Vertical Pullout Behaviour of a Torpedo Anchor Vertically in Stiff-Over-Soft Cohesive Soil Bed

Cheng Wang*, Minxi Zhangb and Guoliang Yu*

SKLOE, CISSE, School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai, China

*Corresponding author e-mail: yugl@sjtu.edu.cn, *wangcheng502781301@sjtu.edu.cn, bzhangmx@sjtu.edu.cn

Abstract. This paper reports the results from a large deformation finite element (LDFE) model to provide insights into the vertical pullout behaviors of torpedo anchors in stiff-over-soft soil beds. 10 sets of numerical data were obtained by varying the top layer thickness, soil shear strength of the stiff-over-soft soil bed, tip embedment depth ratio, and pullout speed. The tip embedment depth ratio of the torpedo anchor (the ratio of the embedment depth at anchor tip to the anchor shaft length) varied from 1.48 to 2.91. Soil flow characteristic was discovered by the finite element analysis. The observation of soil flow characteristics provided deep insight with the interaction between the torpedo anchor and its surrounding soil.

1. Introduction
Torpedo anchor is a new anchor solution for the exploration of deep marine resources, such as deep-water oil and gas, solar energy, wave energy, and so on. It is cone-tipped cylindrical steel pip ballasted with concrete and scrap metal. The first commercial application of torpedo anchors was conducted in the Campos Basin, offshore Brazil in 2002. Torpedo anchors have been used in ocean engineering typically with overall lengths in the range of 12-17 m, shaft diameters in the range of 0.8-1.2 m, and dry weight in the range of 230–1150 kN [1]. The anchor fins usually had length of 4 m to 11 m and width of 0.45 m to 0.9 m. The conical tip angle ranged from 30° to 60°. The typically penetration depth was approximately 2 to 3 times its length into the seabed in a vertical or near-vertical orientation [2]. To prepare it for installation, it should be first placed in a vertical position; and then it is launched, the momentum caused by its own weight would drive it into the seabed. The installation of the torpedo anchor would not require any external source of energy and it is a quick process requiring only one or two anchor-handling vessels and a limited use of ROVs (Remotely Operated Vehicles). Due to the cost effective, low cost fabrication and shorter installation, torpedo anchors were typically used as a component of mooring systems in natural soil bed [3]. Thus, in order to design and apply torpedo anchor in the deep-water oil and gas exploitation engineering, it is necessary to get a better understanding of pullout behaviour of torpedo anchors in natural seabed.

Many studies, including physical laboratory, field tests and numerical analyses, have been conducted to investigate the pullout behaviour of torpedo anchors vertically embedded in single-layered soil bed [1-5]. Theoretically, the vertical holding capacity of torpedo anchor in single-layered soil bed is taken to be consisted of the submerged weight in soil ($W_s$) and the end bearing ($F_b$) and the
shaft friction resistances \((F_s)\). The end bearing, shaft friction resistances and vertical holding capacity were mainly dependent on the maximum soil shear strength obtained at the final embedment depth. Then, the methods proposed by API (American Petroleum Institute) [6], O’Beirne et al. [5], and Fu et al. [3] are regarded as representative method to calculate the holding capacity of torpedo anchor in single-layered soil bed.

In general, soil profiles of seabed were naturally stratified or heterogeneous, rather than single-layered. A distinguished strong or crust layer (either at the surface or underlaid by a soft mud layer) was prevalent in both shallow and deep ocean in the Gulf of Thailand, the West coast of Africa, the Sunda Shelf, offshore Malaysia, Australia’s Bass Strait and North-West Shelf [7-11]. However, according to the research conducted by Kim et al. [12], the motion characteristics of the anchors and soil flow characteristics in two-layered soil bed were obviously different from those in single-layered soil bed.

Recently, the vertical holding capacity of other marine structures such as spudcan foundation and plate anchor in the two-layered soil bed has been intensively studied. According to the research on the extraction of spudcan foundations by Hossain and Dong [13], it was found that the maximum resistance mobilized at a shallow depth in the top layer for stiff-over-soft soil bed rather than at the beginning of extraction for a single-layered soil bed, while the load-displacement curve in a two-layered soil bed was obviously different from that in a single-layered soil bed. Similar experiments for plate anchor in two-layered soil bed were conducted by Rao et al. [14] and Liu et al. [15]. It was found that the vertical holding capacities of plate anchors embedded in a single-layered soil bed as well as a soft-over-stiff layered bed were mainly depended on the embedment depth and soil undrained shear strength at the final depth. However, the vertical holding capacities of plate anchors embedded in the stiff-over-soft soil bed was shown to occur at the top stiff layer rather than at the final depth. According to these studies, the vertical holding capacity of other marine structures was largely dependent on the soil properties of the two layers, the tip embedment depth and the thickness of the top layer.

However, researches on vertical holding capacity of torpedo anchor in a two-layered stiff-over-soft soil bed are very limited. Few field tests were conducted by Sturm et al. [16] at the Troll Field in the North Sea, offshore Norway, where the seabed strength is idealized by \(S_u=5\) kPa from \(Z = 0\) to \(2.5\) m, and by \(S_u=5 + 2.69 Z\) from \(Z =2.5\) to \(15\) m. Then, similar field tests were carried out by O’Beirne et al. [17] in Lower Lough Erne, where the strength profiles may be idealized by \(S_u=1.5 Z\) kPa from \(Z = 0\) to \(1.5\) m, and by \(S_u=2.25 + 0.8 Z\) from \(Z =1.5\) to \(3\) m. It was found by them that the behavior such as load-displacement curve and formula for calculating vertical holding capacity of the torpedo anchor in the soft-over-stiff soil bed was similar to that in single-layered soil bed. However, Sturm et al. [16] proposed that holding capacity in a stiff-over-soft soil bed might be higher than purely in softer layer. So far, few studies were conducted on the pullout of torpedo anchor in stiff-over-soft soil bed. Therefore, further investigations should be experimentally or numerically undertaken to explore the pullout behaviour of the torpedo anchor in stiff-over-soft soil bed.

In this study, the vertical pullout behavior of a torpedo anchor in stiff-over-soft cohesive beds was investigated by a large deformation finite element (LDFE) model. The soil flow characteristics during the pullout process of torpedo anchor was observed by LDFE analyses. In order to simplify the study, the undrained shear strength of the top stiff layer and underneath soft layer were assumed to be uniform, respectively. The effects of the top layer thickness, soil undrained shear strengths of the stiff-over-soft soil bed, tip embedment depth, and pullout speed on the vertical holding capacity were investigated.

2. Numerical analysis

2.1. Torpedo Anchor

In this study, numerical analysis was carried out on for the torpedo anchor ‘A30’ with no fin as shown in Figure 1. The torpedo anchor was identical to that used by Wang et al. [18], and Wang et al. [19].
The anchor with a solid conical tip (30°) and a hollow shaft was made of stainless steel. The geometric dimensions of the anchor are shown in Table 1.

![Photograph of the model anchor.](image)

**Figure 1.** Photograph of the model anchor.

**Table 1.** The geometric dimensions of the model anchor

| Anchor number | Mass, m (g) | Diameter, d (cm) | Length, L (cm) | Slenderness ratio, L/d | Lateral area, A_L (cm²) | Projected area, A_F (cm²) | Cross section perimeter, C_F (cm) |
|---------------|-------------|-----------------|---------------|-----------------------|------------------------|--------------------------|-------------------------------|
| A30           | 176.4       | 1.9             | 20.9          | 11                    | 103.59                 | 4.28                     | 5.97                          |

2.2. Analysis details

A large deformation finite element (LDFE) model was formulated. Herein, the coupled Eulerian-Lagrangian (CEL) method in the commercial package ABAQUS/Explicit [20] was adopted to solve the problem of large deformation of soil in the numerical analysis. The CEL method has been proved to be reasonable to simulate the pullout behaviour of anchor in soil [21, 22]. In the simulation, the torpedo anchor ‘A30’ and the soil were discretized with Lagrangian and Eulerian elements, respectively. The soil was modelled as an elastic-plastic material obeying a Tresca yield criterion. The Poisson’s ratio was taken as 0.49 (sufficiently high to give minimal volumetric strains, while numerical stability was maintained). A uniform stiffness ratio \(E/S_y=500\) (where \(E\) is the Young’s modulus) for both stiff and soft soil layer. The interface between the torpedo anchor and soil was modelled as frictional contact, using a general contact algorithm. The friction coefficient \(\alpha\) at the interface was 0.25 as in Hossain et al. [23]. Considering the symmetry of the pullout behavior and structure, only two 15° slices of the anchor and soil domain were modelled to shorten the calculation time. The typical mesh used in the CEL analysis was shown in Figure 2. In order to eliminate the boundary effects of soil, the soil domain was taken to be 40\(d\) in diameter and 8\(d\) in depth [24]. Besides, in order to accommodate the uplift part of the surface soil, a 5 cm thickness of void layer was also set on the soil bed surface. According to the convergence studies conducted by Kim et al. [24], the minimum mesh sizes of the soil was set as 0.019\(d\). The submerged unit weight of the soil over the soil depth was 6 kN/m³ [24].

3. Results and analysis

3.1. Results

10 sets of numerical simulation data were summarized in Table 2 for vertical pullout of torpedo anchor ‘A30’ vertically embedded in stiff-over-soft soil bed. The top stiff layer thickness ratio \((H_1/L)\) ranged from 0 to 0.96. The tip embedment depth of the torpedo anchor in the present study ranged from 30.9 cm to 60.9 cm.
**Figure 2.** Typical mesh used in CEL analysis: (a) side view; (b) plane view.

**Table 2.** The vertical holding capacity obtained by simulation

| Run | $H_1$ (cm) | $D$ (cm) | $V$ (cm/s) | $S_{sat}$ (Pa) | $S_{sub}$ (Pa) | $F_{PU}$ (N) | Notes                                      |
|-----|------------|----------|------------|----------------|----------------|--------------|--------------------------------------------|
| 1   | 0          | 40.9     | 0.2        | 5430           | 1810           | 16.89        | Effect of top layer thickness             |
| 2   | 5          |          |            |                |                | 18.25        |                                            |
| 3   | 10         |          |            | 20.58          |                | 23.5         |                                            |
| 4   | 15         |          |            |                |                | 32.42        |                                            |
| 5   | 20         | 40.9     | 0.2        | 5430           | 1810           | 24.14        |                                            |
| 6   | 10         | 30.9     | 0.2        | 5430           | 1810           | 20.58        | Effect of tip embedment depth              |
| 7   | 10         | 40.9     | 0.2        | 5430           | 1810           | 22.07        |                                            |
| 8   | 10         | 50.9     | 0.2        | 5430           | 1810           | 23.64        |                                            |
| 9   | 10         | 60.9     | 0.2        | 5430           | 1810           | 24.14        |                                            |
| 10  | 10         | 40.9     | 0.2        | 5430           | 1810           | 20.58        | Effect of undrained shear strength of top |
|    |            |          |            | 3620           | 1810           | 18.66        | stiff soil                                 |
| 11  | 10         | 1810     | 1810       | 1810           | 1810           | 16.89        |                                            |
| 12  | 10         | 40.9     | 0.2        | 5430           | 1810           | 20.58        | Effect of pullout speed                    |
| 13  | 10         | 40.9     | 0.2        | 5430           | 1810           | 30.16        |                                            |
| 14  | 10         | 40.9     | 0.2        | 5430           | 1810           | 23.5         |                                            |
3.2. Load-displacement curve

Typical load-displacement curves during the vertical pullout process according to the numerical results by the LDFE simulation were shown in Figure 3, which the tip embedment depth of the torpedo anchor was 40.9 cm and $Z$ is the displacement of the anchor. The whole pullout process could be divided into three stages. In the first stage, with the increase of the pullout displacement, the pullout load increased sharply to the maximum pullout load (Peak 1), and then decreased. In this stage, the anchor was fully inside the soft soil layer, and the corresponding load-displacement curve in stiff-over-soft soil layer was similar to that in single soil layer. Again, the pullout load was not basically affected by the top stiff layer. In the second stage, the pullout load gradually increased with the increasing of pullout displacement. The pullout load increased gradually, then increased rapidly as the top of the anchor approached the interface between the top stiff layer and the underneath soft layer. The anchor was still fully inside the underneath soft soil layer. In this stage, the pullout behavior was affected by the synthesis influence of top and underneath soil layers. Furthermore, the influence of the top stiff soil layer became more and more obvious. In the last stage, the pullout load firstly increased to be the second maximum pullout load (Peak 2) and then sharply decreased with the increasing displacement. The anchor started to enter into the top stiff soil layer. The pullout behavior was mainly affected by the top stiff soil layer. In Figure 3, the height of the underneath soft soil affected by the top stiff soil was marked as $H_{eff}$. In stiff-over-soft soil bed, the vertical holding capacity ($F_{PU}$) was regarded to be the maximum value from Peak 1 and Peak 2. As shown in Figure 3, it was obviously demonstrated that the load-displacement curve of the torpedo anchor in the stiff-over-soft soil bed was obviously different from that of the torpedo anchor in single soil layer.

![Figure 3. Load-displacement curves.](image)

3.3. Soil flow characteristics

In the first stage (see Stage 1 in Figure 3), as shown in Figure 4(a), the soft soil above the torpedo anchor flowed upward, which was manifested as a general shear failure mechanism [21], while the stiff soil did not move. An approximately inclined shear plane was observed alone with the moving soft soil. The soil below the torpedo anchor separated from the anchor and a cavity was formed. In the first stage, the soil flow characteristics in the two-layered soil were the same as that of a single soil layer.

In the second stage (see Stage 2 in Figure 3), as shown in Figure 4(b), the soft soil above the anchor began to flow horizontally and depart from the anchor. Specially, the soft soil near the top of anchor rotated around the anchor shaft, which was characterized by localized backflows. Meanwhile, the top
stiff soil basically did not move except for a slight uplift near the interface of the stiff-over-soft soil. The stiff soil behaved similarly to a wall boundary and prevented the destruction of the underneath soft soil. The underneath soft soil was gradually compressed under the obstruction of the top stiff soil, the stress of the soft soil gradually increased, and the pullout load of torpedo anchor subsequently increased.

In the third stage (see Stage 3 in Figure 3), as shown in Figure 4(c), the anchor moved into the top stiff soil, while adhering to a small amount of underneath soft soil. The interface of the stiff-over-soft soil was destroyed, which led to a very small amount of underneath soft soil which flowed into the top stiff layer through the damaged interface zone. But, most of the underneath soft soil was blocked by the stiff interface. The flow characteristics of the soil above the anchor was the same as that in the first stage. With the motion of the torpedo anchor, the contact area between the anchor and the top stiff soil increased gradually. Because the stress of the top soil layer was greater than that of the underneath layer, the pullout load of the anchor was increasingly affected by the top stiff soil. With the further pullout of torpedo anchor, as shown in Figure 4(d), the soil failure interface extended from the edge of the torpedo anchor to the mud surface, and the surface was obviously heaved. Due to the low stress of the soil near the bed surface, the end bearing and shaft friction resistances of torpedo anchor decreased gradually, resulted in the pullout load decreased.
3.4. Effect of top stiff layer thickness

The effect of top stiff layer thickness on the pullout load of the torpedo anchor is shown in Figure 5 ($S_w=5430 \ Pa$, $S_d=1810 \ Pa$, $D=40.9 \ cm$). As expected, the second maximum pullout load (Peak 2) increased obviously with the increasing of the top stiff layer thickness $H_1$, while the first maximum pullout load (Peak 1) increased little. For instance, the Peak 2 increased from 18.25 N to 32.42 N when the top stiff layer thickness increased from 5 ($H_1/L=0.24$) to 20 cm ($H_1/L=0.96$). Notably, for the thinner top stiff soil layer (such as $H_1=5 \ cm$), the top soil would not obviously increase the vertical holding capacity of torpedo anchor, which could be interpreted by Figure 6. This may be due to the fact that the average soil stress (along the anchor shaft) produced by the deeper underneath soft soil layer was equal to or greater than that produced by the thin stiff soil layer during the pullout of the anchor. Furthermore, the greater the thickness of the top stiff layer, the larger the influence range of the underneath soft soil layer affected by the top stiff soil would be. For example, when the top stiff layer thickness increased from 5 cm to 15 cm, the height of affected underneath soil layer ($H_{eff}$)

Figure 4. The soil flow characteristics for torpedo anchor in stiff-over-soft soil bed.
increased from $0.82d$ to $1.03d$. Thus, the vertical holding capacity for the torpedo anchor vertically embedded in stiff-over-soft soil bed was influenced by the top stiff layer thickness.

**Figure 5.** Effect of the top stiff layer thickness on the pullout load.

**Figure 6.** Effect of the top stiff layer thickness on the vertical holding capacity.

3.5. Effect of tip embedment depth

The effect of tip embedment depth on the pullout load was shown in Figure 7, where the $H_1$ was 10 cm, $S_{up}$ and $S_{ub}$ was 5430 Pa and 1810 Pa, respectively. For the same top stiff layer thickness, the maximum pullout loads (Peak 1 and Peak 2) and vertical holding capacity of torpedo anchor had little change with the increase of the tip embedment depth of the torpedo anchor. For instances, the Peak 1 increased from 18.11 N to 22.98 N, while the Peak 2 increased from 20.37 N to 23.64 N, when the tip embedment depth increased from 40.9 cm to 60.9 cm. Besides, the greater the tip embedment depth, the larger the $H_{aff}$ would be. When the tip embedment depth increased from 40.9 cm to 60.9 cm, $H_{aff}$ increased from $0.86d$ to $1.78d$, which caused the increase of the Peak 2. For the Peak 1, the greater the tip embedment depth, the greater the Peak 1 would be, which have been confirmed by Chen et al. [21]. However, it should be noted that the vertical holding capacity was not positively correlated with the tip embedment depth, as shown in Figure 8. When the top of the anchor approached to the interface of stiff-over-soft soil bed, the hindrance of the top stiff layer to the underneath soft layer was more significant before the soil was destroyed.
3.6. Effect of soil undrained shear strength ratio of top layer to underneath layer

The effect of the soil undrained shear strength ratio of top layer to underneath layer on the pullout load was shown in Figure 9. For the same thickness and undrained shear strength of the underneath soft soil, the greater the undrained shear strength of the top stiff soil, the greater the $H_{eff}$ would be. Again, the more the top stiff soil hindered the pullout process of torpedo anchor, the larger the vertical holding capacity of torpedo anchor would be. When the undrained shear strength of top stiff soil, $S_{ut}$, increased from 1810 $Pa$ to 5430 $Pa$, the shape of load-displacement curve gradually changed from single peak to two peaks, and the value of the second peak gradually increased. This was due to the fact that with the increase of the undrained shear strength of top stiff soil, the greater the hindrance and reinforcement of the top stiff soil to the underneath soft soil would be, resulting in the gradual increase of the pullout load and vertical holding capacity.
3.7. Effect of pullout speed
The effect of the pullout speed on the pullout load was shown in Figure 10, where the $H_1$ was 10 cm, $D$ was 40.9 cm, $S_{ut}$ and $S_{ub}$ was 5430 Pa and 1810 Pa, respectively. The maximum pullout loads (Peak 1 and Peak 2) and the vertical holding capacity of the torpedo anchor increased with the pullout speed. For instance, when the pullout speed of the torpedo anchor increased from 0.2 cm/s to 2 cm/s, the vertical holding capacity significantly increased from 20.58 N to 30.16 N. This is due to that the larger pullout speed would cause a larger shear rate, and then the soil showed the characteristics of shear reinforcement [12]. Besides, a larger pullout speed enlarged the transmission range of stress and broadened the range of soil disturbance, and thus increased the vertical holding capacity of the torpedo anchor.

Figure 10. Effect of the pullout speed on the pullout load.

4. Conclusions
In present study, the three-dimensional large deformation finite element model was formulated. Numerical analyses were conducted to investigate the vertical pullout behavior of finless torpedo
anchor in uniform stiff-over-uniform soft cohesive beds. The effects of the top stiff layer thickness, anchor tip embedment depth, undrained shear strength ratio of top layer to underneath layer, and pullout speed on the pullout load were intensively investigated. The major conclusions are drawn as follows:

The load-displacement curves of stiff-over-soft soil bed was different from that of single-layer soil bed. The vertical holding capacity ($F_{PV}$) was the maximum value between Peak 1 and Peak 2.

The vertical holding capacity of torpedo anchor increased with the increasing top stiff layer thickness except for the thinner top stiff soil layer. Again, the greater the top stiff layer thickness, the larger the height of the underneath soft soil affected by the top stiff soil would be.

The vertical holding capacity of torpedo anchor were affected by the soil undrained shear strength ratio of top layer to underneath layer and pullout speed. The larger the soil undrained shear strength ratio and pullout speed, the greater the vertical holding capacity would be.

In future, further investigations are necessary to consider the effect of intermittent pullout load rather than constant load. Besides, it is also necessary to propose a formula of vertical holding capacity of torpedo anchor in stiff-over-soft cohesive beds.

**Acknowledgments**

This work was financially supported by the National Key Research and Development Program of China (Grant number: 2016 YFC0402607)

**References**

[1] F.E.N. Brandao, C.C.D. Henriques, J.B. Araújo, O.C.G. Ferreira, C.D.S. Amaral, "Albacora Leste field development-FPSO P-50 mooring system concept and installation," Offshore Technology Conference. Offshore Technology Conference, 2006.

[2] J.T. Lieng, T.I. Tjelta, K. Skaugset, "Installation of two prototype deep penetrating anchors at the Gjoa Field in the North Sea," Offshore Technology Conference, 2010.

[3] Y. Fu, X. Zhang, Y. Li, H. Gu, J. Sun, Y. Liu, F.H. Lee, Holding capacity of dynamically installed anchors in normally consolidated clay under inclined loading, Can. Geotech. J. 54 (2017) 1257-1271.

[4] M.D. Richardson, C.D. O’Loughlin, M. F. Randolph, C. Gaudin, Setup following installation of dynamic anchors in normally consolidated clay, J. Geotech. Geoenviron. Eng. 135 (2009) 487-496.

[5] C. O’Beirne, C. D. O’Loughlin, D. Wang, C. Gaudin, Capacity of dynamically installed anchors as assessed through field testing and three-dimensional large-deformation finite element analyses, Can. Geotech. J. 52 (2014) 548-562.

[6] API RP 2GEO, Geotechnical and foundation design considerations, 2014.

[7] J.P. Castleberry II, N. Prebaharan, Clay crusts of the Sunda Shelf-a hazard to jack-up operations, Proc. 8th Southeast Asian Geotechnical Conference, 1985.

[8] C.J. Ehlers, J. Chen, H.H. Roberts, Y.C. Lee, The origin of near-seafloor “crust zones” in deepwater, ISFOG, 2005.

[9] C.T. Erbrich, “Australian frontiers-spudcans on the edge,” ISFOG, 2005.

[10] J.L. Colliat, H. Dendani, A. Puech, J.F. Nauroy, “Gulf of Guinea deepwater sediments: Geotechnical properties, design issues and installation experiences,” ISFOG, 2011.

[11] M. Kuo, M. Bolton, The nature and origin of deep ocean clay crust from the Gulf of Guinea, Geotechnique 63 (2013) 500-509.

[12] Y.H. Kim, M.S. Hossain, J.K. Lee, Dynamic installation of a torpedo anchor in two-layered clays, Can. Geotech. J. 55 (2017) 446-454.

[13] M.S. Hossain, X. Dong, Extraction of spudcan foundations in single and multilayer soils, J. Geotechn. Geoenviron. 140 (2013) 170-184.
[14] S. N. Rao, Y.V.S.N. Prasad, 1993. Experimental studies on plate anchors in layered marine soils. In The Third International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers.

[15] J. Liu, Y.X. HU, L. L. WU, “Pullout capacity of circular plate anchors in double-layered clays,” In Proceedings of International Symposium on Frontiers in Offshore Geotechnics, 2005.

[16] H. Sturm, J.T. Lieng, G. Saygili, “Effect of soil variability on the penetration depth of dynamically installed drop anchors,” Proceedings of Offshore Technology Conference, 2011.

[17] C. O’Beirne, C.D. O’Loughlin, C. Gaudin, A release-to-rest model for dynamically installed anchors, J. Geotech. Geoenviron. 143 (2017) 04017052.

[18] W.K. Wang, X.F. Wang, G.L. Yu, Penetration depth of torpedo anchor in cohesive soil by free fall, Ocean Eng. 116 (2016) 286-294.

[19] C. Wang, X.H. Chen, G.L. Yu, Maximum force of inclined pullout of a torpedo anchor in cohesive beds, China Ocean Eng. 2019 in press.

[20] Dassault Systemes, Abaqus 6.14 EF documentation, Rhode Island: Hibbitt, Karlsson and Sorensen, Inc., 2014.

[21] Z. Chen, K. Tho, C.F. Leung, Y.K. Chow, Influence of overburden pressure and soil rigidity on uplift behavior of square plate anchor in uniform clay. Comput. Geotech. 52 (2013) 71-81.

[22] Y. H. Kim, M.S. Hossain, Numerical study on pull-out capacity of torpedo anchors in clay, Geotech. Lett. 6 (2016), 275-282.

[23] M. S. Hossain, Y. Kim, D. Wang, “Physical and numerical modeling of installation and pull-out of dynamically penetrating anchors in clay and silt,” In: The 32nd international conference on ocean, offshore and arctic engineering, 2013.

[24] Y.H. Kim, M.S. Hossain, D. Wang, Effect of strain rate and strain softening on embedment depth of a torpedo anchor in clay, Ocean Eng. 108 (2015) 704-715