



Exploration & Production

GENERAL SPECIFICATION

STRUCTURAL

GS STR 661

FPSO - Design requirements for mooring and anchoring systems

02	10/04	Revised § 1.1, 3, 4, 5.2, 6.2.1, 6.2.4.2, 6.3,
01	11/03	Second Issue
00	02/01	First issue
Rev.	Date	Notes

Contents

1. Introduction	4
1.1 General	4
1.2 Interfaces	4
1.3 Units	4
2. Reference documents	4
3. Classification	6
4. MOORING ANALYSIS.....	6
4.1 General	6
4.2 Design/Analysis Cases	7
4.3 Combinations for mooring design	7
4.4 Design loads	8
4.5 Vessels Dynamics	9
4.6 Extreme Design Cases	10
4.7 Operating and Installation Design Cases	10
4.8 Design methodology	10
4.9 Design acceptance criteria	12
5. Model tests	14
5.1 General	14
5.2 Requirements	14
5.3 Model scale	14
6. Mooring components structural design and fabrication	15
6.1 Generality	15
6.2 Mooring system components	16
6.3 Tests	20
7. Control, Measurement and Instrumentation System	20
8. Installation, Inspection and maintenance considerations	20
8.1 Design considerations	20
8.2 Installation of mooring components	20
8.3 Inspection of mooring components	21



8.4	Maintenance of mooring components.....	21
8.5	Monitoring during operations	21

1. Introduction

1.1 General

This specification intends to clarify the basis on which the positioning by anchor legs must be designed. It shall apply to spread or turret moored F(P)SOs. Application to other type of floating units is subject to Company approval.

In case of F(P)SO moored to a CALM Buoy, reference is to be made to **GS STR 631**.

The document [ISO/DIS 19901-7](#) "Floating offshore structures including station keeping, 2004" being worked constitutes the main reference that will be used when available officially. Its content can be used for guidance as required.

It is reminded that the Monitoring, Inspection, Maintenance and Repair features are integral parts of the mooring system design.

1.2 Interfaces

Concerning the mooring system design and fabrication, care must be taken that CONTRACTOR shall perform the design and the fabrication of mooring components in accordance with FPSO CONTRACTOR concerning the implantation of mooring equipment onboard the FPSO such as:

- Fairleads
- Chain stoppers
- Tensioners and associated equipment

Pre-tensioning winches and associated equipment

1.3 Units

SI units shall be used in all documents. Nevertheless, standardized diameters for cable and chain may be expressed in inches. When applied, the symbol for inches (" or in.) shall be clearly mentioned.

2. Reference documents

Where national regulations exist, their provisions and those of the standards and codes to which they refer shall apply, supplementing or amending the provisions of this document.

If there are no national regulations covering all or part of the subject of this document, the reference documents shall be strictly applied, as supplemented by the provisions of this document.

Only the main reference documents are mentioned; the CONTRACTOR shall be responsible for complying with all secondary reference documents dealing with the subject of this document.

Unless otherwise indicated in the detailed contractual conditions, all the reference documents to be used, as well as their supplements shall be the latest editions.

Standards

Reference	Title
ISO 3730	Shipbuilding - Mooring winches, 2 nd edition, 1988
ISO/DIS 19901-7	Floating offshore structures including station keeping, 2004

Professional Documents

Reference	Title
Noble Denton / TTI	Deep water Fibre moorings, an engineers' design guide First Edition Rev 0 – January 1999
OCIMF	Prediction of Wind and Current Loads on VLCCs, 2 nd edition, 1994
DNV OS-E301	Position Mooring, June 2001
DNV RP-E302	Design and Installation of Plate Anchors in clay, dec. 2002
DNV OSS 102	Rules for Classification of Floating Production and Storage Units
DNV CN N°2.5	Certification of Offshore Mooring Steel Wire Ropes
DNV CN N°2.6	Certification of Offshore Mooring Chain
Bureau Veritas NI 461 DTO	Quasi-dynamic Analysis of Mooring systems. Recommended Practice,
Bureau Veritas NI 493 DTM	Classification of mooring system for permanent offshore units, Guidance note
Bureau Veritas NI 432 DTO	Certification of synthetic fibre ropes for mooring systems, Guidance note
Bureau Veritas NR 216 DNC R02 E	Rules and Regulations for the Classification of Ships and Offshore installation – Materials, 1997
API RP 2SK	Recommended practice for design and analysis of station keeping systems for floating structures
API RP 2SM	Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring
API RP 2FP1	Recommended Practice for Design, Analysis and Maintenance of Moorings for Floating Production Systems
API SPEC 2F	Specification for Mooring Chains
API RP 2I	In-service Inspection of Mooring Hardware for Floating Drilling Units

Other Documents

The provisions of this document shall be applied in the light of the supplementary documents supplied by the OWNER, including:

- Country specificity appendices
- Project specification
- Site data information (Bathymetry, Metocean, soil conditions)

Total General Specifications

Reference	Title
GS GEO 702	Requirement for the design and installation of skirted foundations and suction anchors.
GS STR 002	Permanent Lifting and Handling Devices for Offshore Installations
GS STR 201	Materials for Offshore Steel Structures.
GS STR 301	Fabrication of Offshore Steel Structures
GS STR 652	F(P)SO – Steel Hull Design Requirements
GS STR 653	F(P)SO – Hull Fabrication Requirements

3. Classification

The F(P)SO mooring system shall be covered by Classification.

The scope of the Classification shall cover all the activities necessary to obtain the CLASS Notation (equivalent to Bureau Veritas POSA Notation) of the mooring system inclusive of the review of the specification of the equipment to be installed on board the FPSO.

The scope of CLASSIFICATION for the FPSO Mooring System shall include:

- Mooring line components (anchors, chains, wire and accessories...),
- Hull mounted equipment (fairleads, stoppers,...),
- Mooring line handling equipment (winch, sheaves,...).

All equipment, covered or not by CLASS, shall be provided with relevant certifications and track record evidence for COMPANY and CS (Classification Society) review and approval.

4. MOORING ANALYSIS

4.1 General

This section provides methods for implementing and modelling operating and environmental extreme loading conditions on the FPSO, design criteria and minimum requirements for the calculation approach and software to be adopted.

Frequency domain approach only is not accepted at detail engineering stage. Low frequency motions calculation shall be based on time-domain simulations.

Line dynamics for the most loaded line can be analysed separately using time-domain software.

If line dynamics are shown to be negligible, line tension computation can be based on a quasi-dynamic approach.

The results of model tests shall be used to calibrate the numerical models.

The effect of the risers & Offloading lines (Non linear restoring force, drag force and damping) in the FPSO response shall be accounted for in the mooring analysis

A full Risers/Mooring coupled analysis shall be then carried out to assess and verify the moored FPSO dynamic behaviour under a number of fatigue and extreme sea states.

The mooring system shall be optimised through:

- Mooring pattern (line arrangement and spread angle) and layout.
- Chain and steel wire rope grade, diameter and length of each segment of the mooring line.
- Mooring anchors shall be placed appropriate depths in accordance with the field bathymetry. Seabed slope shall be modelled into the analysis.

The Particular Project Specification (PPS) shall define the field layout constraints (sub-sea equipment, pipelines, flowlines, umbilicals,...).

4.2 Design/Analysis Cases

Analysis cases shall cover extreme and operating, intact and damaged mooring conditions.

Environmental and operating loads shall be combined in order to determinate the most onerous loading scenarios on the mooring system for the following conditions as a minimum:

- a) Intact Mooring – FPSO at ballast draught.
- b) Intact Mooring – FPSO at full draught
- c) Damaged Mooring - FPSO at ballast draught.
- d) Damaged Mooring - FPSO at full draught.
- e) Installation conditions: to be addressed within project execution phase.

Intermediate loading conditions shall be investigated to confirm that they are less severe than the above design conditions.

This investigation shall take into account that the cargo distribution in the tanks can significantly affect the hydrodynamic behaviour of the FPSO (free surface and inertia effects).

CONTRACTOR shall document, for COMPANY and CS approval, the methodology used to identify the controlling load cases for the mooring design. The design cases shall include (but not be limited to) the design cases mentioned within this chapter. Extra cases may also be required by the Classification Society.

4.3 Combinations for mooring design

4.3.1 Environmental combinations and headings

Combination of wave, wind and current shall be selected from metocean specification subject to COMPANY and CS approval.

Environment shall be applied in both collinear and non-collinear cases from 0deg to 360deg relative to the FPSO bow.

A minimum of 16 directions spaced around and covering all non-symmetrical environmental combinations shall be analysed for the selection of the design cases.

Heading for non-collinear cases shall be represented by the wave direction (a sufficient number of cases shall be selected spread from 0deg to 360 deg according to metocean available data). Non collinear wind and wave directions shall be referred to the wave incidence. Non-collinear environmental extremes shall be determined in accordance to [DNV OS E-301](#). Additional load cases may be required by Classification Society.

4.4 Design loads

Design environmental forces shall be calculated for all incidences. Collinear environmental conditions and non-collinear combinations of environmental extremes shall be considered.

Design environmental loads on the FPSO Hull and Superstructure shall be validated and calibrated against model test results.

4.4.1 Waves

The estimation of wave loads is to be carried out in irregular waves, with significant wave height (H_s) and peak period (T_p) derived from the Environmental data Specification (Metocean Specification).

The range of peak periods specified in the Environmental Data Specification shall be considered for determining the most onerous design environmental combinations.

The type of wave spectrum to be used in the analysis shall be given in the metocean specification. Sensitivity on the T_p shall be carried out for every wave direction. If not mentioned in the metocean data, the following variations shall be investigated:

$$T_p - 2 < T_{\text{computation}} < T_p + 2$$

The wave loads (first and second order) shall be calculated using recognised diffraction-radiation software.

4.4.2 Wind & current

At design stage, the current and wind coefficients shall be calculated in accordance with approved Classification Society rules. The windage areas will be determined from plan and profile layouts of the FPSO with topsides equipment, cranes, flare tower and accommodation block. The wind and current forces shall be then updated from the wind tunnel measurements when available.

4.4.2.1 Wind

The wind load calculations shall be based on wind tunnel tests.

Dynamic effects of winds shall be addressed within the mooring analysis. A suitable wind gust spectrum is to be used according to the Environmental Criteria.

Local events (such as squalls,...) shall be considered in the mooring analysis if defined in the Environmental specification. Being squalls very non-stationary events, recorded time traces shall be implemented in a time domain analysis. Time traces shall be handled very carefully and sensitivity studies shall be carried out prior to implementation in the analysis in order to assess the effect of each trace on the dynamic response of the floater's dynamics.

4.4.2.2 Current

The current load calculations on the floater hull shall be based on wind tunnel tests.

The marine growth on mooring lines has to be taken into account in the current load calculations since the accumulation of marine growth may affect the weight, hydrodynamic diameters and drag coefficients of the mooring system components. the most prejudicial component characteristics for the mooring system shall be used in the mooring analysis.

For different mooring line locations (surface, mid water and seabed), change in line roughness (due to corrosion, wear, marine growth,...) shall be taken into account in the current loads calculations.

Current shall be considered as a steady load. However, should current fluctuation (in direction and velocity) have an effect on the FPSO response, actual current variation shall be implemented in time-domain analysis. The calculation of current loads shall be based on the current profiles.

Also, the current loads on risers shall be taken into account: seabed to surface current profiles acting on the risers shall be considered as an independent environment, separated from the surface current acting on the hull.

Current loads on mooring lines shall be considered unless proved negligible.

4.4.3 Operating and Functional loads

Risers, offloading lines and umbilicals connected to the F(P)SO generate both static and dynamic loads. The mooring analysis shall take these loads into account.

Offloading in tandem configuration shall be analysed when required by the PPS.

Number, diameter and layout of risers/umbilicals shall be considered to calculate the current loads applied on the unit.

Provision for future risers shall be considered in the mooring design.

4.4.4 Corrosion

Uniform corrosion and pitting corrosion shall be considered for the chain in the design cases.

The following cases shall be adopted for the treatment of corrosion.

- The chain is assumed uniformly corroded so that weight, strength and elasticity are calculated using the corroded diameter.
- The chain is assumed subject to pitting corrosion in which the weight and elasticity remain the same as for the un-corroded chain, but the strength is calculated using the fully corroded diameter.

The corroded chain diameter (d_e) = d – corrosion allowance (mm), where d = un-corroded chain diameter.

For fatigue analysis 50% of the chain's corrosion allowance shall be taken into account for 100% of cycles.

4.5 Vessels Dynamics

The wave frequency response of the FPSO can be estimated separately through frequency domain approach, by the generation of a set of Response Amplitude Operators (RAOs) by the mean of standard diffraction-radiation hydrodynamic software.

RAO data shall be computed for the moored floater including risers/mooring stiffness and damping. They shall be validated against model test results. The motion RAO shall be calculated for 0-degree to 360-degree headings for all considered draughts. The non-linear viscous roll damping shall be properly assessed and calibrated according to model tests.

The wave drift force Quadratic Transfer Functions (QTFs) shall be derived for the same headings and draughts as the RAOs. The use of Newman's approximation for wave drift force calculation in irregular wave is acceptable for COMPANY. Low frequency motions shall be calculated through time-domain approach and damping shall be calibrated against model tests.

4.6 Extreme Design Cases

The analysis cases for the environmental extremes shall include mooring system intact, damaged and transient conditions.

A two line broken condition shall be investigated for 1 year and 100 year storm conditions. The purpose of this analysis is to confirm the possibility to resume oil production with a damaged mooring system until actual repair is carried out. This issue may become critical in remote areas where time to repair may exceed 6 months to 1 year. Safe production may resume after one line failure with an adjusted mooring system (modified line configuration) if all criteria for original intact system are still met with reduced environmental conditions (w.r.t. safety factors and offsets).

4.7 Operating and Installation Design Cases

- a) Where tandem Offloading is required, the mooring system shall be designed to support such operations under 1-year return period environment in intact and 1-line failure with the assistance of tugs. CONTRACTOR shall establish the required tug bollard pull to hold the tanker under those conditions. Necessary analysis shall be carried out to define the operational constraints for the offloading operations (Green, yellow and red sectors).
- b) Design cases for installation scenarios based on 1-year storm conditions shall be addressed.
- c) Mooring lines shall be fully installed before the risers are hanged off the FPSO. Installation cases shall evaluate the required pretension loads on the mooring chains without the presence of risers, marine growth and corrosion. CONTRACTOR shall identify any special equipment (software or hardware) required for installation purposes.

4.8 Design methodology

4.8.1 Frequency and time-domain analysis

Frequency domain and time domain analysis of the moored FPSO shall be conducted in order to determine the 3 dimensional motions at the fairlead functional to the determination of the dynamic response of the mooring lines. Frequency domain approach is allowed by COMPANY for the FPSO wave frequency motion calculation provided that validated damping linearization method is implemented in the roll motion definition. Time domain approach shall be used to calculate the mean position and low frequency motions response accounting for all non-linear effects.

The mooring analysis shall be carried out using validated and approved software.

Important note: when time series of local events shall be taken into account to be in accordance with metocean specifications, time-domain shall be considered as a base case.

These analyses shall be carried out for representative drafts of the FPSO, for the defined extreme environmental conditions and for fatigue design.

Extreme values shall be evaluated on the basis of 3 hours time periods using time domain approach. In order to achieve statistical significance, a minimum of 10 random waves shall be run for designing load cases.

Maximum offsets of the FPSO and mooring line tensions shall be correlated with results of model tests.

Depending on the software/methodology used, if it already includes or not, at this stage, the dynamic behaviour of lines, the line dynamic effect shall be computed in a separate analysis as stated in the next paragraph.

4.8.2 Line Dynamic Analysis

Dynamics of each single mooring line shall be analysed using a standard approved time domain computer program. The extreme cases for each direction identified by the frequency domain analysis, or by time domain analysis, shall be analysed using the time domain tool.

Both irregular and regular wave comparisons shall be carried out.

Mooring line damping varies with environmental loading and load condition and therefore damping shall be carefully implemented in the analysis.

Additional damping coming from the current relative velocity shall be included in the mooring analysis.

4.8.3 Coupled Analysis

Aim of the coupled analysis is to assess the eventuality of coupling dynamic effects between the connected systems and verify the results obtained by previous analyses. A fully integrated coupled analysis for the moored FPSO, risers and offloading system, if any, shall hence be carried out using an approved time domain software.

Method statement and selection of load cases shall be provided for COMPANY approval.

The coupled analysis shall account for all contributions from the mooring lines and risers due to the behaviour and response of the entire system. Results shall be calculated for regular/irregular waves and compared with the regular/irregular wave results of the mooring line dynamics calculations and the results from the model testing.

4.8.4 Fatigue analysis

A fatigue analysis for the FPSO mooring lines shall be carried out in accordance with the **DNV OS-E-301** methodology. The fatigue curve assumed for the assessment of the mooring line fatigue damage shall be in accordance with DNV rules, approved by the appointed Classification Society and COMPANY.

CONTRACTOR shall outline the intended fatigue methodology in a form of FPSO mooring design brief. This document must be issued to COMPANY for review and to the Classification Society for approval.

The analysis shall be based on the intact condition of the mooring system. Load cases shall be chosen to cover the scatter diagram and the extreme wave heights, provided in the meteocean specification combined with associated wind.

The average current for each heading shall be used with the waves and wind for the purposes of the fatigue analysis.

The fatigue analysis of the mooring lines shall account for the wave+low frequency motions of the floater.

When significant, the stress in the chain due to the out of plane (link plane) bending moment caused by friction between the chain links shall be considered in the damage calculation. The methodology used shall be submitted to COMPANY for approval.

For the fatigue analysis the wind velocity is based on 1-hour average velocity for the steady component and the time-varying component is calculated from the wind gust spectrum.

The mooring line chain shall be worn-out at 50% of its wearing allowance and corroded at 50% of its corrosion allowance calculated at a rate of 0.4mm/year, and the damage shall be calculated assuming the stresses in the corroded chain. The nominal strength however will be decreased inversely in line with the worn-out and corroded diameters, giving increased damage on the worn-out and corroded lines.

For all sea-states and directions, the total annual fatigue damage, D_i , will be computed.

$$D_i = \sum_{\text{dir}} \sum_{\text{seas}} D$$

The calculated fatigue life of the mooring system is:

$$L = 1/D_i \text{ (years)}$$

The service life of the mooring system should be less than the calculated fatigue life divided by the factor of safety as outlined in Section 4.9.5.

Whereas maximum tensions are usually found at the fairleads - in absence of subsea buoys -, maximum fatigue damage may be found in any locations along the mooring line. This implies that fatigue assessment is to be made in any individual mooring line component (Chain or wire cable segments, connecting shackles,...) specially around the areas of the fairleads and of the touch down point.

4.9 Design acceptance criteria

In this section are summarised minimum performance acceptance criteria for the mooring system. Hereafter is a list of main design requirements, to be defined in the PPS.

- a) Design life.
- b) Maximum FPSO offsets.
- c) Need for top chain adjustment during field life

4.9.1 Maximum offsets

The maximum offset is the mean offset plus appropriately combined wave frequency and low-frequency FPSO displacements.

Maximum surface excursions of the FPSO shall be within the design limits to prevent damages and clashing to risers and umbilicals in intact, damage and transient condition.

Requirements on maximum offsets shall be amended with results from the riser analysis when available. It is very likely that the critical item for the 2 line broken case will be the maximum offset after the second failure.

4.9.2 Maximum tensions in the mooring lines

The verification of the mooring system shall include the determination of extreme tensions in the mooring lines and subsequent comparison with allowable line safety factors in accordance with CS requirements.

Different approaches are allowed:

- a single safety factor on the line breaking load
- partial safety factors applied on mean and dynamic loads

In this verification, the fully coupled model is to be considered.

Damaged conditions analyses shall also investigate, for both the one-line and two-line damaged criteria, corrective actions to be carried out (re-tensioning/slacking leeward lines, etc.) for the temporary operation of the damaged mooring system.

4.9.3 Minimum line tension

Because of wear due to abrasion, the ropes shall not touch the mud-line (seabed), for any load cases, in intact condition and damage condition.

Then, it shall be checked that no contact between rope and seabed occurs on the least loaded lines.

4.9.4 Maximum tension applied on anchors

Mooring anchors shall be sized for extreme mooring loads with relevance to ultimate lateral capacity, axial capacity (resistance to vertical loads), pile bending moment, resistance to buckling and fatigue damage during installation. Reference shall be made to **GS GEO 702**.

For each environmental design condition, maximum tensions applied on each anchor shall be determined.

Vertical load components (uplift tensions) on anchors are allowed but subject to acceptance by CS and COMPANY of the design criteria in matter of fatigue assessment of suction pile structural details. Based on dynamic approach, a safety factor for the maximum vertical load of 2 and 1.5 respectively in intact condition including the degraded mode with one line damaged and in damage condition with two lines damaged are required for suction pile anchors.

4.9.5 Fatigue

Fatigue life estimates are made by comparing the long-term cyclic loading in a mooring component with the resistance of that component to fatigue damage (allowable number of cycles).

The minimum acceptable fatigue life of the mooring system, in any component, shall be 10 times the field design life.

The mooring system fatigue life shall be assessed and verified on the basis of **DNV OS-E-301** requirements.

The environmental criteria provides the occurrence for swell and wind-generated waves, winds and currents. Directional information together with related occurrence probabilities are provided for each of these environmental parameters.

Environmental data (wave bins) can not be combined in order to reduce the number of analysis cases subject to COMPANY and CS approval.

Impact of damaged condition on the residual fatigue lives of the mooring lines shall be evaluated.

In particular for deep water moorings, fatigue damage due to out of plane bending of the chain shall be analysed. The DnV B1 curve shall be used in absence of any other relevant data.

5. Model tests

5.1 General

The purpose of the model test campaign is to provide sufficient information to calibrate the numerical models used for the design (Strength & Fatigue) of the mooring system.

The model tests campaign shall include:

- Wave tank tests for sea keeping analysis (roll damping calibration)
- Wind tunnel test to derive the wind and current loads
- Coupled mooring/risers system behaviour (to calibrate the numerical model)

5.2 Requirements

A technical specification shall be written, including but no limited to the following:

- Test objectives
- Type of tests (full or partial modelling)
- Model scale
- Number and type of measured parameters, frequency of acquisition
- Test matrix detailing configuration and environmental conditions modelled

The choice of the testing facilities shall be based on

- The possibility of modelling the full anchoring system and/or riser system (sizes and depth of the tank) without affecting the accuracy of the results (scaling effect, fatigue sea state ...)
- The capacity to generate irregular waves for a sufficient time without inducing reflection on the tank walls (performance of the wave maker, efficiency of the beach)
- The capacity to generate wind and current, which are stable in space and time (minimization of turbulent effects).
- The capacity to generate local events such as squalls, gusts in velocities and directions

One aim of the model tests is to check calculations and to give a good point of reference for further numerical modelling.

5.3 Model scale

The choice of the model scale shall be documented. The expected level of accuracy of the measurement shall be indicated for:

- Design storm case
- Fatigue case

Good compromise should be made on the correct modelling of the design condition which in deep water may require to reduce the scale as much as possible to fully represent the actual water depth and line behaviour and the accuracy of the fatigue case with smaller waves.

Truncation of the water depth/mooring lines is COMPANY preferred option for fatigue driven design in benign environment such as in West Africa.

Potential scaling effects on damping assessment shall be addressed and accounted for in the numerical model calibration.

6. Mooring components structural design and fabrication

6.1 Generality

6.1.1 General consideration on Fatigue design

Fatigue-wise, special care shall be given to the choice and design of equipment deemed to handle and support the mooring lines: fairleads, stoppers, shackles, etc.

Such equipment shall fit perfectly with mooring line component regarding dimensions and strength and shall not induce undesired tension in the mooring lines.

Fairleads and stoppers are found to be fundamental for the fatigue life of the mooring lines.

Design shall adequately prove that no in/out of plane bending is generated in the chain links.

The use of universal joint type fairlead/stopper assembly is recommended.

Conservative Stress Concentration Factor (SCF) due fairlead arrangement shall be adopted. SCF shall be calculated and/or provided by the fairlead Manufacturer or/and CS. The chosen SCF shall be assessed versus detailed finite element analyses and proposed for COMPANY and CS approval.

6.1.2 Welding

Welding shall be performed as per [AWS D.1.1 code](#).

Welding procedure shall be submitted to COMPANY and CS and shall comply with [AWS D.1.1](#). Welder qualification test shall be performed as per [AWS D.1](#).

Except otherwise specified herein, all welded assemblies shall be performed according to preparation and welding procedures, performed by qualified welder and 100% NDT controlled.

Codes and standard for welding and post welding inspections are given in the table below.

Subject	European codes	US codes
Welding		
Welding procedure qualification	EN 288	ASME section IX
Performance qualification	EN 287	ASME section IX
NDT control		
Personnel performing NDT	EN 473	ASNT-TC-1A
Visual inspection	EN 970	ASME section V article 9
Liquid penetrant technique	EN 571	ASME section V article 6 ASTM E165
Magnetic particles technique	EN 1290	ASME section V article 7
Radiographic technique	EN 1435	ASME section V article 2 ANSI B31-4
Ultrasonic technique	EN 1714	ASME section V article 5

6.1.3 Marking

All pieces of equipment shall be marked with tag numbers provided by COMPANY. All pieces of equipment shall also be properly labelled with serial numbers and with the mooring line number. All text and markings shall be a minimum of 50 mm high, using Arabic numerals and English language.

Labelling and tagging shall be suitable for the environment, including corrosion resistant materials and fixtures.

6.2 Mooring system components

Mooring equipment shall be designed to fulfil the required design life.

In this section are outlined types, grades and minimum requirements of the mooring lines components. The mooring lines shall be made of chain and wire ropes. Other material will be subject to COMPANY approval. In particular, synthetic ropes are not applicable for F(P)SO mooring.

6.2.1 Chains

Studless chains are recommended.

The ground chains and the anchor forerunners are typically in a high wear, low inspectability area.

The fairlead chains (top chains) are located in the splash zone subject to high wear and corrosion. Also top chains are subject to the most severe fatigue damages.

This specification calls for a minimum design life on the chain as there is no provision for changing out corroded chains. In case of chain failure or any other damage reason, chain replacement must be possible and shall be demonstrated by a suitable procedure.

Offshore Chain grades R4, R3 or ORQ defined by **API SPEC 2F** can be used. The choice of the appropriate grade shall depend on whether the design is governed by strength or fatigue requirements.

If R4 or R3 chain is used then the **DnV-OS-E301** fatigue curves shall be used. If ORQ is used then the **API-RP-2SK** fatigue curves shall be used.

Manufacturer fatigue curves can be adopted subject to acceptance by COMPANY and appointed Classification Society of provided technical and construction data together with details of tests results carried out in seawater.

A corrosion allowance of 0.4mm per year on the diameter shall be used in accordance with **DnV-OS-E301** for no-inspection of bottom components. For fairlead top chain, a corrosion allowance shall be used in accordance with the requirement of the appointed Classification Society, but it shall not be less than 0.4mm per year on the diameter for no-inspection splash zone components.

The splash zone is defined for all top chain. Also, the minimum length of this segment shall be such that the spiral strand segment is fully and permanently immersed.

The ground chain length shall be long enough such that there is some length lying on the seabed after installation pretension. The elastic modulus, weight per meter and the breaking load of the chain shall be as obtained from the manufacturer of the chain (this applies to the fairlead chain as well).

The fabrication of mooring chains shall be performed in accordance with **DNV CN N°2.6**.

6.2.2 Steel Wire

Steel wire shall be of sheathed spiral strand type, torque free, galvanised type suitable if the required minimum design life exceeds 10 years.

The spiral strand shall be sheathed in high density polyethylene to minimise corrosion and be suitable for deepwater applications.

The elastic modulus, weight per meter and the breaking load of the wire shall be as obtained from the manufacturer of the wire. There is no provision for the replacement of the steel wire during the life of the FPSO, hence a six strand steel wire is not acceptable.

DnV-OS-E301 fatigue curves for spiral strand steel wire shall be used. CONTRACTOR may use manufacturer's tested data subject to approval by COMPANY and by the appointed Classification Society.

The fabrication of mooring wire ropes shall be performed in accordance with **DnV CN N°2.5**.

6.2.3 Tri-plates/Shackles

Connection elements between different line segments are generally required.

Offshore shackles, tri-plates or similar solutions are acceptable subject to compliance with the field design life and with the relevant fatigue and corrosion requirements.

Where fatigue loading is the design driver, the use of LTM D-shackles is recommended as they have shown good fatigue performances. Kenter shackles are not accepted for long-term mooring.

New types of connection links may be accepted for the mooring system, provided their fatigue life is shown to be adequate and be documented by testing.

6.2.4 Mooring equipment on FPSO

Design and fabrication requirements concerning mooring equipment (fairleads, stoppers, tensioners, winches) located on FPSO deck are outlined in this section.

6.2.4.1 FPSO Fairleads

Each mooring line shall be secured to the hull by means of a chain stopper and an underwater fairlead.

Fairleads are located at the each corner of the FPSO and are to be integrated in the Hull structure by the FPSO CONTRACTOR.

Fairlead shall be capable of holding the breaking load of the Top Chain.

Fairlead design shall take into account exact actual design of the chain, and also the deformations of the chain in the fairlead. Out of plane (link plane) bending shall be avoided.

Fairlead design itself shall comply with the required service life, and shall be submitted to a detailed fatigue analysis and test procedure. Relevant fatigue analysis procedure shall be submitted to COMPANY and CS for approval.

6.2.4.2 Chain Stoppers

Chain stoppers can be positioned at deck or underwater. They can be placed near or integrated to the fairlead.

Chain stopper shall be designed in order to minimise the chain wear on the fairlead induced by repetitive FPSO motions.

Chain stopper system shall be capable of holding the breaking load of the top Chain.

Chain stopper design shall take into account exact actual design of the chain, and also the deformations of the chain in the fairlead. Out of plane (link plane) bending shall be avoided.

Chain stopper design shall comply with the required service life, and shall be submitted to a detailed fatigue analysis and test procedure. Relevant fatigue analysis procedure shall be submitted to COMPANY and CS for approval.

Important note: Integrated solutions with the stopper articulated on the fairlead are recommended as they ensure that bending in the chain link will be reduced, and that the fairlead will not see the tension in the chain under normal service conditions.

6.2.4.3 Pull-in Equipment

A suitable wire pull-in system shall be provided as part of the permanent equipment on the FPSO.

The design of the chain handling system shall allow for displacement of the FPSO due to riser configuration changes and in case of unpredicted wear and deterioration of top chains.

CONTRACTOR shall estimate the magnitude of mooring installation loads at the point at which the top chain enters the chain tensioning system, and consequently size a pull-in system capable of allowing for friction in the system and account for suitable safety margins. Margins shall be defined for CS and COMPANY review.

A single pulling winch for each end of the FPSO (for a total of 2 winches) shall be proposed.

As a base case, chain jacks (see following section) are deemed to perform the final tensioning of the mooring lines. Alternatively, CONTRACTOR can propose to tension the mooring lines by means of the pull-in winches if feasibility and cost-efficiency is proven.

CONTRACTOR can propose any suitable and cost effective alternative for the pulling system, provided that the proposed system fully satisfies the COMPANY standards and requirements and the applicable Codes and Regulations as per the present document.

CONTRACTOR shall provide, together with any proposed alternative for the pulling system, a general outline of the related mooring system installation procedure for COMPANY review.

Deck turning sheaves shall be provided as appropriate in order to allow a single pull-in system to service all the mooring lines at each FPSO end. Turning sheaves shall be designed for the maximum pulling load.

An appropriate length of steel wire rope for each winch with suitable diameter for the specified pulling load shall also be supplied. A spare wire drum with appropriate wire length might be required for installation purposes.

6.2.4.4 Chain Tensioners

The chain tensioners should be mounted at deck edge corresponding to each bundle of mooring lines. Chain jacks should be bolted onto a supporting structure, but suitable alternatives can be proposed for COMPANY approval.

A fairlead has to be mounted onto the tensioner system to ease the handling of the wire and chain during the pull-in phases and to ease the handling of the chains to the chain lockers.

The chain tensioning system may be required to make occasional adjustments to the pre-tension, after installation is complete.

Movable tensioners shall be designed for ease of de-mounting and re-mounting from a chain tensioner / stopper assembly to another one. As a guide, a complete move of a tensioner from one chain to another should be achievable within about 3 hours, by rigging crews. CONTRACTOR shall provide chain blocks and overhead structures to facilitate lifting and lay-down.

The chain tensioning system shall be capable of adjusting the pre-tension of the moorings lines in a normal operating range around the nominal pretension of the mooring lines.

Chain jacks shall provide live read-out of the tension applied during tensioning.

6.2.5 Anchors

Anchor type will be defined in PPS according to project needs. The following types of anchors are acceptable to COMPANY:

- Drag anchor
- Suction embedded Pile Anchor (suction piles)
- Vertically Loaded Plate Anchor
- Gravity Anchors

Suction embedded pile anchors (suction piles) shall be considered as COMPANY BASE CASE for the anchoring system since capable of withstanding significant uplift loads with a good margin of safety and offer the advantage of pinpoint installation precision.

Alternative anchor solution might be proposed proven the compliance with the field design life, installation constraint, COMPANY General and Particular Project Specifications, CS and Industry Codes and Standards. **GS GEO 702** is applicable to gravity and suction piles anchors.

In case vertically loaded plate anchors are proposed, the design shall be in accordance with **DNV RP-E302**.

6.3 Tests

For drag embedded anchors, the mooring line shall be tested at the design storm maximum load to ensure adequate holding capacity.

For other, purpose of the test will be to detect damage to any mooring line component during installation and to ensure correct line alignment between anchor and fairlead. Insufficient test tension may result in an un-balanced mooring system.

7. Control, Measurement and Instrumentation System

Real time monitoring of mooring tension is to be provided at the chain stopper.

The load monitoring shall be exerted by load cells or similar systems, and read-out shall be provided locally at each stopper, as well as on a repeater system in the control room of the FPSO.

The monitoring system shall therefore be complete with processing units and shall be interfaced with the ICSS (Information, Control and Safety System) of the FPSO.

Local control stations shall be provided at each mooring location. CONTRACTOR shall provide P&IDs with his offer together with technical details of the control cabinet / console.

8. Installation, Inspection and maintenance considerations

8.1 Design considerations

The design has to minimise corrosion and prevent degradation of the components:

- to take into account corrosion and chafing on the seabed, it is more practical to oversize the components.
- adequate design of the fairleads shall minimise bending stresses in the mooring lines.
- an inspection program has to be supplemented.

Also, all aspects related to installation, maintenance, inspection, monitoring and abandonment shall be carefully taken into account in the original design of the mooring system.

Inspection procedure and frequencies must follow the recommendation given by the Classification Society and COMPANY General Specifications.

Even if an inspection program is supplemented, design should not include, as a base case; requirements for change the components during normal circumstances.

No buoy pennant shall be part of the permanent mooring system.

8.2 Installation of mooring components

Outline installation procedures shall be developed to take into account installation constraints.

The installation of the mooring system is to be performed following detailed and careful engineering procedures, in order to avoid torsion, excessive bending, undue slackening of ropes, and wearing or other local damage.

Requirements for installation (including positioning tolerances) shall be developed at design stage.

Detailed installation analysis and sensitivity studies shall be to establish acceptance criteria for installation.

Method statement for installation analysis shall be approved by COMPANY.

8.3 Inspection of mooring components

The inspection of a mooring line concerns all its components, from the chain stopper onboard the FPSO to the place where the anchor chain embeds into the seabed, and to the top of the suction anchor (if any).

The inspection procedure should normally consist of a visual inspection by ROV of the mooring components.

The details of the inspection procedure and the criteria for acceptance or reject of the components inspected may be based, in a first approach, on the recommendations of [API RP 21](#) document related to the inspection of mooring systems.

8.4 Maintenance of mooring components

The procedure to replace a damaged component shall be derived from the installation procedure for laying of the mooring and connection to the FPSO.

8.5 Monitoring during operations

During any phase of the mooring system life, continuous monitoring is to be provided for all-important parameters, which shall at least include:

- FPSO position;
- FPSO heading;
- Line tension at fairlead.

For each parameter, an alarm system is to be settled, with high and low limit; the low-tension alarm can be interpreted as a line failure.