A REVIEW OF DRAG ANCHOR PENETRATION MODELS TO INFORM CABLE BURIAL RISK ASSESSMENT

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ABSTRACT The constant expansion of the offshore wind farm industry towards new markets has led to a number of challenges, one of which is the protection and maintenance of subsea power cables in a broader range of seabed conditions. The main hazard to these buried cables comes from vessel-deployed drag anchors, as pointed out by Carter (2010). Therefore, the assessment of the penetration depth of a drag anchor during its installation process is of paramount importance to determine the appropriate burial depth of such cables. This paper provides a comprehensive review of models of drag anchor behaviour by grouping them by area and providing an assessment of each model currently available.

Keywords: drag anchor, embedment depth, cable burial depth, anchor penetration.

INTRODUCTION

Managing and maintaining the infrastructure constitutes a crucial strategy for the future of offshore energy systems. In this context, one of the facilities that can be threatened by external factors are subsea cables. Such power cables transport and distribute the electricity generated offshore in wind turbine generators (WTGs) to the onshore transmission system. Since the cables can span long distances between the wind farm and the shore, they are exposed to different hazards. As the wind energy industry grows, wind farms are being pushed further offshore, resulting in longer cable routes which in turn has resulted in additional hazards being encountered and overall greater exposure. Cable routing and cable burial are regarded as the primary methods of protection for subsea power cables. Where a hazard to such infrastructure exists, the most effective way to reduce this risk is to reroute these facilities away from the hazard, e.g. away from a designated anchorage area. Nevertheless, in many instances, it is not possible to do this, and the cable must be buried in the seabed to reduce the risk of external threats. According to Carter (2010), the most known threat to a subsea power cable—which have been buried more than $60\ cm$ into the seabed—is considered to be anchor strike whether be it due to emergency anchoring or to drag anchor standard installation procedures (the difference between these cases will be fully explained later in this work). The assessment of anchor penetration of drag anchors is therefore a critical consideration.

In the windfarm industry, it is considered best practice to define burial depths based on a Cable Burial Risk Assessment (CBRA) as outlined by the Carbon Trust methodology (2015). The aim of the CBRA is to define an optimum depth of burial by applying a risk-based approach, yielding an adequate and economical burial with a consistent level of protection. However, this paper focuses on deterministic methods, which constitute part of a wider probabilistic approach.
In the past, field-scale tests were used to determine burial depths due to anchor penetration (see, for instance, NAVFAC (1987)). Nevertheless, the recent development of numerical analyses has led to their use for this application. Concerns (Luger and Harkes 2013) also exist that old guidelines - which were derived from the above-mentioned field tests - could be over-conservative in some situations. In order to check the validity of these concerns, understanding the drag anchor installation process is of the utmost importance to quantify a suitable burial depth for different anchors and soils. This also allows consideration as to which physical phenomena are predominant and which can be ignored.

To describe the regular process (i.e. not in an emergency simulation), let us consider Fig. 1a. Once the ship crew has deployed the drag anchor, this, as well as part of the installation line, lies on the seabed. In the literature (for instance, Gault and Cox, 1974), the shape of the remaining part, which stays in the water, takes the form of a *catenary*. Because of vessel motion and anchor geometry, the embedding process starts. The profile of the line embedded in the soil is called a *reverse-catenary* owing to its opposite curvature compared to the length of line within the water column. The installation stops when equilibrium is reached between the vessel's inertia force and the holding capacity developed both by the mooring line and the anchor. It is essential to underline that these three steps usually take place in the case of a traditional mooring, whereas they can be different or even absent in the case of emergency anchoring. In this instance, the embedment process does not always occur, and the anchor can be dragged on the seabed for long distances. However, it is difficult to consider emergency situations because of their inherent unpredictability. As such, the majority of the articles take standard anchoring into account, except for Luger and Harkes (2013), Maushake (2013; 2015), and Grabe and Wu (2016).

It is useful to divide the above-described procedure into two separate problems (see Fig. 1b). The first relates to the shape of the *reverse catenary* (the portion of the installation line embedded in the seabed), which is responsible for transmitting the force to the drag anchor. This includes studying the shape of the installation line and the friction between this and the soil and is the first step in understanding the forces applied to the anchor. The second problem deals with anchor trajectory and kinematics. In the authors' opinion, this is the most crucial aspect since the ultimate embedment depth can be known if, and only if, the anchor behaviour is successfully understood. Moreover, the installation line, the anchor, the water and the soil affect this process simultaneously. Therefore, the main subdivisions of a full literature would be into the two following problems: installation line, and anchor trajectory and kinematics. However, due to space limitations, the former is not covered in this paper.

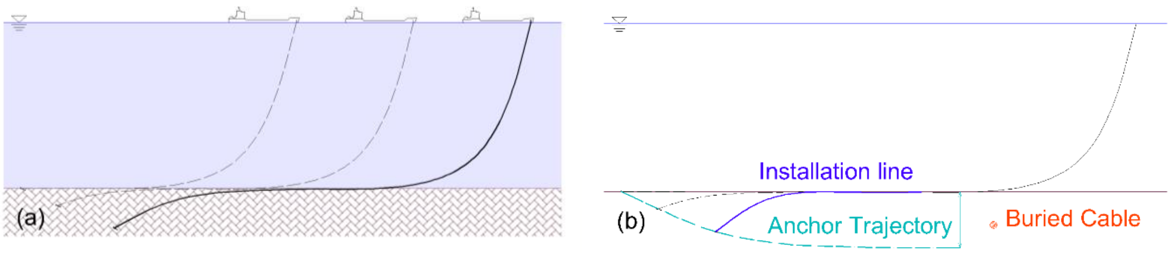

Fig. 1. Anchor models: from (a) physical to (b) literature categorization.

ANALYTICAL SOLUTIONS FOR ANCHOR KINEMATICS

Several papers have proposed methods for predicting anchor trajectory or its ultimate embedment depth. In this area, analytical models represent an excellent tool because of both their simplicity and effectiveness. In general terms, these approaches can be grouped into four categories according to their initial hypotheses: *limit equilibrium method* (LEM), *yield envelope* formulation, *limit analysis* and *kinematic enforcement*.

Limit equilibrium method

The *limit equilibrium method* (LEM) describes the soil surrounding the anchor under failure conditions in which the resisting mechanisms of the soil are independently considered as separate ultimate resistances. Neubecker and Randolph (1996b) proposed an easily implementable solution for clays whose shear strength can be represented by a power law in terms of its variation with the depth. Two fundamental assumptions, which are still regarded as valid for fixed shank anchors, underlie Neubecker's and Randolph's work: the trajectory direction of the anchor was parallel to its fluke and the drag angle θ_a (see Fig. 2) was considered constant during the embedment process. Due to the former hypothesis, the anchor resistance can be considered as a function of the anchor area projected in the travel direction and the soil bearing capacity. Moreover, this paper showed a procedure for computing the ultimate embedment depth in the case of arbitrary layered clayey soil.

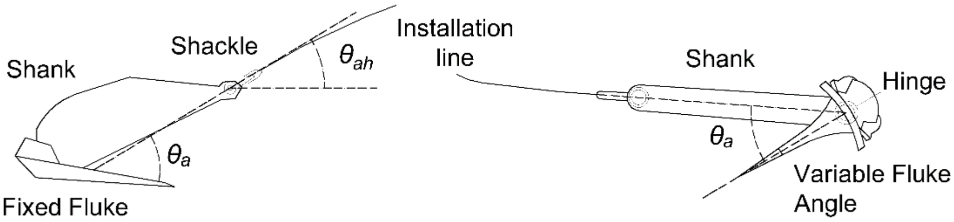

Fig. 2. Anchor main components and parameters for different models.

Thorne (1998) described soil resistance dividing it into more specific components. This author's iterative procedure for describing anchor trajectory involved equations different from Neubecker's and Randolph's, but the idea behind these methodologies was the same: they consisted of predicting a certain direction for the anchor movement per each displacement increment and then correcting it via equilibrium equations. Ruinen (2004) varied this procedure again, but his major contribution was the investigation of anchor behaviour in the case of a stiffer layer existing within an otherwise uniform soil. The author evaluated the presence of such a layer at different depths and with different shear strengths. Surprisingly, he found out that the presence of a stiffer layer (up to three times the strength of the surrounding soil) influenced anchor trajectory by only 2%. However, in this paper, the results are not further confirmed, e.g. by numerical analyses or physical tests.

Liu *et al.* (2010a) expanded Neubecker's and Randolph's theory to determine the ultimate embedment depth for sand. These authors carried out parametric studies by changing different physically meaningful values, some of them related to the soil characteristics, such as the adhesion factor , the undrained shear strength , and the bearing capacity factors or , and others related to the anchor, such as the effective bearing width of the drag line, or the angle θ_a (see Fig. 2). Despite their extensive research, Liu et al.'s model is still dependent on the above-mentioned parameter θ_a, which had to be chosen *a priori*. Zhang *et al.* (2013; 2015) not only provided an analytical formulation for this value, but they also confirmed the underlying hypothesis of considering it as constant during the embedment process. In 2012, the work of Liu *et al.* (2012b) shed new light on Neubecker's and Randolph's first assumption (trajectory parallel to fluke). These authors developed an analytical approach to better determining the anchor trajectory direction in the case of rectangular and wedge-shaped flukes. In the former design, their study agreed with this hypothesis, whereas, in the latter, the authors rectified the direction since the anchor moved parallel to the fluke's bottom surface.

Yield envelope formulation

The second category of analytical methods uses plasticity concepts. This approach consists in determining a combination of forces acting on the anchor which leads to soil failure. The locus described by these forces is called the *yield envelope surface*. The formulation of the yield envelope has to be completed by numerical analyses to determine the parameters relating the forces in each considered direction. Once the yield surface has been established, the magnitude and the direction of the anchor motion are evaluated via an *associated flow rule* and the *orthogonality condition* respectively.

The first proposal using this method for clay was published in O'Neill *et al.* (2003). In this paper, the behaviour of a rectangular and a wedge-shape anchor was taken into account. In the former case, it was noticed that the yield envelope was symmetrical about its axes, whereas, in the latter, offset force values were necessary to include the non-symmetric geometry of the anchor. To assess the validity of their function, the authors compared their solutions, in case of non-interactive mechanisms, to limit analyses. Elkhatib and Randolph (2005) improved the same model by including a non-smooth contact surface between the anchor and the surrounding soil. By decreasing the parameter controlling the roughness of the surface, this paper showed a substantial increase (by 75% for a friction value of 0.4) in the ultimate embedment depth prediction. Tian *et al.* (2015) merged the yield envelope formula with analytical formulations to present a closed-form solution describing the whole installation line-anchor system. Owing to the use of adimensional quantities which reduced the number of unknowns in the considered equations, the authors were able to explore the influence of these on drag anchor behaviour more immediately. Nevertheless, they acknowledged that considering the rotation point of the anchor coincident with its centroid was the main drawback of their theory. These authors believed that this approximation could be regarded as valid for anchors with a thin bridle shank. Tian *et al.* (2019) expanded O'Neill *et al.*'s (2003) yield function to finite displacement theory. In this fashion, more data from experimental tests were directly applicable to fit the yield function parameters. Separate mention should be made for Aubeny and Chi (2009), where a merger between analytical forces calculated with LEM and their interaction via yield envelope method was proposed.

However, all the above-mentioned papers in this subject area were restricted to plane strain analyses. Hence, a possible development could be including three-dimensional strain effects in such models to quantify the variation between these and bi-dimensional results.

Limit Analysis

The third analytical method was developed and investigated by Aubeny, Kim and Murff in a number of papers (Aubeny *et al.* 2005; Kim 2007; Aubeny *et al.* 2008). They focused on establishing an implementable tool based on *limit analyses* to predict anchor trajectory for anchors with a bulky shank in clay. Their main idea was to achieve an upper bound solution by selecting the centre of rotation of a kinematically admissible displacement field such that the virtual work was a minimum. The outcome in terms of tension at the shackle was then plotted as a function of its direction. This curve, called the *characteristic* curve, was superimposed on a similar graph derived from an analytical solution of the installation line. The intersection between these two curves determined the anchor movement direction. These solutions were also successfully compared with large-scale tests. Furthermore, Aubeny and Chi (2010) studied the effects of an out-of-plane traction force applied with the same method after the installation process.

Kinematic enforcement method

Lastly, Liu *et al.* (2012a) proposed a completely different approach. In this case, the anchor motion is chosen *a priori* to be a *cycloid* (a curve traced by a point on the circumference of a circle whose centre is moving at constant speed along a straight line without slipping). In this model, it is necessary to calculate the reverse catenary length to describe the anchor kinematics. Moreover, two quantities are essential to determine the installation line shape: the angle θ_{ah} (see Fig. 2) and the ultimate embedment depth z_a. Data or expressions about these quantities can be found in Liu *et al.* (2010a). The strengths of this method are that it describes the anchor behaviour both in clay and sand, and it considers the interaction system between the installation line and the anchor.

NUMERICAL METHOD FOR ANCHOR KINEMATICS

Numerical analyses have only recently become more common to predict anchor trajectory since the traditional Finite Element formulation is not the most appropriate tool for this problem. For the most part, the problems lie in mesh distortion as a consequence of large soil displacements. Therefore, only the implementation of the Coupled Eulerian Lagrangian method (CEL) within commercial software, which makes use of a Lagrangian mesh for discretizing the structure, and an Eulerian one for discretising the soil, increased the number of papers which used numerical analyses for these type of problems. The above-mentioned CEL method appears to have been first used for this problem in Liu and Zhao (2014). In this paper, a comprehensive relationship between anchor geometry and its corresponding trajectory, and the role played by installation line velocity were analysed in clay. The results were also useful to assess Liu and co-authors' analytical methods, in particular Liu *et al.* (2010a) and Liu *et al.* (2012b). In 2015, Grabe *et al.* (2015) explored anchor trajectory in sands using the CEL method under drained and undrained conditions and considered these two situations as the deepest and shallowest embedment respectively. Most probably, as the authors suggest, field conditions are somewhere in between the extreme scenarios. Moreover, they modelled the constitutive relationship through non-trivial formulae to properly consider dilatancy, non-linearity and hysteretic behaviour in the material. Their analyses focused on a particular commercial type of anchor whose fluke-shank angle can vary from -35 to $+35$ degrees; real-scale tests (Luger and Harkes 2013) confirmed their numerical results.

CEL simulations were also performed by Grabe and Wu (2016) in clay using a visco-plastic stress-strain model. More importantly, emergency anchoring was simulated by applying an initial momentum to the end of the installation line. This boundary condition makes anchor embedment continue until an equilibrium condition is reached. This paper reported some results radically different from previous literature: the observed anchor penetration process was periodic and dragging velocity plays a role in anchor trajectory if soft clay is considered.
To the author's knowledge, it is difficult to attribute these results to the type of anchor, where the fluke-shank angle can vary, or to the emergency conditions or even to the adopted constitutive relationship. As such, further investigation should be conducted in this area to understand the cause of these differences. Osthoff *et al.* (2017) published a paper dealing with the interaction between anchor trajectory and buried cable in sands. These authors took three cable burial depths into account and showed that severe (but not damaging) traction and pressure are applied to the cable, even if the anchor passed above it. In this case, drained conditions were simulated to achieve the maximum penetration depth.

LABORATORY AND FIELD EXPERIMENTS FOR ANCHOR KINEMATICS

Experimental data have played a key role both in assessing some of the hypotheses necessary for the development of analytical methods and in studying the uncertainties regarding the drag anchor kinematics. The latter aspect was essential, especially in the early stages of research, when the relationship between fundamental quantities had not been adequately defined. In particular, several laboratory tests provided a useful comparison tool for verifying analytical trajectory predictions. On the other hand, field tests (especially real-scale ones, in which commercial anchors were deployed) and numerical data were analysed to understand the whole anchor-installation line system, even under emergency conditions, where more variables, such as the drag speed of the anchor, have to be considered.

Dunnavant and Kwan (1993) performed centrifuge tests of drag anchor embedded in a normally consolidated kaolin clay and discovered a quasi-linear relationship between the soil shear strength and anchor capacity. According to the authors, the plots of anchor weight against anchor capacity showed a good agreement between the empirical data coming from the NCEL (1987) and the American Petroleum Institute (1991). These authors also studied the consolidation phenomenon, called *anchor soaking*, which can take place in the proximity of the anchor if the anchor itself is permitted to rest for some time. It was noticed that the disturbed zones around the anchor increased their capacity, but this effect vanished as the movement continued. O'Neill *et al.* (1997) ran centrifuge tests on very similar soil, but they employed a novel procedure using a rigid loading arm instead of the line. According to the authors, a marked scaling dissimilarity between the chain and the anchor did not allow correct interpretation of the forces acting on the system. In these tests, the anchor type was a $1:80$ scale model of a commercial prototype. These experiments provided a better understanding of the angle between the fluke and the horizontal when the ultimate capacity was approached. In this case, it was discovered that this became close to zero (the anchor travelling parallel to the mudline). Even small-scale centrifuge tests were performed by O'Neill and Randolph (2001) in normally consolidated clay. In this case, the authors decided to use the same anchor, but with different fluke-shank angles, even though the presence of the clay typically requires wider angles (up to 50^o). This choice is due to the necessity of evaluating two parameters (a shape parameter, called f, and the shank angle θ_a), crucial for Neubecker's and Randolph's analytical formula (Neubecker and Randolph 1996b). The authors chose to conduct two different types of tests: in the former, the rigid loading arm was fixed, whereas, in the latter, the anchor embedment could vary. In other work, Neubecker and Randolph (1996a) considered silica and calcareous sands to perform numerous plane strain centrifuge tests, where their $1:80$ scale model was dragged between two smooth walls. The density and the compressibility of soil samples varied from dense to loose, and these factors affected the results, particularly from a kinematic point of view. Nonetheless, the direction of the anchor was confirmed to be parallel to the bottom surface of the fluke, and this result is widely accepted in the literature if wedge-shape anchors are considered. The authors also documented that a consistent decrease in terms of anchor holding efficiency takes place if three-dimensional tests are run.

The aims of the investigation carried out by Liu *et al.* (2010b) were to explore some relationships previously unexplored in fine loose sands. A drag and retrieval system together with a tank were used, both of which did not influence the three-dimensional anchor behaviour. Two aspects were emphasised in this paper: it was shown that no guarantee for the trajectory direction of the anchor exists if its geometry becomes more complicated (as with commercial anchors), and that the initial orientation of the anchor affects only the early stage of the penetration. Extensive work was done by Aubeny *et al.* (2011), who tested both $1:30$ and $1:10$ scale models in two different kaolin clays under different conditions. The performances of the smaller model focused on the effects of varying installation lines. It was found that thinner chains led to significantly higher (up to 50%) embedment, whereas anchor initial orientation has negligible effects on its trajectory since anchors tend to converge to a unique path. Moreover, it appeared that bearing factors derived from small-scale tests exceeded values from large-scale tests by 10%, and the authors attributed this to different fluke thickness of the models. Furthermore, in the $1:10$ scale tests, the effect of loads acting on a plane oblique to the vertical symmetric axis of the anchor was evaluated. Results showed that the anchor line could orient itself and lay in the same inclined plane, leading to two counteracting effects: a reduction in the embedment depth, which makes anchor capacity decrease, which was balanced by the increase in the soil volume which has to be mobilised to reach the ultimate pull-out condition. Beemer and Aubeny (2012) ran some small-scale tests in a translucent silicate gel whose trajectory was verified by a digital image processing device to avoid any uncertainty. Even though the repeatability of these tests was confirmed, the thixotropy (i.e. time-dependent viscosity) of the considered gel did not allow proper comparison between these results and other data coming from clays. Thus, this testing methodology can be regarded as a qualitative tool for visualising large displacements undergone by the soil, especially if a non-conventional anchor geometry is considered.

Real-scale analyses were performed on behalf of the company CREL (2010) employing a 1.5 and 3 tonne commercial anchor at different sites. In medium and dense sands ($D_r = 40 - 80\%$), investigations demonstrated that the anchor shank was not entirely buried and, hence, the mooring was hardly achievable. The embedment depth increased in case of mixed sandy ($D_r = 20 - 30\%$) and clayey soils and even more in soft clay sites, with a maximum penetration of $1.95\,m$ the last-mentioned seabed. These quantities are significantly smaller compared to other data in the literature (see Kim 2007) and, to the author's knowledge, they can be due either to low-efficiency anchors (according to the Vryhof Guide 2010) or to soil characteristics (and it is significant that no mechanical properties have been published about the clay site).

Even though the results mentioned above are unusual if compared to analytical or numerical solutions, similar findings for real-scale tests were published by Luger and Harkes (2013) and Maushake (2013; 2015). These authors ran their field tests on three different areas, two in sands and the other with a layered sandy-clayey soil. Nevertheless, it is essential to emphasise that the tests were conducted to be representative of emergency anchoring, where the anchor embedment depth is close to zero and the drag distance is significant.

SUMMARY AND CONCLUSIONS

A review of currently available models in the literature (summarised in Matrix 1) has been conducted to better understand drag anchors embedment, one of the most significant threats to subsea power cables. The review focuses on analytical models, numerical simulations, and laboratory or field experiments on anchor trajectory and kinematics. As such, models describing the shape and the forces acting on the installation line are not discussed in this paper. Analytical models can be considered easier to implement and perhaps can be more attractive to the industry because of this. Overall, these models provide an appropriate representation of the anchor drag phenomena. Nevertheless, in the authors' opinion, some adjustments and refinements could still be proposed. In particular, the limit equilibrium method (LEM) entirely relies on the appropriate choice of bearing capacity factors. These values are a function of the anchor geometry and of the anchor movement in the soil, thus, they are extremely difficult to estimate *a priori*. Moreover, as underlined by the study of Liu et al. (2012), the anchor movement is not always parallel to the bottom direction of its fluke. Limit analyses share the same uncertainties of LEM on bearing capacity factors. However, to the authors' knowledge, this method has not been applied to study anchor behaviour in sands. This could be due to the necessity of evaluating the bearing capacity factor N_q, which is related to the lateral overburden of the soil and, as such, varies with the anchor depth. A plausible solution could be to approximate this value as proposed by Liu et al. (2010) and Zhang et al. (2013; 2015) for the LEM. The yield envelope formulation can be regarded as a more reliable but computationally expensive tool according to the authors' opinion. Nevertheless, there exist no such analyses taking sandy soils into account. The kinematic enforcement method described by Liu et al. (2012a) deserves a separate mention: this can be recognised as the model which describes the physics of the embedment processed in the most detailed fashion. However, it relies on the appropriate choice of the parameter θ_a, which Liu et al. estimated by comparing their results with other analytical solutions. Numerical analyses using the CEL method have shown to be an appropriate tool for investigating drag anchor behaviour, especially if compared to traditional FE formulations, which struggle to model phenomena involving large plastic deformations. From this perspective, a comparison between the results coming from CEL analysis and others from a different numerical method could be valuable for assessing both outcomes. Experimental tests constitute the basis for validating the results from analytical and numerical formulations, since they provide a fully-controlled environment, especially if compared to real-scale tests, where the system cannot be entirely monitored. Overall, the studies considered in this review provide a good foundation to understand the main principles and factors which govern drag anchor trajectory and kinematics and to model this process for predicting anchor penetration, even though some aspects require further investigation to reduce uncertainty and hence achieving reliable models.

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Matrix 1. Literature review content: anchor kinematics and trajectory.

Papers	Seabed Material	Anchor efficiency	Method	Notes
Aubeny and Chi (2009)	Cl.	*A\B	An.	Yield envelope and LEM
Aubeny and Chi (2010)	Cl.	*A\B	An.	Out-of-plane limit analysis
Aubeny *et al.* (2005)	Cl.	*A\B	An.	2D limit analysis
Aubeny *et al.* (2008)	Cl.	*A\B	An.	2D limit analysis
Aubeny *et al.* (2011)	Cl.	A	An., Ex.	2D limit analysis; 1:10 and 1:30 scaled lab tests
Beemer and Aubeny (2012)	-	A	Ex.	Laboratory tests (in gel)
CREL (2010)	Cl., Sa.	E & F	Ex.	Offshore tests
Dunnawant and Kwan (1993)	Cl.	A	Ex.	Centrifuge tests
Elkhatib and Randolph (2005)	Cl.	*A\B	An.	Yield envelope
Grabe and Wu (2016)	Cl.	E	Num.	CEL
Grabe *et al.* (2015)	Sa.	E	Num.	CEL
Kim (2007)	Cl.	A	An., Ex.	2D limit analysis; Field tests
Liu and Zhao (2014)	Cl.	*A\B	Num.	CEL
Liu *et al.* (2010a)	Cl., Sa.	*A\B	An.	LEM solved analytically
Liu *et al.* (2010b)	Sa.	-	Ex.	Laboratory tests
Liu *et al.* (2012a)	Cl., Sa.	*A\B	An.	Kinematic enforcement
Liu *et al.* (2012b)	Cl., Sa.	*A\B	An.	LEM solved analytically
Luger and Harkes (2013)	Cl., Sa.	E & F	Ex.	Offshore tests
Maushake (2013)	Cl., Sa.	E & F	Ex.	Offshore tests
Maushake (2015)	Cl., Sa.	E & F	Ex.	Offshore tests
Neubecker and Randolph (1996a)	Sa.	-	Ex.	1:80 scaled centrifuge tests
Neubecker and Randolph (1996b)	Cl.	*A\B	An.	LEM solved iteratively
O’Neill and Randolph (2001)	Cl.	A	Ex.	1:160 scaled centrifuge tests
O’Neill *et al.* (1997)	Cl.	A	Ex.	1:80 scaled centrifuge tests
O’Neill *et al.* (2003)	Cl.		An.	Yield envelope
Osthoff *et al.* (2017)	Sa.	E	Num.	CEL
Ruinen (2004)	Cl.	*A	An.	LEM solved iteratively
Thorne (1998)	Cl.	*A\B	An.	LEM solved iteratively
Tian *et al.* (2015)	Cl.	-	An.	Yield envelope and analytical formulae
Tian *et al.* (2019)	Cl.	-	An.	Yield envelope
Zhang *et al.* (2013)	Cl., Sa.	*A\B	An.	LEM solved iteratively
Zhang *et al.* (2015)	Cl., Sa.	*A\B	An.	LEM solved iteratively

Legend:
models describing emergency conditions;
** in case of estimated efficiency where applicable. Efficiency is based on Vryhof (2010);*
models considering Cl. = clay or Sa. = sand seabeds;
An. = Analytical Solution, Num. = Numerical Analysis, Ex. = Experimental Data.