2)

Figure 9. Effect of strength of curst layer on diving potential and anchor trajectory (Groups III ~ V, Table 2)

Figure 10. Design chart for anchor travelling (Groups III ~ V, Table 2)

425 **Table 1. Diveable anchor details**

Description	Symbol (unit)	OMNI-Max anchor [8, 10]	Fish anchor [11, 12]
Total anchor length	L_A (m)	9.15	11.0
Fin thickness	t_F (m)	0.1	0.1
Anchor frontal projected area equivalent diameter	D_p (m)	1.56	2.08
Anchor volume	V_A (m ³)	5.02	14.45
Anchor dry weight	W_d (kN)	390	850
Anchor submerged weight	W_s (kN)	341	702
Padeye offset	e_p (m)	0.684	0.716
Padeye eccentricity	e_n (m)	1.96	1.80
Offset angle	ω (deg.)	19.3	21.7
Padeye offset ratio	η^*	0.35	0.4

426 ^{*} $\eta = \tan\omega = e_p/e_n$ (see Figure 1)

427 **Table 2. Summary of 3D LDFE analyses performed**

Group	Anchor	S _{ut} (kPa)	S _{ut} /S _{ubs} [*]	H (m)	v _i (m/s)	d _{e,t} /d _{e,p} (m)	θ _a (deg.)	φ (deg.)	Note
I	OMNI-Max	54	10	2.7	20	12.10/ 8.05	-	-	Effect of impact velocity
	8				19.35/ 15.20				
	Fish				15	13.90/ 9.76			
					20	22.70/ 18.56			
II	OMNI-Max	81	15		19.3	7.20/ 3.15	—	-41 [#]	Effect of initial embedment: d _{e,p} ≈ 3.1 m
							20	-23	
							25	36.2	
							30	42.3	
	Fish				8	7.21/ 3.07	—	-64 [#]	
							15	-48	
							30	-16	
							32.5	69	
III	OMNI-Max	81	15		30	16.90/ 12.85	—	-34.3 [#]	Effect of initial embedment: d _{e,p} ≈ 13 m
							30	-28.8	
							45	-11.2	
							—	-42.8 [#]	
	Fish				15	17.3/ 13.16	30	-36.5	
							35	-30.9	
							45	-17.2	
							55	4.3	
IV	OMNI-Max	26.9	5		23.5	16.7/ 12.65	30	-21.1	Effect of top layer strength
		54	10				27	16.78/ 12.73	
					30	-27.2			
					45	-4.8			
V	OMNI-Max	2.4+ 1.1z	-	-	19	16.78/ 12.73	30	-15.8	Single clay layer [15]
							45	19.8	

* $S_{ubs} = 2.4 + 1.1H = 5.37$ kPa; $S_{ub} = S_{ubs} + 1.1(z - H)$ kPa (see Figure 1)

[#]Loading angle at the mudline is zero ($\theta_0 = 0^\circ$): considering embedded anchor chain profile

432 **NOMENCLATURE**

433	A_p	anchor frontal projected area
434	D_p	equivalent diameter (including fins)
435	$d_{e,p}$	anchor padeye embedment depth
436	$d_{e,t}$	anchor tip embedment depth
437	e_n	padeye offset distance
438	e_p	padeye eccentricity
439	H	top layer thickness
440	k	shear strength gradient
441	L_A	anchor shaft length
442	s_u	undrained shear strength
443	s_{ub}	soil strength of bottom layer
444	s_{ubs}	soil strength at top-bottom layer interface
445	s_{ut}	soil strength at mudline
446	$s_{u,ref}$	reference undisturbed soil strength
447	t_f	anchor fin thickness
448	v_i	anchor impact velocity
449	V_A	anchor volume
450	W_d	anchor dry weight
451	W_s	anchor submerged weight in water
452	z	depth below soil surface
453	δ_{rem}	remoulded strength ratio
454	δx	horizontal displacement
455	δz	loss of embedment depth
456	$\dot{\gamma}$	shear strain rate

457	$\dot{\gamma}_{\text{ref}}$	reference shear strain rate
458	η	padeye offset ratio
459	φ	anchor travelling angle
460	λ	rate parameter for logarithmic expression
461	θ_a	pullout angle at padeye
462	θ_0	pullout angle at mudline
463	τ_{max}	limiting shear strength at soil-anchor interface
464	ω	padeye offset angle
465	ξ	cumulative plastic shear strain
466	ξ_{95}	cumulative plastic shear strain required for 95% remoulding