



Exploration & Production

GENERAL SPECIFICATION

PIPELINES - RISERS

GS EP PLR 151

Design of steel catenary riser system

05	10/2009	Revised § 4.8 and updated with DNV-OS-F101: 2007
04	10/2008	Revised § 4.7
03	10/2006	Revised § 4.4
02	10/2005	Addition of "EP" root to GS identification
01	09/2003	General review - Change of Group name and logo
00	10/2002	First issue
Rev.	Date	Notes

Contents

1. Scope	4
2. Reference documents.....	5
3. General.....	6
3.1 Definitions	6
3.2 Nomenclature and abbreviations	6
4. Design philosophy	7
4.1 Design code.....	7
4.2 Engineering capability.....	7
4.3 General layout configuration.....	9
4.4 Interface with floating supports	11
4.5 Corrosion	11
4.6 Anti-fouling recommendation	11
4.7 Material selection.....	11
4.8 Welding.....	12
4.9 Through riser operations.....	12
4.10 Flow assurance.....	13
4.11 Installation considerations	13
4.12 Pressure test.....	13
4.13 Riser disconnection	14
4.14 Inspection, maintenance and repair.....	14
4.15 Riser monitoring.....	14
5. Design data.....	15
5.1 Riser data	15
5.2 Fluids data	15
5.3 Meteocean data	15
5.4 Geotechnical and geophysical data.....	16
5.5 FPS motion characteristics	17
5.6 Ancillary components data.....	19
5.7 Operational data	19
6. Design methodology.....	19

6.1	Acceptance criteria	19
6.2	Design load case combinations	20
6.3	Safety class	21
6.4	Wall thickness sizing analysis.....	21
6.5	Finite element analysis	22
6.6	Strength analysis	26
6.7	Fatigue analysis.....	26
6.8	VIV analysis	29
6.9	Interference analysis.....	31
6.10	Installation analysis.....	31
6.11	Coupled analysis	32
6.12	Sensitivity studies	32
7.	Design requirements for SCR ancillary equipment.....	33
7.1	Flexible joints	33
7.2	Stress joints	33
7.3	Buoyancy	34
7.4	VIV suppression devices	34
7.5	Thermal coating or pipe in pipe	35
7.6	Anode attachment.....	36
Appendix 1	Bibliography	37
Appendix 2	FPS motion convention.....	38
Appendix 3	Geotechnical data	39
Appendix 4	Hydrodynamics	40
Appendix 5	Engineering Critical Assessment	42
Appendix 6	Riser - soil interaction	46
Appendix 7	Special material	47
Appendix 8	Riser pipe property	48
Appendix 9	Meteocean data	49
Appendix 10	Sea states	51
Appendix 11	Calculation Of Riser Fatigue Damage	55
Appendix 12	Spreading of VIV Fatigue Damage in the TDZ	60
Appendix 13	Vortex Induced Vibrations.....	63
Appendix 14	Static sizing.....	67

1. Scope

This document - which supplements the **GS EP PLR 100** - defines the minimum requirements for the structural detail design specific to carbon steel catenary riser systems operated from floating production systems (application on deep water field developments).

Applicability

This specification is limited to the design of carbon steel catenary riser in sweet service conditions.

Pipe-in-pipe SCR, titanium, composite catenary risers or SCR with a piggy back system are not within the scope of this document.

Important remark

The design and installation of steel catenary risers is still a developing technology and experience within the offshore industry is limited to a small number of installations on recent field developments.

Technical uncertainties remain regarding some aspects of the design process.

Physical basis underlying some key phenomena such as VIV, riser - soil interaction shall be carefully assessed.

Recommendations of this specification are therefore based on the last most reliable research findings and observations.

Continued development is undergoing to include the recognised shortcomings and to keep this specification updated.

Basis

DNV-OS-F201 is used as the basis for this specification.

The intent of this specification is to provide statements of guidance relating to catenary risers to supplement the basic requirements of **DNV-OS-F201**.

In addition to the design issues covered in this specification, the overall philosophy to be adhered to during SCR construction, is to emphasis quality over speed so as to achieve production of very high quality welds.

Overview of the document

The overall approach towards SCR analysis and design is outlined below.

- Section 4 - Design philosophy: field of application of SCR technology and limit of applicability
- Section 5 - Design data: data required to enable detail design of SCR
- Section 6 - Design methodology: minimum requirements in terms of calculation, load cases, etc.
- Section 7 - Design of ancillary SCR components: important remarks on SCR components non covered by the Design methodology section
- Appendix 1 is providing a bibliography in relation with theoretical approach and technology of SCRs
- Appendix 2 to Appendix 14 are providing outlines of calculation methods for the design of the SCRs.

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.

Standards

Reference	Title
BS 7910	Guide on methods for assessing the acceptability of flaws in metallic structures
DNV-OS-F201	Offshore Standard - Dynamic Risers
DNV-OS-F101	Offshore Standard Submarine Pipeline Systems
ISO/TS 29001	Sector-specific quality management systems - Requirements for product and service supply organizations

Professional Documents

Reference	Title
API RP 2A-WSD	Planning, Designing and Constructing - Fixed Offshore Platforms - Working Stress Design
API RP 2RD	Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)
API RP 2SK	Design and Analysis of Station Keeping Systems for Floating Structures
API RP 1111	Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines
API SPEC 5L	Specification for Line Pipe
DNV-RP-C203	Fatigue Strength Analysis of Offshore Steel Structures

Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
DoE	U.K. Department of Energy Guidance Notes 1990
HSE	Offshore Technology Report OTO2000-043 - Guidance for Fatigue Design and Assessment of Pipeline Girth Welds

Total General Specifications

Reference	Title
GS EP GEO 504	Comprehensive evaluation of meteocean conditions
GS EP PLR 001	Documentation requirements
GS EP PLR 002	Organisation of the design works
GS EP PLR 100	Submarine pipeline systems
GS EP PLR 201	Fabrication of seamless pipes for pipelines (sweet service)
GS EP PLR 430	Automated Ultrasonic Examination (AUT) of pipeline girth welds
GS EP SAF 021	Lay-out
GS EP SAF 261	Emergency Shut-Down and Emergency De-Pressurisation (ESD & EDP)

3. General

3.1 Definitions

For the purpose of this specification, the following are interpretations irrespective of any other meanings the words may have in other connections:

WORK Means the design, engineering, procurement, installation, commissioning of the steel catenary riser.

Project Specification Project specific document defining the functional requirements for equipment and systems required for a field development project.

3.2 Nomenclature and abbreviations

Ca	Added mass coefficient
Cd	Drag coefficient
Cf	Design case factor (reference API 2RD)
Cm	Inertia coefficient
D	External Diameter, dimensional tolerance in DNV-OS-F101 , section 7
F	Fracture arrest requirement in DNV-OS-F101 , section 7
FPS	Floating Production Support
FPSO	Floating Production Storage Off Loading

L	Length
LAT	Lowest Astronomical Tide
NDT	Non Destructive Testing
P-M	Pierson-Moskowitz
QA/QC	Quality Assurance / Quality Control
RAO	Response Amplitude Operator
Re	Reynolds number
RMS	Root Mean Square
ROV	Remotely Operated Vehicle
SCR	Steel Catenary Riser
SMYS	Specified Minimum Yield Strength
TDA	Touch Down Area
TDP	Touch Down Point
TLP	Tension Leg Platform
U	Specific requirement for pipe material in DNV-OS-F101 , section 7
VIV	Vortex Induced Vibration
WSD	Working Stress Design

4. Design philosophy

4.1 Design code

The basic design code is the [DNV-OS-F201](#) with reference to [DNV-OS-F101](#) for material, testing and installation issues.

Adequate supporting documentation and validation of computational methodology by physical testing shall be supplied, demonstrating adherence to [DNV-OS-F201](#) and [DNV-OS-F101](#) requirements.

4.2 Engineering capability

4.2.1 CONTRACTOR selection

The CONTRACTOR proposed for the WORK shall satisfy the following:

- Its design team shall be made of experienced personnel familiar with the design, engineering, fabrication, installation and commissioning of marine riser systems. Key personnel shall have previous experience in the detailed design of SCRs
- Its design team shall have a high performance support hot line for all the software used and must be competent in Finite Element Analysis (FEA)
- Its design team shall include the necessary experienced personnel in charge of interfacing with all others disciplines (flow assurance, installation, etc.) to ensure the design will fulfil all functional and operational requirements

- A quality management system in compliance with [ISO/TS 29001](#) or other equal quality management system, covering all aspects of the WORK shall be operated
- The systems shall ensure that quality management of the WORK as a whole is applied from inception to completion
- [GS EP PLR 002](#) requirements.

4.2.2 Software selection

4.2.2.1 Global analysis software

SCRs analyses shall be performed with a 3-D finite element code dedicated to the analysis of marine riser systems.

The selected software shall have an independent certification based on analysis of general riser modelling.

CONTRACTOR shall provide model test comparisons for validation of specific items listed above.

The software shall have the capacity to:

- Enable static and dynamic (time domain) analyses, modal analysis and frequency analysis
- Allow 3-D formulation for translation, rotation and torsion
- Model slender structures and cope with large displacements
- Model hydrodynamic forces and FPS motions (Low Frequency motions, RAOs)
- Model non-linearity's (material properties, flexible joint characteristics, riser - soil interaction, etc.)
- Model elastic seabed contact with anisotropy friction law and slope (coherent with non linear soil behaviour)
- Predict in-plane and out-of-plane buckling of the pipe.
- Take into account bending - torsion coupling effect
- Take into account interference between risers
- Enable mooring - riser coupling analysis
- Model thermal, pressure and slugging loading
- Model adequate structural damping formulation
- Model sudden vertical displacement leading to a peak bending stress travelling along the riser, caused by mooring failure for instance (ref. Stride Phase 3 - 1300RPT009).

With regard to post-processing, the following items shall be direct standard outputs:

- Global riser position (distance to other structure, deviation angles, curvature)
- Cross-sectional forces (effective tension, bending moments, torsional moment)
- Stresses (principal stresses and combined)
- Forces at riser connection to rigid structure

- Fatigue life assessment
- [DNV-OS-F101](#) and [DNV-OS-F201](#) codes unity checks for local buckling (combined loading criteria) at each node along the riser length.

4.2.2.2 Vortex induced vibration analysis software

Vortex Induced Vibration analysis shall be computed based on multi-modal response analysis, wake oscillators or resolution of Navier-Stokes equations. Partial resolution of RANS equation i.e. using strip theory and assuming 2D flow in transverse direction, may be acceptable providing software validation is produced to COMPANY satisfaction.

Selected software shall be validated or calibrated against a set of small and full scale tests representative of the currents characteristics analysed.

Efficiency of anti-VIV devices shall be supported by CFD calculation, small or full scale tests.

The software shall, as a minimum, have the capacity to:

- Take into account current direction, speed and their variation with depth
- Take into account realistic Reynolds numbers (and associated turbulence modelling)
- Take into account riser displacement inducing VIV
- Take into account anti-VIV devices with their location, shape and efficiency.

The following outputs shall be calculated by the selected software:

- Modified drag coefficient
- Fatigue damage calculation
- Vibration amplitude of the riser response
- Curvature and bending stress along the riser curvilinear length
- Definition of the excited modes (lock in zone) along the riser curvilinear length
- Identification of the most energetic mode as well as the most damaging one
- Detail of the energy level associated to each excited mode
- Fluid velocity
- Strouhal number.

4.3 General layout configuration

The general configuration of the site layout including SCRs shall take into account the following considerations:

- The SCR shall not contribute to the mooring of the floating unit
- Clashing of the SCRs with adjacent risers, umbilicals, mooring lines or the FPS is not permitted neither during installation nor operation
- Layout shall allow for SCR disconnection (see section 4.13). Requirement for SCR pre-installation may also be considered and shall be specified in Project Specification if applicable
- Layout shall allow for future riser installation on the FPS

- Crane operations should be prohibited above sealines and risers unless they are suitably protected against maximum load impact
- Consequence assessment using dropped cone type analyses may be required to ensure dropped loads cannot damage the pipeline and riser system
- Where the potential of damage from dropped loads cannot be completely eliminated, a derogation from **GS EP SAF 021** shall be required
- This shall include justification that the possibility of damage is sufficiently reduced and that suitable measures have been put in place in the event of damage occurring
- Impact protection shall also be considered in the safety analysis of the general lay out
- First assessment of the minimum clearance between SCRs shall be conducted considering that no wake effect is present i.e. for risers analysed in pairs assumption that one riser is not affected by current shall be made. However, if clashing does occur, a less conservative approach considering “partial” wake effect can be used providing methodology is approved by COMPANY
- SCR layout shall optimise the riser attachment location on the FPS and flaring angle so as to minimise motion effects. However, due consideration for installation safety shall be accounted for
- The length of riser on the seabed shall be sufficient to prevent dynamic tension or bending being transmitted to the attached flowline or other subsea equipment
- Adverse installation tolerances of the host FPS and the interface with the attached subsea flowline/pipeline shall be included in the analyses
- SCR installation tolerances, such as but not limited to, TDP target box and flaring angle, shall be accounted for in the design
- Variations in water depth and host FPS draft in conjunction with the defined FPS excursions due to operational and accidental load conditions shall be allowed for
- The effect of pipeline and riser expansion combined with SCR bottom tension and seabed slope, shall be considered in the riser “in-place” study; this may require straight length of pipeline close to TDP followed by large bending radius and anchoring of the pipeline if the static section is short with a soil with low friction characteristics. The system shall provide adequate resistance to prevent slippage of the SCR TDP
- The evolution of the TDA (long term, including trenching and natural backfilling) shall be taken into account
- Preference shall be given to a Full Pressure Rated Design i.e. capable of withstanding the worst foreseeable normal or abnormal process conditions. Thereafter, active protection systems shall be applied as per **GS EP SAF 261**
- Location shall be selected to minimise potential for escalation of riser events (fires/explosions/unignited gas) to other safety critical areas such as adjacent risers, other flammable inventories, accommodation, emergency response facilities and systems maintaining FPS station or integrity
- Conversely, the vulnerability of the SCR from other fire and explosion events such as sea pool fires or topsides explosions shall also be a fundamental consideration when selecting the riser location. Design reviews shall thoroughly address the Safety issues during this phase of the FPS layout and SCR design process

- Need for SSIV shall be evaluated to reduce pipeline inventory; if deemed necessary SSIV shall be included in the layout (on the sea bed or at pontoon level).

4.4 Interface with floating supports

The top of the SCR shall be connected to the host floating support structure in a location which minimises the exposure to hazard and the effect of FPS dynamics on the riser.

The preferred location depends on the type of facility, installation modes, inspection philosophy, etc.

In all cases, the hang-off shall be close to the centre of pitch / roll and shall be designed to resist torque in the riser arising from reel installation of the riser, accumulated changes in flowline direction and floating support offset and yaw motions.

4.5 Corrosion

There is at present insufficient confidence relating to corrosion fatigue aspects to specify SCR for sour service: SCRs shall be used for sweet applications.

External corrosion protection of SCR shall be achieved using a combination of corrosion resistant coatings and sacrificial anodes. Additional coating protection shall be considered in the TDA.

The design of the corrosion protection system shall be compatible with the cathodic protection systems fitted to the host FPS and to any subsea equipment close to the riser.

Particular attention shall be paid to the system voltages and current density where use is made of dissimilar materials e.g. titanium or material which may be prone to hydrogen embrittlement, e.g. super duplex.

For application where corrosion is foreseen, the use of internal cladding at TDA and at high stress zone shall be investigated.

4.6 Anti-fouling recommendation

Anti-fouling coatings shall be applied on the SCR to inhibit marine growth.

Any marine growth appearing shall be removed periodically in order to ensure the efficiency of the VIV suppression device.

Despite the above, the design shall allow for a reasonable level of marine growth.

4.7 Material selection

High quality line pipe is required for SCR application and in order to ensure a uniformly consistent level of integrity in design and manufacture the line pipe shall meet the requirements of [DNV-OS-F101](#), section 7.

Material selection shall cover the detailed assessment of:

- Strength requirements
- Adequate material toughness for fracture and fatigue performance
- Weld defect acceptance criteria
- Corrosive environment requirements.

In addition, the following considerations shall be adopted:

- Supplementary requirements identified in [DNV-OS-F101](#) (fracture arrest (F) and dimensions (D)) shall apply
- Grade above X65 are not qualified for SCR's
- Threaded connection are not qualified for SCR's
- Pipes up to 16.00 inch (406.4 mm) outside diameter shall be seamless
- Pipes above 16.00 inch (406.4 mm) outside diameter shall be longitudinal seam welded. The longitudinal weld shall be designed against fatigue and Engineering Critical Assessment (ECA) performed in accordance with section 4.8. Particular attention shall be paid on the longitudinal / girth weld crossing.
- Machining or matching of the pipe ends is recommended in order to avoid geometrical discontinuity between each pipe joint
- For the sections subject to large bending (TDA, top of riser), selection of pipe joint with similar strength properties and stiffness is recommended.

Temperature de-rating of material properties shall satisfy [DNV-OS-F201](#) - section 5 - C303 requirements.

4.8 Welding

A Project Particular Specification shall cover the Welding Issues of the SCR's.

The following minimum requirements shall be satisfied:

- Repairs to SCR's welds are not allowed
- A hi-lo of 0.5 mm shall be achieved in the SCR critical welds area (typically in the TDA and at the top of the SCR - but these areas have to be defined by the detailed fatigue analysis)
- Only automatic welding process are allowed
- Engineering Critical Assessment (ECA) shall be carried out according to Level 2 of [BS 7910](#) taking into account plastic-collapse and brittle fracture modes of failure as detailed in Appendix 5. In any cases, the final SCR acceptance criteria shall be approved by COMPANY before implementation. This criteria shall be within the values tabulated in Appendix 5 where typical data gained from past experience are outlined
- Welding Procedure Qualification shall satisfy the requirements defined in the Project Specification. In addition, tensile specimens tested during the welding procedure qualifications must fail in the pipe body and not in the weld area. This overall qualification process shall culminate with the performance of full scale fatigue testing. These tests shall satisfy the requirements defined in the Project Specification.

4.9 Through riser operations

4.9.1 Pigging

The overall design of the SCR shall take into account the requirement to pig the riser and associated pipeline both during commissioning and as a routine part of operations.

In particular, flexible joints shall be specified to permit pigging operations and the limiting values of FPS offset shall be established corresponding to the maximum angular displacements of the flexible joints for satisfactory pigging operations.

4.9.2 Well service, coil tubing

Unless the SCR is specifically designed for it, it is not permitted to carry out well service operations through SCRs, or coil tubing interaction.

4.10 Flow assurance

Detailed studies should be performed as part of the SCR design process to establish the required line diameters, thermal insulation requirements and the size, frequency and velocity of slugs appearing in the risers.

Slugging shall be examined in sufficient detail to identify any requirement for a separate design load case.

4.11 Installation considerations

CONTRACTOR shall ensure that the installation operations will not induce temporary or permanent strain in the pipe wall that could affect the integrity of the SCR over its full service life.

Installation by reeling is accepted provided that a project's specific detailed study of the reeling effects has demonstrated that the reeling operation does not adversely affect the integrity of the SCR. In particular, the high strains involved in reeling and straightening of the pipes can give rise to simultaneous ductile tearing and low-cycle fatigue crack growth (so-called tear fatigue) that can cause pre-existing weld flaws to extend, thereby potentially reducing the life of reeled risers compared to conventionally installed risers with the same fabrication flaws. As a result, simultaneous ductile tearing and tear fatigue shall be quantified based on a combination of analytical formulations, small scale testing and full scale testing.

In addition, the study shall include tests using samples of the riser pipe to establish limits on residual ovality, residual strain and on full scale welds to establish any effect on fatigue life.

Installation method shall enable suspension and reversal of the procedure.

General configuration shall be selected such as the installation can be performed with standard equipment (maximum capacity of about 500T without any safety factor).

4.12 Pressure test

The riser system shall be pressure tested in place following installation but before being put into operation.

Pressure testing shall be carried out to demonstrate the integrity of the completed riser system. Test pressures, hold time and acceptance criteria shall not be less onerous than required by [DNV-OS-F101](#) Section 5 B200.

If the riser appurtenances are all hydrotested prior to installation then the pressure test performed on the riser system might be conducted as a combined strength and leak test.

4.13 Riser disconnection

SCRs shall be designed to be safely disconnected and recovered or temporary wet stored (laid on the seabed, etc.) in the event that the host facility is required to leave site as per planned schedule.

Provision shall be made on the host facility for the temporary equipment and facilities required for this operation.

Transfer of the riser from the host FPS and lay down on the seabed shall be engineered with extreme care taking into account the different load cases applying to installation (e.g., flooded riser, dynamics of lift FPS, effects of off-design configuration).

Equipment should be specified based on the results of simulation analysis of disconnection operations and should include substantial margins to account for the critical and non-standard nature of these operations.

4.14 Inspection, maintenance and repair

4.14.1 Inspection

As a minimum, the design of SCR shall accommodate the following routine inspection operations:

- External visual and cp potential surveys carried out on an annual basis using ROVs
- Intelligent pigging
- Riser support on the FPS (flexible joint or stress joint) inspection for wear or damage.

4.14.2 Maintenance and repair

The risers system shall be designed for operation throughout the life of the installation without any scheduled maintenance or repair.

In-situ repair of structural damage to catenary risers is not considered feasible.

It is therefore recommended that project considers sufficient redundancy / flexibility in the riser system (use of dual production riser, interconnectability, etc.).

The layout of the field and riser facilities shall facilitate the removal of a damaged SCR and the installation of a replacement (without any clash with other existing facilities).

4.15 Riser monitoring

Each riser system including SCRs shall be fitted with a riser monitoring equipment.

The minimum requirement will be to obtain a measure of the consumption of fatigue life of, at least, one of the SCRs. This can be achieved by calibration of the fatigue life consumption assessment based on riser monitoring at early stage of the field development.

The monitoring system shall require analytical calibration to correlate between the results obtained at the locations of the monitoring equipment and the rest of the riser.

The monitoring equipment shall be located to respond to both wave action and to VIV.

Measurement of the associated vessel motion shall be conducted.

5. Design data

The purpose of this section is to define the information required to design an SCR. The following information shall be gathered before starting SCR engineering.

5.1 Riser data

The minimum riser data required for conducting riser design are:

- Line size
- Top angle
- Material properties
- Coatings characteristics
- Hydrodynamic properties
- Pipe external roughness
- Presence of anode
- Shielding/enhancement from adjacent risers and structures.

5.2 Fluids data

5.2.1 Internal fluid

The minimum internal fluids data required for conducting riser design are:

- Internal pressure (incidental, operating)
- Density (max, min, average)
- Temperature (max, min)
- Chemical composition of effluent and chemical (used for service, drilling, etc.).

5.2.2 External fluid

- Temperature
- Density
- Presence of H₂S, etc.

5.3 Meteocean data

Due to the high sensitivity to hydrodynamic loads, it is essential that site specific meteocean data shall be available for the design of SCR systems.

Where there are specific events such as summer storms, winter storms, loop currents or tropical storms/hurricanes, the data relating to these conditions should be grouped in a way that the designer can address each of these meteocean events as a specific design case.

The minimum meteocean data required for conducting riser design are:

- Local wave/swell data (simultaneous crossed seas)
- Current data (profile and scatter diagram)
- Marine growth.

A detailed description of the meteocean data required is given in appendix 9 of this document.

Local waves shall be investigated: meteocean data sometimes do not allow for the wave category since they are less important than swell. However local sea can have an impact on fatigue.

5.4 Geotechnical and geophysical data

5.4.1 Geotechnical data

The geotechnical data shall be specific to the development site and representative of the conditions that will be encountered by the riser in service.

Details of soil chemistry and composition should also be obtained for the purpose of adequately specifying the pipe coating, corrosion protection and anti-abrasion coatings.

The soils at or close to the seabed in deep water are generally very soft to soft clays, although the presence of sand layers cannot be discounted.

Normally only the upper 5 meters of the seabed are of interest for SCR analysis.

The soil properties required for SCR modelling are different for clays and sands, and are given in the sections below.

For SCR analysis the main riser - soil interaction effects to model are summarised below:

- Downward vertical soil reaction - indentation into the soil, including static soil stiffness and dynamic cyclic loading
- Upward vertical soil reaction - resistance to uplift of the riser from the seabed including soil suction, static soil stiffness and dynamic cyclic loading
- Longitudinal and transverse soil reaction including frictional forces and passive resistance to lateral motion
- Viscous effects of soil damping.

5.4.1.1 Clay

- The clay soil parameters required for SCR analysis are given in table below:
- Undisturbed shear strength
- Shear strength gradient with depth
- Sensitivity of clay
- Submerged unit weight
- Poisson's ratio
- Void ratio
- Plasticity index

- Lateral friction coefficient
- Axial friction coefficient.

Typical values are given in Appendix 3.

5.4.1.2 Sand

The sand parameters required for SCR analysis are given in table below:

- Submerged unit weight
- Angle of friction
- Poisson's ratio
- Voids ratio
- Lateral friction coefficient
- Axial friction coefficient.

Typical values are given in Appendix 3.

5.4.2 Geophysical data

Sea bottom profile as well as the presence of any geo hazards (such as shallow gas, hydrates, etc.) shall be identified in the TDA.

5.5 FPS motion characteristics

5.5.1 General

Accurate characterisation of host FPS motions is critically important in developing reliable designs of riser system.

The key FPS motion data required for riser analysis is as follows:

- Static offset - the displacement resulting from mean environmental loads acting on the FPS i.e. wind, wave, current, often referred to as FPS mean position
- Wave frequency motions - the first order dynamic motions resulting from wave action and normally described by Response Amplitude Operators (RAOs)
- Low frequency motions resulting from second order wave forces and wind gust, often referred to as slow drift motions
- Other motions: VIV on FPS, springing ringing effect, etc.

Tests in basin shall be performed in order to validate numerical calculation of floating production unit RAOs and low frequency motions with risers in-place.

5.5.2 Mean position

The FPS mean position shall be determined from a mooring analysis based on environmental conditions which are consistent with the key riser design load cases.

This analysis shall consider normal operational conditions, failure/accidental loading cases and specific offset conditions associated with non standard operations (e.g. installation operations or offset to allow access to seabed equipment).

The effect of tension and drag from the risers shall be taken into account in the mooring analysis for the purposes of assessing FPS excursions and motions.

However, no account is to be taken of the risers when assessing the integrity of the mooring system or checking compliance with mooring system design codes.

5.5.3 Low frequency motions

Low frequency FPS motions data resulting from second order wave effects (long-term drift data) and wind gust loading is used in detailed SCR fatigue analysis where it is combined with FPS mean offset data.

These data should be determined from a mooring analysis conducted specifically for the mooring configuration intended for the host FPS and combined with the FPS mean position as described in [API RP 2SK](#) to provide the long term FPS motion data.

Influence of risers on wave drift damping shall be investigate and take into account if necessary.

5.5.4 Response Amplitude Operators (RAO)

FPS RAO data shall be provided describing the relationship between wave and corresponding FPS motion characteristics in six degrees of freedom.

They are often a key point in the riser system design and fatigue analysis; therefore, the derivation of these data shall be clearly documented on the following points:

- Values and method used to take into account the required damping for the waves frequencies motions, specially for ROLL, PITCH and HEAVE motions
- Values of the global stiffness used for the RAOs if a no free floating analysis is performed
- Riser/mooring stiffness, influence on the wave frequency motion should be highlighted if necessary
- Riser and mooring participation on the low frequencies damping
- Damping and H_s values considered for roll motion (maximum 1 meter).

They also shall be accompanied by the following information for correct conversion into formats suitable for the analysis software:

- Definition of FPS co-ordinate reference system and axis orientation
- COG location or RAO's reduced point shall be provided
- Associated FPSO condition: ballasted or fully loaded or mid laden (internal and external compartments)
- Definition of FPS direction relative to wave
- Definition of wave conventions (sine or cosine)
- Definition of phase angle relative to wave crest and platform origin (ie positive phase denoting lag or lead).

For preliminary design studies, the use of generic data may be adequate; however, for detailed design analysis, the RAO data shall, as a minimum be derived from a diffraction analysis of the specific hull form intended for the host FPS.

Where available, the use of model basin test data should be considered however, the data used should be representative of the sea states required for riser design analysis.

5.5.5 FPS loading configurations

The above information shall be given for different load conditions:

- Ballasted
- Full
- Mid laden (external and internal compartment).

5.5.6 Other motions

Other FPS related effects having a significant influence on the design of SCR systems (such as SPAR VIV, TLP springing and ringing) shall be identified and taken into account if necessary.

CONTRACTOR shall investigate all other motions of the FPS which could impact on the SCR design:

- VIV on the hull of FPS
- Springing effect (on TLP)
- DP
- Etc.

5.6 Ancillary components data

The minimum required data for the flexible joint are:

- Axial and torsional stiffness as a function of the flexible joint angle
- Max and mean angle
- Temperature and pressure (operating and incidental).

5.7 Operational data

The minimum operational required data are:

- Slugging characterisation
- Shut down/start up number of cycles per year
- Risk of deposition (debris, wax, etc.)
- Pressure variation cycles.

6. Design methodology

6.1 Acceptance criteria

The in-service design cases/load combinations are defined in the table below.

Each of these design cases shall be conducted for sufficient environmental loading directions to prove the design.

Typical limiting design criteria are given in the table below:

Design criteria	Acceptance value
Stress in normal operating, etc.	Refer to DNV-OS-F201 - Section 5
Fatigue due to combined load (WF, LF, VIV, etc.)	10 times design life
Fatigue due to VIV	20 times design life
Clearance from the FPS, mooring lines, umbilical and other risers	No clashing (probability of occurrence < 10^{-4} per design life)
Limiting flexible joint rotations	90% of maximum flexion characteristics, based on tested components
Maximum interface loads	As per structural design code (API RP 2A-WSD , if not specified)
Possible compression in the TDA	Effective tension > 0
Tension on flowlines	No residual tension on subsea component connected to SCR

6.2 Design load case combinations

6.2.1 Accidental design load cases

Failed mooring with a 100 year wave condition is an accidental design case typically used in SCR design. One failed mooring line is not the only potential failure mechanism that will have an effect on the riser integrity. Other accidental design cases applicable to SCRs are listed as follows:

- Two or more failed mooring lines (or tethers on a TLP). The location of the failed mooring lines for the analysis shall be selected so as to result in the most onerous condition in terms of SCR damage
- Damaged hull compartments.

The probability of each combination of environmental event with an accidental design case may be established by means of quantitative risk assessment.

For example, two failed mooring lines combined with a 100 year wave condition may have a low probability of occurrence.

In these situations an increase in the allowable stress, or a less severe environmental condition may be considered.

All design loads shall be considered as per [DNV-OS-F201](#) - Section 3.

6.2.2 Internal fluids

For strength analysis, loading due to the internal fluid shall be included in terms of hydrostatic pressure and mass contribution to the riser system.

Fluids shall be considered static or in the steady flow regime (constant velocity).

The range of densities to be used in the analysis shall be chosen such as to cover all aspects of the riser installation and operation.

The effect of the axial elongation shall be investigated.

For fatigue analysis, the phenomenon of slugging shall be examined separately and the effect on the riser assessed as part of the detailed design.

6.2.3 Other loads

- Typically other loads are expansion of the riser, expansion of the line
- The FPS shall be considered in its worst loading condition (which is normally the empty case)
- Temporary installation loads shall be included in the design
- Functional loads induced by operation such as emergency shut down or fluids slugging or line pigging.

6.3 Safety class

Safety class classification shall satisfy [DNV-OS-F201](#) - section 2 requirements.

In addition, for risers installed in array, due account of the geometric configuration and its inherent constraint shall be made for the definition of the safety class.

6.4 Wall thickness sizing analysis

6.4.1 Pressure containment criteria

The design of the riser pipe to resist internal pressure shall be in accordance with the methods and criteria of [DNV-OS-F201](#).

The design shall take account of design pressure, maximum operating pressure and accidental overpressure and shall take correct account of relevant external pressures.

Unless directed otherwise by the project specification, the design pressure for the riser shall take account of the maximum pressure likely to be seen in the riser during its full life (emergency shut down included).

Care shall be given in the definition of the incidental pressure and subsequent design pressure so as to ensure consistency between the DNV pressure definition and the FPSO topsides design code definition.

6.4.2 Collapse criteria

Collapse criteria shall be used to ensure adequate wall thickness for the maximum water depth to be encountered.

Collapse design of catenary risers shall follow the requirements of [DNV-OS-F201](#) - Section 5 D300 in the assessment of resistance to external pressure.

The combined resistance to external pressure, bending and tension shall satisfy the [DNV-OS-F201](#) - Section 5 D500 requirements

The initial ovality of the riser sections shall not be taken less than the minimum value indicated by [DNV-OS-F101](#). Ovalisation introduced during the construction phase shall be included in the ovality.