



GUIDANCE NOTES ON

DESIGN AND INSTALLATION OF DRAG ANCHORS AND PLATE ANCHORS

MARCH 2017

**American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862**

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Foreword

These Guidance Notes provide ABS recommendations for the design and installation of drag anchors and plate anchors for offshore service. Included in these Guidance Notes are the site investigation, methodologies for geotechnical design and structural assessment, and installation and testing recommendations for drag anchors and plate anchors. Other approaches that can be proven to produce at least an equivalent level of safety will also be considered as an alternative.

These Guidance Notes are applicable to the design of drag anchors and plate anchors, as a component of taut, semi-taut, or catenary mooring systems. These Guidance Notes are to be used with the criteria contained in the *ABS Rules for Building and Classing Offshore Installations*, the *ABS Rules for Building and Classing Floating Production Installations*, the *ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations*, and the *ABS Rules for Building and Classing Mobile Offshore Drilling Units*.

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SECTION 1 General

1 Introduction

The purpose of these Guidance Notes is to provide recommendations for the design and installation of drag anchors and plate anchors for taut, semi-taut or catenary mooring systems. These Guidance Notes are to be used in conjunction with the *ABS Rules for Building and Classing Offshore Installations (OI Rules)*, the *ABS Rules for Building and Classing Floating Production Installations (FPI Rules)*, the *ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations (FOWTI Guide)*, and the *ABS Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*.

3 Scope and Application

These Guidance Notes cover the geotechnical design, structural assessment and installation for both drag anchors and plate anchors.

5 Terms and Definitions

DIP follower: The dynamically installed pile (DIP) used to install the dynamically embedded plate anchor (DEPLA) by self-weight penetration.

Embedment ratio: The ratio of anchor embedment depth to the width of anchor fluke.

Keying: The process that a plate anchor is pulled and rotated until the plate surface is perpendicular to the load direction to achieve the maximum capacity.

Loss of embedment: Vertical displacement at the center of the anchor fluke during keying.

Soil overburden pressure: The pressure caused by the soil self-weight. It is defined as the soil unit weight times the anchor embedment depth.

Soil non-homogeneity: A non-dimensional factor to represent the non-homogeneity of the soil. It is defined as the rate of increasing undrained shear strength with depth time the width of the anchor fluke divided by the soil undrained shear strength (kB/s_u).

Suction follower: The suction caisson that used to penetrate the plate anchor and can be reused to install the suction embedded plate anchor.

Thickness ratio: The ratio of plate anchor fluke width to thickness.

7 Symbols and Abbreviation

7.1 Symbols

A_f = area of the anchor fluke

A_{plate} = projected maximum fluke area perpendicular to the direction of pullout

A_{in} = plan view of inside area where suction pressure is applied

A_{inside} = inside lateral area of the suction follower

A_{wall} = sum of inside and outside wall area embedded into soil

A_{tip} = vertical projected sectional area for both suction follower and plate anchor

B	=	width of the plate
b	=	chain bar or wire diameter
d	=	nominal diameter of chain, or diameter of wire or rope.
D	=	outside diameter of the suction follower
D_{water}	=	water depth
e	=	loading eccentricity
e_f	=	loading eccentricity for friction resistance
e_w	=	loading eccentricity for anchor weight
E_t	=	multipliers to give the effective widths in the tangential direction
E_n	=	multipliers to give the effective widths in the normal direction
F	=	resistance offered by the soil tangential to the chain (per unit length)
$F_{friction}$	=	friction of mooring line on the sea bed
f_s	=	anchor shank resistance
f_{sl}	=	frictional coefficient of mooring line on sea bed at sliding
F_{anchor}	=	maximum load at anchor for design environmental condition
FOS	=	factor of safety
k	=	rate of increasing of undrained shear strength with depth
L	=	length of the plate
L_{bed}	=	length of mooring line on seabed at the design storm condition
M_0	=	initial moment corresponding to zero net vertical load on the anchor
N_c	=	bearing capacity factor
N_e	=	bearing capacity factor under combined loading
N_q	=	bearing capacity factor, depending on the friction angle
$N_{n,max}$	=	bearing capacity factor under condition of pure normal loading
$N_{t,max}$	=	bearing capacity factor under condition of pure tangential loading
$N_{m,max}$	=	bearing capacity factor under condition of pure moment loading
P_{line}	=	maximum mooring line tension
Q	=	resistance offered by the soil normal to the chain (per unit length)
Q_{ave}	=	average bearing resistance per unit length of chain over the soil depth D
Q_1	=	normalized soil resistance due to mudline strength
Q_2	=	normalized soil resistance due to strength gradient
Q_{tot}	=	total penetration resistance
R_{anchor}	=	holding capacity of drag anchor
R_{PLA}	=	holding capacity of plate anchor
s	=	distance measured along the chain

s_u	=	undrained shear strength of soil at the depth of anchor fluke
$s_{u_{tip}^{AVE}}$	=	average of triaxial compression, triaxial extension, and direct simple shear (DSS) undrained shear strength at anchor tip level,
$s_{u_{DSS}}$	=	direct simple shear strength
$s_{u,r}$	=	remolded undrained shear strength
s_{u0}	=	undrain shear strength at mudline
S_t	=	soil sensitivity
t	=	thickness of the anchor fluke
T	=	tension of the chain
T_a	=	tension at the attachment point
T_0	=	tension at the mudline
T^*	=	normalized tension
μ	=	coefficient
w	=	anchor line self-weight per unit length
W_{sub}	=	submerged unit weight of mooring line
W'	=	submerged weight during installation
W'_a	=	difference between the anchor weight in air and the anchor buoyancy force in soil
x	=	horizontal length of the mooring line from anchor
x^*	=	x/D
Δz	=	loss of anchor embedment
z	=	anchor embedment depth
z'	=	embedment depth of the mooring line from the mudline
z^*	=	z'/D
z_{tip}	=	tip penetration depth
α_{ins}	=	adhesion factor during installation, it is usually defined as the ratio of remolded shear strength over undisturbed shear strength
α	=	adhesion factor for anchor line
γ'	=	effective unit weight of soil
γ	=	soil unit weight
η	=	reduction for soil disturbance due to penetration and keying
σ_{eqv}	=	equivalent Von Mises stress
σ_{yield}	=	yield stress of the considered anchor structural component
β	=	load inclination during the keying
τ_a	=	average shear stress
τ_{cy}	=	cyclic shear stress amplitude

$\tau_{f,cy}$	=	cyclic shear strength
τ_0	=	initial soil shear stress prior to the installation of anchor
θ	=	orientation of the chain to the horizontal
θ_a	=	anchor line angle from horizontal at shackle point
θ_f	=	fluke angle to horizontal
θ_0	=	angle of anchor line from horizontal at mudline
δ	=	interface friction angle at soil-mooring line interface

7.3 Abbreviations

CPTU	piezocone penetrometer test
DEC	Design Environmental Condition
DEPLA	dynamically embedded plate anchor
DIP	dynamically installed pile
DSS	direct simple shear
SEPLA	suction embedded plate anchor
VLA	vertical loaded anchor



SECTION 2 Site Investigation

1 General

Site investigation is conducted to determine the seabed stratigraphy and soil engineering parameters for the anchor design and geohazards analysis. Generally, the procedure for the site investigation program should include:

- Desk study to obtain regional and relevant data for the site
- Sea floor survey to obtain relevant geophysical data
- Subsurface investigation and test to obtain the necessary geotechnical data
- Additional sea floor survey and/or subsurface investigation and/or laboratory test as required

Depending on the size of a project and/or the complexity of the geotechnical context and associated risks (geohazards), additional intermediate stages may be necessary.

The site investigation should satisfy the requirements given in 3/6.3 of the *OI Rules*.

It is important that the geophysical and geotechnical components are planned together as integrated parts of the same investigation. Data analyses should be considered as a single exercise drawing together with the results of geological, geophysical, hydrographic and geotechnical work, performed by specialists, in an integrated manner into one final report.

3 Desk Study

The desk study assembles existing data for the preliminary site assessment and will formulate requirements for subsequent sea floor surveys and subsurface investigations. The desk study should include a review of all sources of appropriate information, collect and evaluate all available relevant data for the site including:

- Bathymetric information
- Regional geological data
- Regional meteorological and oceanographic data
- Information and records of seismic activity
- Existing geotechnical data and information
- Previous experience with foundations in the area

Data of the regional geological characteristics is also to be used to verify that the findings of the subsurface investigation are consistent with known geological conditions. An assessment of the seismic activity, fault plane, seafloor instability, scour and sediment mobility, shallow gas and seabed subsidence are used when necessary.

5 Sea Floor Survey

Geophysical data for the conditions existing at and near the surface of the sea floor should be obtained during the sea floor survey. It should provide information about the soil stratigraphy, local soil condition and evidence of geological features. The geophysical survey report should be provided for the scope of the geotechnical investigation. It should be performed before geotechnical investigation. Geophysical survey should provide qualitative assessment across site. So whenever possible, the acquired geophysical data should be used in the subsequent planning of the geotechnical site investigation which provides quantitative assessment. The following information should be obtained where applicable:

- Seafloor bathymetry and topography (particularly in area of uneven seafloor, outcrops, corals, pockmarks, sand waves, etc.) – by echo-sounding or swath echo-sounding
- Seafloor features and obstructions (e.g., the presence of boulders, small craters, faults, scarps and run outs from debris flows) – by side-scan sonar
- Seabed sub-bottom profiling to define structural features within the near surface sediments –by means of reflection seismic systems or seismic refraction systems

The kinds and sizes of features that can be identified with these surveys depend on the resolution of the data. Different survey types with their uses, features that can be identified, typical resolution limits and advantages and limitations can be referred to *ABS Guidance Notes on Subsea Pipeline Route Determination*. It is recommended that a high-quality, high-resolution geophysical survey be performed. The minimum survey area for the geophysical survey should be the full extent of anchor spread. For drag anchors, the extension of site investigation may increase due to the associated large drag distance. The regional geophysical survey is a convenient starting point since it is collected to support oil and gas exploration over the reservoir or field development area and is typically available early in the process.

The seabed location of the anchors may change due to changes in mooring lines lengths and/or headings, field layout, platform properties, and mooring leg properties during the detailed platform and mooring design process. This should be taken into consideration in the site investigation program.

The following information should be obtained where applicable to the planned anchor design.

- Soundings or contours of the sea bed
- Presence of boulders, obstructions, and small craters
- Gas seeps
- Shallow faults
- Slump blocks
- Subsea permafrost or ice bonded soils

7 Subsurface Investigation and Testing

The subsurface investigation and testing program is to obtain reliable geotechnical data concerning the stratigraphy and properties of the soil. This data is to be used to assess whether the desired level of structural safety and performance can be obtained and the feasibility of the proposed method of installation.

7.1 Subsurface Investigations

As the quality of soil sample is expected to decrease with increasing water depth, the use of in-situ testing techniques is encouraged for deepwater sites. Typical tools used include remote vane, piezoprobe, CPTU (piezocone penetrometer tests), T-bar or ball penetrometer, etc. The required depth of site investigation is at least the anticipated design penetration depth plus a consideration for the zone of influence of the loads imposed by the base of the foundation. The zone of influence should be at least the anchor diameter or anchor fluke width^[1]. The sampling frequency and depth of sampling will depend on a number of project-specific factors such as the number of anchor locations, soil stratigraphy and water depth. Typically, soil characterization is performed at each anchor location or at each anchor group for a group mooring pattern,

or at least at two locations per anchor cluster over the anchor pattern if the interpretation of the survey shows little variation in soil properties across the pattern. However, if high-quality geotechnical data already exists in the general vicinity of the anchor pattern then little variation of soil properties is inferred over the areal extent of the foundation. However if extensive experience with the chosen foundation concept in the area can be drawn upon, the above recommendations may be modified as appropriate. For anchors such as drag anchors, the extension of site investigation may increase due to the associated large drag distance. If the soil investigation is performed primarily using CPTU, it is recommended that at least one boring with sampling be taken to properly calibrate the CPTU results. This boring/core should be taken at one of the CPTU locations.

7.3 Soil Testing Program

The soil testing program is to reveal the necessary engineering properties of the soil including strength, classification and deformation properties of the soil. Testing should be performed in accordance with recognized standards, such as ASTM standards.

The soil testing program is to be in accordance with the *OI Rules*.

For the anchoring system, additional tests should be considered to adequately describe the creep and set-up characteristics of the soil as well as the cyclic soil shear strength properties for the reliable design.

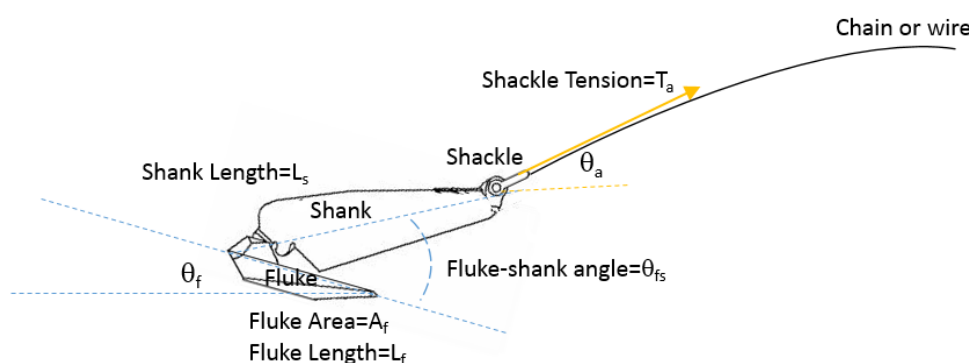
If the reference site is within a seismic zone, geotechnical investigations should include tests to determine dynamic soil properties and liquefaction potential.

SECTION 3 Drag Anchor

1 Introduction

The drag anchor is designed to penetrate into the seabed, either partly or fully. The holding capacity of the drag anchor is generated by the resistance of the soil in front of the anchor. The drag anchor is more suitable for resisting large horizontal loads.

FIGURE 1
Skematic of Drag anchor



The main components of a drag anchor are fluke, shank, shackle and chain or wire, shown in Section 3, Figure 1. The fluke-shank angle (θ_{fs}) is normally between 30° and 50° , with the lower angle used for sand or stiff clay and the higher one for soft clay. A fluke-shank angle in between these is more appropriate in certain layered soil conditions. When an anchor is used in very soft clay (mud) with the fluke-shank angle set at 30° , the anchor penetration depth will be less than the case when the fluke-shank angle is 50° , consequently the holding capacity will be lower. It is also found that the anchor penetrates deeper when the anchor is connected to wire rope compared to that connected to chain. Hence, the anchor connected to wire rope will yield higher holding capacity.

3 Installation Performance

Drag embedded anchors are installed by dragging the anchor through the soil. The applying load is generally equal to the maximum design load determined by dynamic analyses for the intact design condition. After installation the anchor is capable of resisting loads equal to the installation load without further penetration.

The anchor needs to travel a certain horizontal distance, called the drag length, to achieve the resistance. In cohesive soil without significant layering, the gradient for the drag distance versus penetration depth curve (Section 3, Figure 2) decreases with increasing depth. At the ultimate penetration depth (z_{ult}), the anchor fluke becomes horizontal ($\theta_f = 0$) and the anchor will not penetrate farther, shown in Section 3, Figure 2. At this stage, the anchor reaches its ultimate resistance.

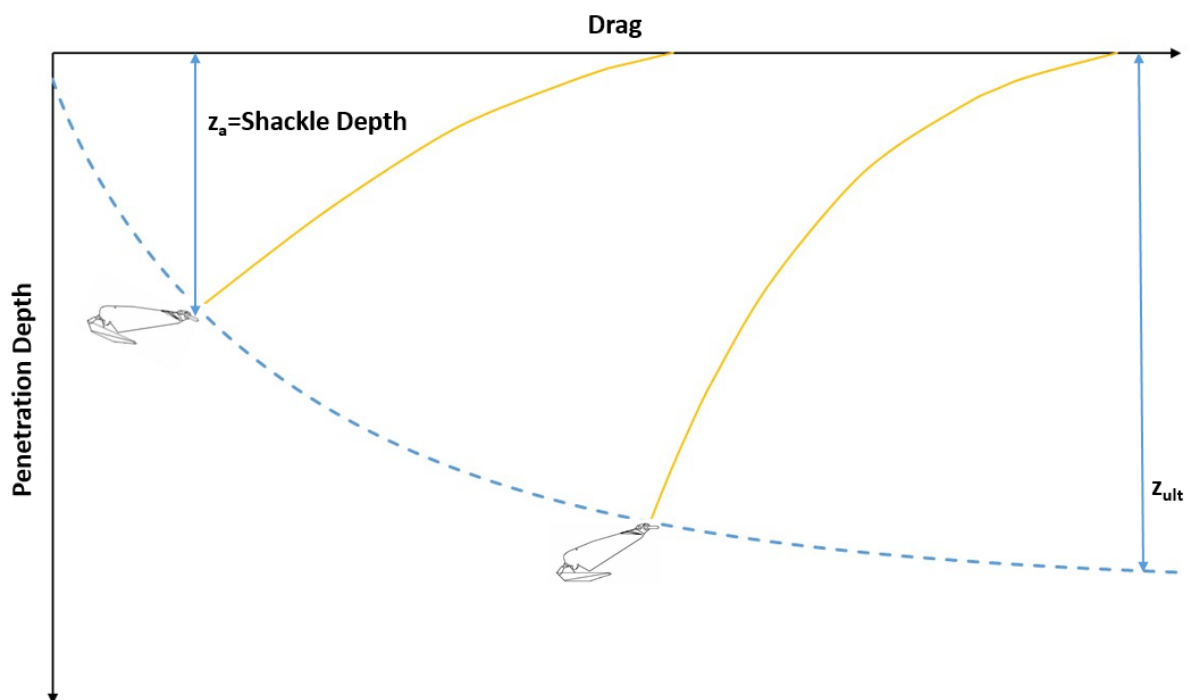
The drag anchor holding capacity typically increases with the increasing of the embedment depth. Therefore, the ability of the anchor to penetrate, the applied installation tension and realistic prediction of anchor trajectory during installation are particularly important in design. The installation aspects should be considered at the anchor design stage, if applicable.

The geotechnical design of drag anchor should include the following if applicable:

- Anchor resistance and anchor trajectory during installation
- Anchor ultimate holding capacity
- Post installation effects (i.e., setup effects and cyclic loading effects)
- Additional drag under damaged case with one mooring line broken conditions, if applicable
- Maximum allowable additional drag

The recommended design procedure for drag anchor in soft to medium stiff clay is presented in Appendix 1. This procedure is based on the limit equilibrium method, see Appendix 1 for more details. The tension force along the anchor mooring line as well as the shape of the anchor line are illustrated in Appendix 6.

FIGURE 2
Drag Trejectory of Drag anchor



5 Holding Capacity

The holding capacity of a drag embedded anchor depends on the anchor type, opening angle of the flukes, anchor size, embedded depth, stability of the anchor during dragging, soil strength characteristics, type and size of chain or rope, and installation procedure, etc. The opening angle of the fluke for drag embedded anchor used in clay is usually larger than that used in sand.

The methods to determine the drag embedded anchor holding capacity can be classified as the following:

- Empirical method
- Analytical method based on limit equilibrium principles
- Finite element method

In order to yield reliable predictions, all these methods need to be calibrated against lab or field test.

5.1 Empirical Method

The empirical method for determination of the anchor holding capacity is using a power formulae in which the ultimate anchor resistance (when the anchor penetration depth reaches the ultimate depth, z_{ult}) is related to the anchor weight. Naval Facilities Engineering Service Center (NAVFAC) ^[2] published design curves which represent in general the lower bounds of the test data and are suitable for “soft clay” and “sand”. These design curves have been adopted in API RP 2SK ^[1] and ISO 19901-7 ^[3]. However, the design curves suffer from the limitations in the database and inaccuracies due to scale effect using extrapolation from small size anchor tests to prototype anchors.

5.3 Analytical Method Based on Limit Equilibrium Principle

The analytical method satisfies the equilibrium equations for both the drag anchor and the embedded anchor line. It takes into account a more detailed site specific soil condition and different anchor geometry. It could provide detailed anchor performance information during installation such as the anchor trajectory, anchor rotation, anchor ultimate holding capacity and the relationship between line tension and anchor penetration.

Analytical methods to obtain the anchor holding capacity based on the limit equilibrium principle for soft to medium stiff clay are illustrated in Appendix 1. In other soils like stiff clay, dense sand, layered soil, cemented carbonate sand, and coral, etc., the analytical method is not yet mature. The methodology to calculate the anchor reverse catenary line is illustrated in Appendix 6.

5.5 Finite Element Method

The finite element method can obtain a rigorous solution for all aspects of anchor design. It is able to find the critical failure mechanism without prior assumptions and can assess complex anchor geometries, spatially varying soil properties and nonlinear material behaviors. The major limitation of the finite element method is the large time and effort required to formulate, set up and solve, even for a simple anchor trajectory.

5.7 Post Installation Effect

The post installation effects (i.e., cyclic loading effect and setup effect) on the anchor holding capacity may be considered if applicable.

Cyclic loading tends to affect the soil’s undrained shear strength in two ways. First, cyclic loadings generally tend to break down the soil structure and degrade the strength. Secondly, there can be an increase in the soil’s undrained shear strength due to the high loading rate from wave frequency load cycles compared with the monotonic load. The first effect is most pronounced when the soil is subjected to a two-way cyclic loading (with load reversals) and increases with increasing over consolidation ratio of the soil. Since the mooring line is always in tension (no load reversals), there is less degradation effect on the shear strength. The net effect of cyclic loading is mostly the increase of the soil’s undrained shear strength. See Appendix 2 for more details.

The set-up effect is caused by clay thixotropy as well as clay consolidation after the anchor installation. Following disturbance and remolding during installation, the soil shear strength in the vicinity of the anchor can gradually increase with time due to the set-up effect. See Appendix 3 for more details.

It is a conservative approach to disregard the effects of cyclic loading and set-up in design. If the increase in the anchor resistance due to these two effects is taken into account in soft/medium stiff clays, the detailed analysis based on laboratory tests should be verified.

5.9 Uplift Angle

According to the *FPI Rules*, the design of drag anchors is typically based on the requirement of zero uplift angle at the seabed for both installation and operation.

The design criteria for holding capacity of drag anchor is to be assessed for both intact condition and broken line condition, see Appendix 7 for details.

Field tests are necessary and the requirement can be found in Section 6-1-3 of the *FPI Rules*.