



Exploration & Production

GENERAL SPECIFICATION

SURVEYS

GS GEO 703

**Requirements for design and installation of
drag anchors and anchor piles for
offshore floating structures**

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1. Scope and purpose

1.1 Objective

This document gives the minimum requirements applicable for the design and installation of conventional drag anchors and anchor piles for mooring offshore floating structures. The objective is to obtain satisfactory and consistent quality in the studies and works to be provided by the CONTRACTOR in charge of design and/or installation of such anchors.

For temporary moorings for exploration drilling rigs (MODUs), or for permanent moorings for production structures (e.g. FPSO/FSO, semi-submersible FPU, or other DDCUs such as the SPAR), it covers the following types of anchors:

- conventional drag anchors in catenary mooring systems
- drag-in plate anchors in taut-leg moorings
- anchor piles for permanent moorings for production structures.

This General Specification applies to:

- acquisition and interpretation of specific site and soil data
- geotechnical and structural design considerations
- minimum requirements for monitoring of the installation behaviour.

Deviations from any of the requirements defined herein shall be treated as non-conformances in accordance with COMPANY procedures.

1.2 Abbreviations

The following abbreviations are used:

- API American Petroleum Institute
- CALM Catenary Anchor Leg Mooring
- CPTU Cone Penetration Test with pore pressure measurement
- DDCU Deep Draught Caisson Unit
- FPSO/FSO Floating Production Storage and Off-loading vessel
- FPU Floating Production Unit
- ISO/DIS International Standard Organisation / Draft International Standard
- MODU Mobile Drilling Unit
- ROV Remotely Operated Vehicle
- TLM Taut Leg Mooring
- TLP Tension Leg Platform
- VLA Vertically Loaded Anchor

2. Reference documents

The reference documents listed below form an integral part of this General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the EFFECTIVE DATE of the CONTRACT.

This specification is complementary to the following documents:

- **GS STR 402** and **GS STR 661** for design and installation of mooring systems
- **GS STR 431** for installation of driven piles
- **GS GEO 101** and **GS GEO 201** for site investigation equipment and procedures.

Therefore, this specification shall be read in conjunction with above documents and the other COMPANY specifications and standards identified herein.

Standards

Reference	Title
ISO/DIS 19900	Petroleum and Natural Gas Industries – Offshore Structures – Part 1: General Requirements
ISO/DIS 19901-4	Petroleum and Natural Gas Industries – Offshore Structures – Part 1-4: Geotechnical and Foundation Design Considerations
ISO/DIS 19902	Petroleum and Natural Gas Industries – Fixed Steel Offshore Structures
ISO/DIS 19904	Materials, Equipment, and Offshore Structures for Petroleum and Natural Gas Industries – Floating Offshore Structures Including Stationkeeping

Professional Documents

Reference	Title
DNV RP-E301	Recommended Practice for Design and Installation of Fluke Anchors in Clay
DNV RP-E302	Recommended Practice for Design and Installation of Drag-In Plate Anchors in Clay
API RP 2A WSD/LRFD	Recommended Practice for Planning, Designing, and Constructing Fixed Structures – Working Stress Design / Load and Resistance Factor Design
API RP 2SK	Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures
API RP 2T	Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms
API Bulletin 2U	Bulletin on Stability Design of Cylindrical Shells
API Bulletin 2V	Bulletin on Design of Flat Plate Structures
AISC ASD	Manual of Steel Construction – Allowable Stress Design



Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
Not applicable	

Total General Specifications

Reference	Title
GS GEO 101	Offshore Geotechnical Soil Survey
GS GEO 201	Offshore Geophysical Survey
GS GEO 301	Offshore Surface Positioning Works
GS GEO 302	Subsea Positioning Works
GS STR 402	Anchorage for a Support Vessel on an Offshore Site
GS STR 431	Installation of Piles for Offshore Steel Structures – Driven Piles
GS STR 661	FPSO - Design Requirements for Mooring and Anchoring Systems

3. General requirements for site and soil investigation

The general offshore site and soil investigation equipment and procedures shall be in agreement with the COMPANY Specifications:

- **GS GEO 201** for the performance of geophysical site survey
- **GS GEO 101** for the performance of geotechnical investigation, including soil sampling and laboratory testing, in-situ testing, as well as data interpretation.

The following site specific data shall be determined:

- seabed features and seabed topography
- type, thickness and strength of sea bottom and subsurface soils, with particular attention to the possible presence of obstacles (e.g. boulders), or detrimental soil conditions such as cemented layers.

The scope and extent of the soil investigation will depend on the soil type and natural variability over the site, but a minimum of one investigation point per group of anchors shall be performed. Regarding drag anchors, the data acquisition methods shall focus on the detailed determination of the nature and characteristics of the first 20-30 metres of sediments (depending on the anticipated anchor penetration below the seabed). Concerning anchor piles, the soil investigation shall cover the anticipated pile length, plus 5 pile diameters below pile tip depth, with a minimum of 50 metres.

The soil investigation shall combine in-situ testing (e.g. CPTU, field vane, etc.) and high quality sampling. Equipment and procedures allowing continuous soil profiling and sampling shall be used.

Use of correlations to determine the soil characteristics and strength from in-situ testing results, to be documented by CONTRACTOR, shall be based on local experience and site specific data.

Prior to start of testing, the quality of the soil specimen shall be determined in the onshore laboratory, with a procedure to be submitted to COMPANY for approval. Advanced laboratory testing (e.g. direct simple shear or cyclic triaxial testing), shall be performed on the highest quality samples. The lowest quality samples shall be used to perform classification tests, as well as tests on remoulded soil for simulating the situation during anchor installation or pile driving.

When applicable, specific geotechnical concerns shall be addressed, in particular:

- sensitivity, thixotropy, and strain rate effect
- creep effect under sustained loading
- cyclic loading effect
- sea bottom hazards, such as risk of scour or slope instability.

4. Requirements for design and installation of drag anchors

4.1 General requirements for design of drag anchors

The above referenced ISO/DIS, API and DNV documents shall be used as guidelines for the design of conventional drag anchors. Design methods which differ significantly from these documents shall be submitted to COMPANY for approval.

The following general requirements apply for all types of drag anchors:

- The general design conditions shall be provided in a specific Design Brief Report, which shall be submitted to COMPANY for approval before start of the design studies. This report shall include at least:
 - Scope and purpose, with the type of floating structure of concern and the water depth at the Project site
 - Complete list of applicable design rules and regulations, including specific requirements from the Classification or Certifying Company (if any)
 - Type of catenary mooring considered (e.g. spread mooring, turret mooring, or CALM system), with the number of mooring lines and the composition of the lines (i.e. chain or steel wire rope)
 - Design principles, with the minimum safety coefficients (for a working stress design approach) or the minimum soil and load factors (for a load resistance factor design approach) to be applied

- List of directional combinations of wind, wave and current forces considered, consistent with the environmental conditions at the Project site
- Summary of the soil investigation results, and assessment of the design strength profiles, with lower, best estimate and upper bound profiles, for taking into account the possible natural variation and range in the design parameters
- Description of the calculation programmes to be used
- Material properties for structural design considerations
- Installation tolerances
- Uplift and sliding resistance of the anchors shall be sufficient to overcome vertical and horizontal loading from externally-applied forces, such as trawl board impact and snagging, in accordance with the Project requirements
- Sea bottom movements, possibly due to earthquakes and/or slope instability, shall not cause loss of the anchor capacity with soil liquefaction or excessive displacements

4.2 Holding capacity of conventional drag anchors for catenary moorings

The ultimate holding capacity of a conventional drag anchor in a particular soil type corresponds to the maximum horizontal steady pulling load which can be resisted by the anchor at continuous drag. For a conventional anchor, this load includes the resistance along the embedded part of the chain or wire rope, but excludes the friction of the chain or wire rope on seabed.

The holding capacity of a drag anchor is a function of several parameters, including (a) soil type and soil strength at the depth of anchor penetration, (b) anchor type (i.e. fluke area, fluke opening angle and shape) and anchor weight, (c) anchor behaviour during deployment (i.e. penetration depth, dragging distance and anchor stability during dragging), and (d) type of forerunner (i.e. chain or wire rope).

Anchor holding capacity calculations should be performed using limit equilibrium models, which shall take into account the following aspects:

- uniform soil conditions, or multi-layered soils
- effect of soil consolidation with anchor soaking after installation (if applicable)
- capacity under dynamic (i.e. short term) and static (i.e. long term or sustained) loading
- effect of interaction between horizontal and vertical loading (if relevant).

Note: Some high efficiency anchors have demonstrated significant uplift resistance to vertical loading when relatively deep penetration is achieved in soft soil. The existing ISO/DIS and API design guidelines allow limited vertical loads under extreme environmental conditions, meanings that drag anchors may be subjected to limited vertical loading only. The design of the drag anchors shall take into account a reduction in holding capacity when the mooring line angle at seabed becomes significant.

Alternatively, the ultimate holding capacity of conventional drag anchors can be determined from full-scale or model-scale tests and/or previous field experience. However, when CONTRACTOR propose to apply anchor performance graphs to design the Project anchors (e.g. anchor holding capacity versus anchor weight graphs provided in the ISO/DIS and API documents), he shall document that such graphs include anchors and soil conditions similar to those at the Project site.

When a new type of drag anchor is proposed, or when the soil conditions at the Project site are not covered within the previous experience database, the performance of full-scale or model-scale field tests may be warranted. In such a case, the test set-up shall be as far as possible representative of the prototype conditions, in particular with respect to the expected anchor penetration and lead line type (i.e. chain or wire rope forerunner).

The design analyses for mooring systems with conventional drag anchors shall cover the following points:

- Quasi-static, dynamic, and transient analyses, with the intact mooring (intact case) or with one mooring line broken (damage case)

Note: Unless otherwise indicated in the Project requirements, a quasi-static analysis may generally be sufficient for the design of temporary mooring systems.

- Definition of the most severe loading criteria and of the design condition for the floating structure of concern
- Configuration of the mooring line length embedded into the soil under design loading condition, with the line angle at the anchor pad-eye and seabed touch-down point, and the load component taken by friction along this length (to be determined with a validated calculation model)
- Definition of the required proof-test loading criteria

Note: (a) For permanent moorings, and unless otherwise indicated in the Project requirements, the proof-test load shall not be less than the maximum quasi-static operating load for the intact case and shall be at least equal to 80% of the maximum anchor load determined by the dynamic analysis for the same intact case. (b) For temporary moorings, the proof-test load will depend on the environmental site conditions, the mooring duration, and the loading/winching equipment available onboard the MODU for tensioning and retrieving the anchors.

- Prediction of anchor penetration and drag distance under the required proof-test loading and design loading conditions
- Effect of scour in sandy soils (if applicable), when shallow anchor penetration is expected with the anchors not fully buried after proof-test loading
- Effect of installation tolerances, in particular the mis-orientation of the anchor with respect to the mooring line heading. Unless otherwise indicated in the Project requirements, a maximum deviation of $\pm 10^\circ$ on the anchor orientation shall be considered.

4.3 Holding capacity of drag-in plate anchors for taut-leg moorings

For permanent moorings in a taut-leg configuration, the mooring lines will have a large initial angle to the seabed and will always impose a significant vertical loading component at the anchor. The drag-in plate anchor concept (also known as vertically loaded anchor, or VLA), when deeply penetrated into soft clay, has demonstrated its capability for such TLM moorings.

The design of a VLA and the calculation of its ultimate holding capacity involve specific issues to be addressed, in particular:

- For ensuring deep penetration into soft clay, the mooring line forerunner should be made of a wire rope. The configuration of the line length embedded into the soil shall be determined with a validated calculation model, but no mooring load decrease from the component taken

by friction along this length shall be allowed. The detailed composition of the mooring lines (i.e. chain, steel wire rope, or synthetic rope) shall be given.

- A plate anchor gets its ultimate pull-out capacity by having its fluke oriented nearly perpendicular to the applied mooring line load. To ensure that the VLA will present a maximum projected bearing area to resist the design mooring loads, the plate anchor design and/or installation procedure shall (a) facilitate rotation of the fluke during installation, (b) ensure that no significant or unpredicted penetration is lost during anchor rotation which may move the fluke upward into weaker soil, and (c) take into account the effective fluke area by using appropriate shape factor and projected fluke area.
- The ultimate holding capacity of a VLA is directly related to the in-situ soil strength at the depth of penetration of the anchor. The installation equipment and procedure shall provide the necessary means to demonstrate that the VLA has reached its design target penetration under pre-tensioning and proof-test loading condition.
- The bias (uncertainty) safety B factor for TLP pile foundations (as given in the [API RP 2T](#) and [ISO/DIS 19904](#) documents) is not directly applicable to the design of a VLA anchor. However, considerations for such increased safety factor is warranted, in particular with respect to the effect of cyclic degradation and creep under sustained tension for permanent taut-leg moorings.
- In a TLM system, where the vertical loading component becomes predominant, a VLA anchor may not penetrate deeper when the line load increases beyond the installation proof-test load. Therefore, and unless otherwise indicated in the Project requirements, all VLA anchors shall be proof-tested at least up to 100% of the maximum storm load determined by a dynamic analysis for the intact case.
- The effect of installation tolerances on the mis-orientation of the VLA with respect to the mooring line heading shall be taken into account. Unless otherwise indicated in the Project requirements, a maximum deviation of $\pm 10^\circ$ on the VLA orientation shall be considered.

4.4 Structural design

The structural design of drag anchors made of steel plates shall be performed in accordance with the [ISO/DIS 19904](#) document, completed by the [API Bulletin 2U](#), the [API Bulletin 2V](#), and the [AISC](#) manual.

For drag anchors in permanent moorings, the structural design analyses shall include (a) load-out, transportation, lifting and deployment at the site, (b) penetration, (c) retrieval (contingency), (d) in-place analysis under operating and extreme conditions, and (e) fatigue analysis.

Structural design shall cover the global anchor design, and local design checks for areas where strong stress concentrations are expected. In particular, the anchor pad-eye area and shackle arrangement shall be designed in such a way that it shall allow for a minimum installation tolerance of $\pm 10^\circ$ on the mis-orientation of the anchor heading with respect to the mooring line.

The structural design report to be provided by CONTRACTOR shall include:

- detailed input data and material properties
- complete list of loading conditions considered
- description of the calculation programmes used
- detailed calculation results and safety coefficients or utilisation ratios
- design drawings.

4.5 Installation operations and reporting

4.5.1 Penetration and retrieval of drag anchors

- Penetration:
 - Prior to the deployment of the mooring lines, penetration of the drag anchors to design depth below seabed shall be performed with the necessary tensioning equipment to reach the required proof-test load. The proof-test load shall be increased by steps and the maximum load shall be applied at least 30 minutes. Since some tension load relaxation will be inevitable, the tensioning equipment shall be capable to apply at least 125% of the required maximum proof-test load.
 - Depending on the required proof-test load and Project requirements, anchor tensioning and proof-test loading can be performed by means of the vessel bollard pull, tension winch, tensioning two opposite Project anchors against each other, or tensioning the Project anchors against reaction anchors.
 - A detailed anchor installation procedure shall be submitted by CONTRACTOR, with all necessary equipment, including the pull-in hardware onboard the vessel (i.e. tension winch, A-frame, or other), with the maximum loading capacity, reaction anchors (if any), and (if applicable) pendant lines, surface buoys, ROV for diver-less operations, etc.
- Retrieval:
 - In cohesive soils, the anchor retrieval analysis shall take into account the increase in soil strength with set-up time. For temporary moorings of drilling MODUs, retrieval can be required several months after installation, which shall be taken into account in the retrieval and structural analyses.
 - For permanent moorings, such anchor retrieval is mainly a contingency during installation operations. However, in accordance with the Project requirements, retrieval of the complete mooring system at the end of the field lifetime may be a design issue to be addressed.
 - A detailed anchor retrieval procedure shall be submitted by CONTRACTOR, with all necessary equipment, including the pull-out hardware onboard the vessel (i.e. tension winch, A-frame, or other), with the maximum loading capacity, and (if applicable) pendant lines, surface buoys, ROV for diver-less operations, etc.

4.5.2 Monitoring of installation operations and reporting

Accurate control and monitoring of installation operations is required in order to ensure that the drag anchors reach their target design penetration within tolerances. In particular, the determination of the load-displacement behaviour of drag anchors is a key issue, requiring that:

- Anchor pre-tensioning and proof-test load, as well as anchor dragging distance and penetration depth, shall be measured as accurately as possible
- Surface and subsea positioning equipment shall allow real time measurement of the anchor dragging length during proof-testing operations.

Note: (a) For anchor proof-testing, one shall clearly differentiate the tensioning load at sea surface and that applied at the anchor; The accuracy of the measurement of the tensioning load at the anchor shall be documented by CONTRACTOR. (b) Unless otherwise indicated in the Project requirements, the anchor dragging distance and penetration depth shall be measured with an accuracy of 1 to 2m.

For deep water operations, a number of back-up equipment, and a minimum of two ROVs, shall be available for providing a level of redundancy (to be defined in agreement with the Project requirements).

The complete installation results shall be provided by CONTRACTOR in an as-built report, together with a recapitulation of the site soil conditions and installation tolerances. In the same as-built report, the installation results shall be compared to the original predictions, in particular with respect to anchor penetration and dragging distance. Significant differences between the predictions and actual installation results shall be addressed, with particular concern about the estimated as-installed anchor capacity as compared to the design ultimate holding capacity.

5. Requirements for design and installation of driven anchor piles

5.1 General requirements for design of driven anchor piles

The above referenced ISO/DIS and API documents shall be used as guidelines for the design of driven anchor piles. Design methods which differ significantly from these documents shall be submitted to COMPANY for approval.

Note: (a) Anchor piles are generally applied for permanent moorings only, and generally installed by driving. Therefore, other methods of installation, such as drilling and grouting or vibratory hammering, are not covered in the present document. (b) TLP foundation piles under constant tension loading are not covered by the present document.

The following general requirements apply:

- The general design conditions shall be provided in a specific Design Brief Report, which shall be submitted to COMPANY for approval before start of the design studies. This report shall include at least:
 - Scope and purpose, with the type of floating structure of concern and the water depth at the Project site
 - Complete list of applicable design rules and regulations, including specific requirements from the Classification or Certifying Company (if any)
 - Type of mooring considered (e.g. spread mooring, turret mooring, or CALM system), with the number of mooring lines and the composition of the lines (i.e. chain, steel wire rope, or synthetic rope)
 - Design principles, with the minimum safety coefficients (for a working stress design approach) or the minimum soil and load factors (for a load resistance factor design approach) to be applied
 - List of directional combinations of wind, wave and current forces considered, consistent with the environmental conditions at the Project site
 - Summary of the soil investigation results, and assessment of the design strength profiles, with lower, best estimate and upper bound profiles, for taking into account the possible natural variation and range in the design parameters
 - Description of the calculation programmes to be used
 - Material properties for structural design considerations
 - Installation tolerances.

- Uplift and lateral resistance of the anchor piles shall be sufficient to overcome vertical and horizontal loading from externally-applied forces, such as trawl board impact and snagging, in accordance with the Project requirements.
- Sea bottom movements, possibly due to earthquakes and/or slope instability, shall not cause loss of the anchor pile capacity with soil liquefaction or excessive displacements.

5.2 Holding capacity of driven anchor piles

The penetration of driven anchor piles shall be sufficient to develop the required ultimate lateral and vertical capacity to resist the design mooring load with appropriate safety coefficients. The mooring load may be decreased from the component taken by friction along the embedded line length, but not from the friction of the chain or wire rope on the seabed.

The design of driven anchor piles shall cover the ultimate lateral pile capacity, lateral pile displacement, and pile bending stresses. Anchor piles under predominantly lateral loading can be modelled using soil resistance – deflection ($p - y$) curves, as described for various soil types in the ISO/DIS and API documents.

Calculation of the ultimate pile capacity shall take into account the following aspects:

- uniform soil conditions, or multi-layered soils
- effect of soil consolidation after installation (if applicable)
- capacity under dynamic (i.e. short term) and static (i.e. long term or sustained) loading
- effect of interaction between horizontal and vertical loading (if relevant).

The design analyses for mooring systems with anchor piles shall cover the following points:

- Quasi-static, dynamic, and transient analyses, with the intact mooring (intact case) or with one mooring line broken (damage case)
- Definition of the most severe loading criteria and of the design condition for the floating structure of concern
- Configuration of the mooring line length embedded into the soil under design loading condition, with the line angle at the anchor pile pad-eye and seabed touch-down point, and the load component taken by friction along this length (to be determined with a validated calculation model)
- Definition of the required proof-test loading criteria (if applicable).

Note: Generally, driven anchor piles do not require to be proof-loaded, and pre-tensioning is applied for stretching and alignment of the mooring lines only. However pile driving monitoring may be required.

- Driveability prediction (in accordance with General Specification **GS STR 431**)
- Effect of scour in sandy soils (if applicable)
- Effect of installation tolerances, in particular the mis-orientation of the anchor pile with respect to the mooring line heading. Unless otherwise indicated in the Project requirements, a maximum deviation of $\pm 10^\circ$ on the pile orientation shall be considered.

For moorings in a taut-leg configuration, the mooring lines will have a large initial angle to the seabed and will always impose a significant vertical loading component at the anchor pile. The bias (uncertainty) safety B factor for TLP pile foundations (as given in the **API RP 2T** and

ISO/DIS 19904 documents) is not directly applicable to the design of an anchor pile. However, depending on the level of vertical loading, considerations for such increased safety factor should be considered, in particular with respect to the effect of cyclic degradation and creep under sustained tension.

5.3 Structural design

The structural design of anchor piles shall be performed in accordance with the ISO/DIS 19904 document, completed by the API Bulletin 2U and the AISC manual.

The structural design analyses shall include (a) load-out, transportation, lifting and deployment at the site, (b) installation by driving, (c) in-place analysis under operating and extreme conditions, and (d) fatigue analysis.

Structural design shall cover the global pile design, and local design checks for areas where strong stress concentrations are expected. In particular, the pad-eye area and shackle arrangement shall be designed in such a way that it shall allow for a minimum installation tolerance of $\pm 10^\circ$ on the mis-orientation of the pile heading with respect to the mooring line.

The structural design report to be provided by CONTRACTOR shall include:

- detailed input data and material properties
- complete list of loading conditions considered
- description of the calculation programmes used
- detailed calculation results and safety coefficients or utilisation ratios
- design drawings.

5.4 Installation operations and reporting

Accurate control and monitoring of installation operations is required, in order to ensure that the anchor piles reach their target design penetration within tolerances. A detailed installation procedure shall be submitted by CONTRACTOR.

Pile driving monitoring for anchor piles shall be in accordance with COMPANY General Specification GS STR 431.

For deep water operations, a number of back-up equipment, and a minimum of two ROVs, shall be available for providing a level of redundancy (to be defined in agreement with the Project requirements).

The complete installation results shall be provided by CONTRACTOR in an as-built report, together with a recapitulation of the site soil conditions and installation tolerances. In the same as-built report, the installation results shall be compared to the original driveability predictions. Significant differences between the predictions and actual installation results shall be addressed, with particular concern about the estimated as-installed anchor pile capacity as compared to the design ultimate holding capacity.