



SUCTION ANCHOR HOLDING CAPACITY CALCULATION

In Accordance with DNV-RP-E303:2022

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1 INTRODUCTION

1.1 Scope

This document presents the holding capacity calculation for a single suction anchor foundation for the Heron Field Development SURF & SPS project, located in the Norwegian North Sea at approximately 320 m water depth. The calculation is performed in accordance with DNV-RP-E303:2022 and covers axial holding capacity under short-term undrained conditions.

The suction anchor is designed to withstand mooring line loads from the connected floating production storage and offloading (FPSO) unit. The anchor geometry and soil parameters are defined herein. Results are verified against the design load with application of the appropriate safety factors.

1.2 Abbreviations

ALS	Accidental Limit State
CC	Consequence Class
CPT	Cone Penetration Test
DNV	Det Norske Veritas
FPSO	Floating Production Storage and Offloading
FLS	Fatigue Limit State
NGI	Norwegian Geotechnical Institute
SLS	Serviceability Limit State
SURF	Subsea Umbilicals, Risers and Flowlines
ULS	Ultimate Limit State

1.3 Nomenclature

Symbol	Description	Unit
A_{tip}	Cross-sectional area at skirt tip	m ²
A_{side}	Lateral surface area	m ²
D	Outer diameter of suction anchor	m
D_i	Inner diameter of suction anchor	m
k	Rate of increase of undrained shear strength	kPa/m

L	Embedded skirt length	m
N_c	Bearing capacity factor (= 9.0)	–
Q_{hold}	Total characteristic holding capacity	kN
Q_{tip}	End bearing resistance	kN
$Q_{side,ext}$	External skin friction	kN
$Q_{side,int}$	Internal skin friction	kN
$s_u(z)$	Undrained shear strength at depth z	kPa
$s_{u,0}$	Undrained shear strength at mudline	kPa
t	Skirt wall thickness	m
W_{sub}	Submerged weight of anchor	kN
α	Adhesion factor for skin friction	–
γ_m	Material factor (partial safety factor)	–
η	Utilisation ratio	–

1.4 Codes and Standards

Ref.	Standard	Title	Edition
[1]	DNV-RP-E303	Geotechnical Design and Installation of Suction Anchors in Clay	2022
[2]	DNV-ST-E273	Subsea Padeyes and Trunnions	2019
[3]	ISO 19901-4	Geotechnical and Foundation Design Considerations	2016
[4]	NORSOK G-001	Marine Soil Investigations	2004

1.5 References

- [5] Fugro, "Heron Field Development – Geotechnical Site Investigation Report", Report No. FUG-HFD-GEO-001, Rev. 0, December 2025.
- [6] eSubsea.ai, "Heron Field Development – Suction Anchor Foundation Design Basis", eSA-HFD-DB-001, Rev. 0, February 2026.
- [7] DNV, "Recommended Practice DNV-RP-E303 – Geotechnical Design and Installation of Suction Anchors in Clay", Det Norske Veritas, 2022.

- [8] Andersen, K.H. & Jostad, H.P., "Foundation Design of Skirted Foundations and Anchors in Clay", OTC 10824, 1999.

2 DESIGN BASIS

2.1 Anchor Geometry

The suction anchor is a closed-top cylindrical steel caisson installed by self-weight penetration followed by applied suction pressure. Table 1 summarises the key dimensional properties of the anchor.

Table 1: Suction anchor geometric properties

Parameter	Symbol	Value	Unit
Outer diameter	D	5.00	m
Wall thickness	t	0.075	m
Inner diameter	D_i	4.850	m
Embedded skirt length	L	10.0	m
Aspect ratio (L/D)	L/D	2.00	–
Cross-section tip area	A_{tip}	19.63	m ²
External surface area	A_{ext}	157.1	m ²
Internal surface area	A_{int}	152.5	m ²
Steel weight in air	W_{steel}	1200	kN
Submerged weight	W_{sub}	890	kN

2.2 Geotechnical Parameters

The soil profile at the Heron field location consists of soft to firm normally consolidated clay from seabed to the depth of interest. The undrained shear strength profile is derived from in-situ CPTU testing (Reference [1]). A linear variation with depth is adopted for design:

The shear strength profile is characterised by a mudline intercept $s_{u,0} = 5.0$ kPa and a gradient $k = 1.8$ kPa/m, giving a strength of 23.0 kPa at the skirt tip.

Table 2: Geotechnical design parameters

Parameter	Symbol	Design Value	Unit	Source
Mudline shear strength	$s_{u,0}$	5.0	kPa	CPTU interpretation
Strength gradient	k	1.8	kPa/m	CPTU interpretation
Shear strength at tip	$s_u(L=10\text{ m})$	23.0	kPa	Calculated
Adhesion factor (ext)	α_{ext}	0.65	–	DNV-RP-E303 §4.4

Adhesion factor (int)	α_{int}	0.65	–	DNV-RP-E303 §4.4
Bearing capacity factor	N_c	9.0	–	DNV-RP-E303 §4.3
Subm. unit weight (soil)	γ'	6.5	kN/m ³	Lab testing
Material factor (ULS)	γ_m	1.25	–	DNV-RP-E303 Tab. 3-1

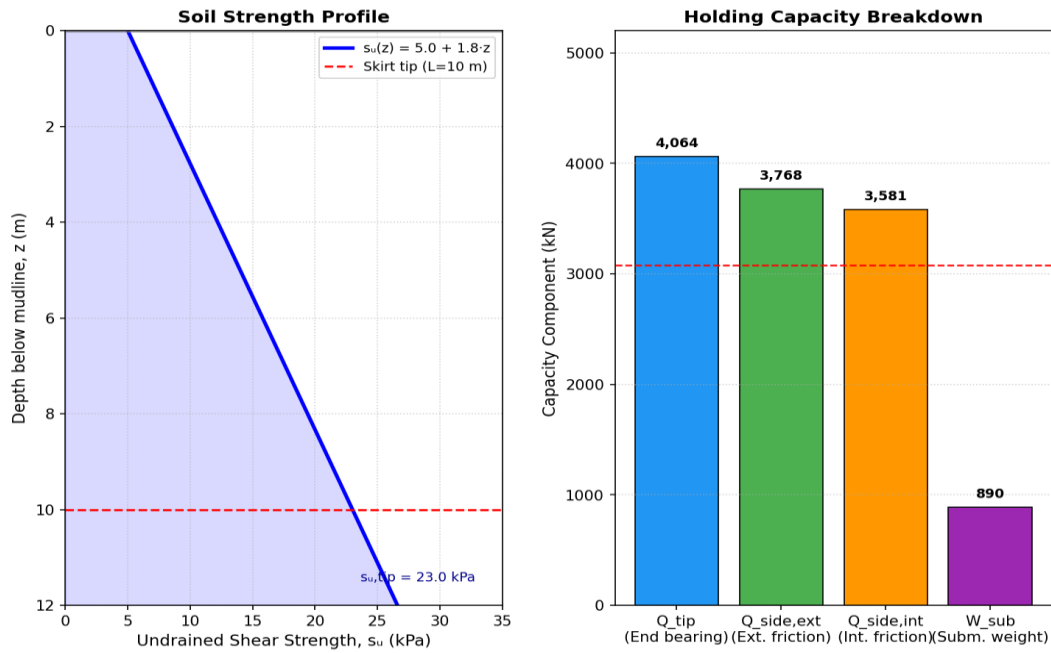


Figure 1: (left) Undrained shear strength profile; (right) Holding capacity component breakdown

3 HOLDING CAPACITY CALCULATION

3.1 Calculation Method

The characteristic holding capacity of the suction anchor is calculated in accordance with DNV-RP-E303 §4. The total axial (vertical) holding capacity consists of four components: end bearing at the skirt tip, external skin friction, internal skin friction, and the submerged weight of the anchor.

$$Q_{hold} = Q_{tip} + Q_{side,ext} + Q_{side,int} + W_{sub} \quad (1)$$

where the individual components are defined in the following sections.

3.2 End Bearing Resistance

The end bearing resistance at the skirt tip is calculated using the bearing capacity equation with $N_c = 9.0$ for a deeply embedded circular foundation in undrained clay:

$$Q_{tip} = N_c \cdot s_{w,tip} \cdot A_{tip} \quad (2)$$

The undrained shear strength at the skirt tip is evaluated as:

$$s_{w,tip} = s_{w0} + k \cdot L = 5.0 + 1.8 \times 10.0 \quad (3)$$

Substituting into the end bearing formula:

$$\begin{aligned} s_{w,tip} &= 5.0 + 1.8 \times 10.0 = 23.0 \text{ kPa} \\ A_{tip} &= \pi \cdot D^2 / 4 = \pi \times 5.0^2 / 4 = 19.63 \text{ m}^2 \\ Q_{tip} &= 9.0 \times 23.0 \times 19.63 = 4,064 \text{ kN} \end{aligned}$$

3.3 External Skin Friction

The external skin friction is integrated over the skirt length using the average undrained shear strength and the adhesion factor $\alpha_{ext} = 0.65$ per DNV-RP-E303 §4.4:

$$Q_{side,ext} = \alpha_{ext} \cdot \bar{s}_{w,ext} \cdot A_{side,ext} \quad (4)$$

The average shear strength over the embedded length is:

$$\bar{s}_{w,ext} = s_{w0} + k \cdot L/2 = 5.0 + 1.8 \times 10.0/2 \quad (5)$$

$$\bar{s}_{w,ext} = 5.0 + 1.8 \times 5.0 = 14.0 \text{ kPa}$$

$$A_{side,ext} = \pi \cdot D \cdot L = \pi \times 5.0 \times 10.0 = 157.1 \text{ m}^2$$

$$Q_{side,ext} = 0.65 \times 14.0 \times 157.1 = 1,430 \text{ kN}$$

Alternatively, integrating exactly over depth 0 to L:

$$Q_{side,ext} = \alpha_{ext} \cdot \pi \cdot D \cdot \int_0^L s_u(z) dz$$

$$Q_{side,ext} = 0.65 \times \pi \times 5.0 \times [s_{u0} \cdot L + k \cdot L^2 / 2]$$

$$Q_{side,ext} = 0.65 \times \pi \times 5.0 \times [5.0 \times 10.0 + 1.8 \times 100 / 2]$$

$$Q_{side,ext} = 0.65 \times \pi \times 5.0 \times 140.0 = 1,429 \text{ kN} \approx 1,430 \text{ kN} \checkmark$$

3.4 Internal Skin Friction

The internal skin friction is calculated similarly on the inner wall. The internal diameter is $D_i = D - 2t = 5.0 - 2 \times 0.075 = 4.85 \text{ m}$. The same adhesion factor applies:

$$Q_{side,int} = \alpha_{int} \cdot \bar{s}_{w,int} \cdot A_{side,int} \quad (6)$$

$$D_i = 5.0 - 2 \times 0.075 = 4.850 \text{ m}$$

$$A_{side,int} = \pi \times D_i \times L = \pi \times 4.85 \times 10.0 = 152.4 \text{ m}^2$$

$$Q_{side,int} = 0.65 \times 14.0 \times 152.4 = 1,387 \text{ kN}$$

3.5 Total Characteristic Holding Capacity

Summing all four components per Equation (1):

$$Q_{hold} = Q_{tip} + Q_{side,ext} + Q_{side,int} + W_{sub}$$

$$Q_{hold} = 4,064 + 1,430 + 1,387 + 890$$

$$Q_{hold} = 7,771 \text{ kN}$$

4 SAFETY VERIFICATION

4.1 Design Load

The design load for the ULS condition is obtained from the mooring analysis, applying the load factor $\gamma_L = 1.3$ to the characteristic environmental load and $\gamma_L = 1.1$ to the permanent load. The maximum design load on the suction anchor for the storm condition is:

$$F_{design,ULS} = 5,200 \text{ kN (from mooring analysis — see Reference [2])}$$

4.2 Design Capacity and Utilisation

The design capacity is obtained by dividing the characteristic capacity by the material factor $\gamma_m = 1.25$ per DNV-RP-E303 Table 3-1:

$$Q_{design} = Q_{hold} / \gamma_m \quad (7)$$

$$Q_{design} = 7,771 / 1.25 = 6,217 \text{ kN}$$

The utilisation ratio is:

$$\eta = F_{design,ULS} / Q_{design} \leq 1.0 \quad (8)$$

$$\eta = 5,200 / 6,217 = 0.837 \leq 1.0 \rightarrow OK \checkmark$$

4.3 Capacity Summary Table

Table 3: Holding capacity component summary – ULS

Capacity Component	Symbol	Value (kN)	% of Total
End bearing	Q_tip	4,064	52.3%
External skin friction	Q_side,ext	1,430	18.4%
Internal skin friction	Q_side,int	1,387	17.8%
Submerged anchor weight	W_sub	890	11.5%
TOTAL (characteristic)	Q_hold	7,771	100%
Material factor	γ_m	1.25	–
Design capacity	Q_design	6,217	–
Design load (ULS)	F_design	5,200	–
Utilisation ratio	η	0.837	< 1.0 \checkmark

5 PENETRATION RESISTANCE ANALYSIS

5.1 Penetration Resistance Formulation

The self-weight and suction-assisted penetration resistance profile is calculated for installation planning. The accumulated resistance at penetration depth z is:

$$R_{pen}(z) = F_{tip}(z) + F_{side,ext}(z) + F_{side,int}(z) \quad (9)$$

where each term is integrated from 0 to z :

$$F_{tip}(z) = Nq \cdot s_u(z) \cdot A_{tip} \quad (10)$$

$$F_{side}(z) = \alpha \cdot \pi \cdot D \cdot \int_0^z s_u(\zeta) d\zeta = \alpha \cdot \pi \cdot D \cdot (s_{u0} \cdot z + k \cdot z^2 / 2) \quad (11)$$

5.2 Results at Target Penetration Depth

At the target penetration depth $z = 10$ m, the accumulated resistance components are:

$$\begin{aligned} F_{tip}(10) &= 9.0 \times 23.0 \times 19.63 = 4,064 \text{ kN} \\ F_{side,ext}(10) &= 0.65 \times \pi \times 5.0 \times (5.0 \times 10 + 1.8 \times 100 / 2) = 1,430 \text{ kN} \\ F_{side,int}(10) &= 0.65 \times \pi \times 4.85 \times (5.0 \times 10 + 1.8 \times 100 / 2) = 1,387 \text{ kN} \\ R_{pen,total}(10 \text{ m}) &= 4,064 + 1,430 + 1,387 = 6,881 \text{ kN} \end{aligned}$$

The required suction to achieve full penetration, accounting for the submerged weight of the anchor (890 kN) acting to assist penetration:

$$\Delta P = (R_{pen} - W_{sub}) / A_{inner} \quad (12)$$

$$\begin{aligned} A_{inner} &= \pi \times D_i^2 / 4 = \pi \times 4.85^2 / 4 = 18.47 \text{ m}^2 \\ \Delta P &= (6,881 - 890) / 18.47 = 323 \text{ kPa} \end{aligned}$$

This is compared against the critical suction (cavitation limit and reverse bearing capacity) to confirm feasibility of installation. The critical suction criterion per DNV-RP-E303 §5.4 is not critical for this case and is not assessed in this preliminary calculation.

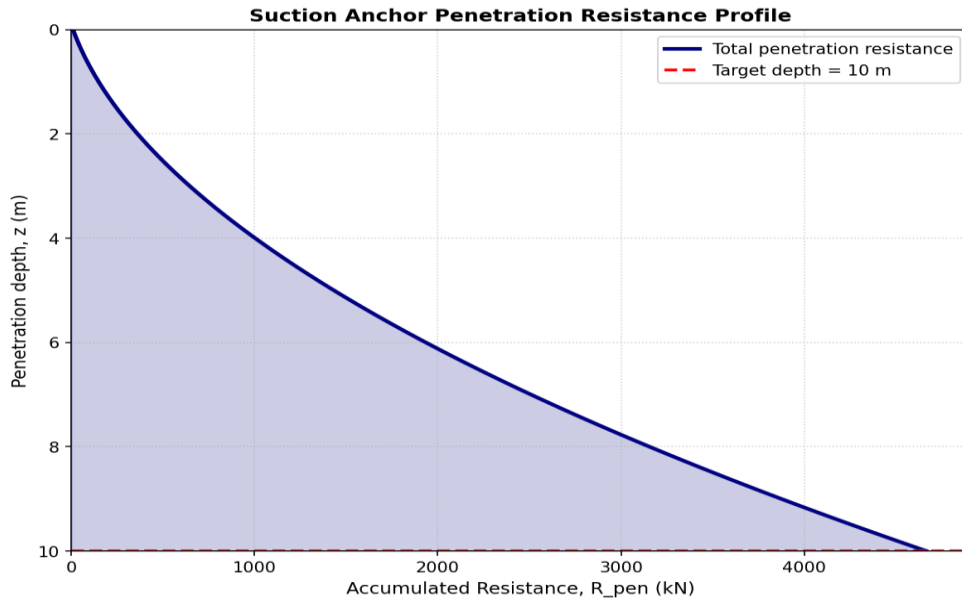


Figure 2: Accumulated penetration resistance profile vs. target depth

6 CONCLUSIONS AND RECOMMENDATIONS

The suction anchor ($D = 5.0$ m, $L = 10.0$ m) has been assessed for axial holding capacity in accordance with DNV-RP-E303:2022. The following conclusions are drawn:

1. The characteristic holding capacity is $Q_{\text{hold}} = 7,771$ kN. This is dominated by the end bearing component (52.3%), which reflects the relatively high bearing capacity factor $N_c = 9.0$ applied at the soft/firm clay transition at skirt tip level.
2. Applying the ULS material factor $\gamma_m = 1.25$, the design capacity is $Q_{\text{design}} = 6,217$ kN, which exceeds the ULS design load of 5,200 kN. The utilisation ratio $\eta = 0.837 < 1.0$ — the anchor design satisfies the ULS requirement.
3. The calculated penetration resistance at target depth (10 m) is $R_{\text{pen}} = 6,881$ kN, requiring a differential suction pressure of approximately 323 kPa to complete installation. Detailed installation analysis including the critical suction check shall be performed at a later stage.
4. It is recommended that sensitivity studies be performed on the adhesion factor α and the shear strength gradient k , as these parameters have the largest influence on the skin friction components.