



Exploration & Production

GENERAL SPECIFICATION

STRUCTURAL

GS STR 652

F(P)SO - Steel hull design requirements
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1. Scope

This specification aims at defining the minimum requirements, which are applicable to the design and the construction of a F(P)SO Floating (Production) Storage Offloading hull in both new build or conversion projects. Application for FPU projects will be subject to a Project Particular Specification that will provide detailed interpretation of this General specification.

It does not address any design requirements for modules or packages, which will be ultimately placed on the F(P)SO deck, and to risers related to subsea production equipment.

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.

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 following reference documents are applicable as described in the following sections. When not explicitly referred in the following sections they may be used as guidance when relevant.

Attention is drawn to IMO MEPC No 406 "Guidelines for Application of MARPOL Annex I requirements to FPSOs and FSUs" which is fully applicable.

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.

Standards

Reference	Title
ISO WD 19904	Materials, equipment and offshore structure for petroleum and natural gas industries - Offshore Structure - Part 4: Floating Offshore structures
ISO DIS 19901-5	Offshore structures Weight control during engineering and construction
ISO 3730	Mooring winches
ISO 6067	Winches for lifeboats
ISO 7365 (if relevant)	Towing winches for deep sea use
ISO 7825	Deck machinery General requirements
ISO 9089	Anchor winches
ISO TR 14564	Marking of escape routes

Professional Documents

Reference	Title
ISGOTT	International Safety Guide for Oil Tankers and Terminals - Rev 4 1997
NORSOK N001	Structural Design
NORSOK N004 Annex L	Design of Steel Structures Special Design Provisions for ship shaped units.
NORSOK M101	Structural Steel Fabrication
OCIMF	Guidance Manual for the inspection and condition assessment of Tanker Structures - Rev 1 1986

Regulations

Reference	Title
COLREG	Convention on the International Regulations for Preventing Collisions at Sea, 1972
ICLL	International Convention on Load Lines, 1966
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships
IMO MEPC 406	Guidelines for Application of MARPOL Annex I requirements to FPSOs and FSUs
SOLAS 1974	International Convention for the Safety of Life at Sea
IMO Resolution A749	Code on Intact Stability Criteria

Code

Reference	Title
Not applicable	

Other documents

Classification Society Rules

When converting a tanker, (which by nature was built to ship and not offshore rules), the offshore rules will apply at least to the permanent mooring systems, the turret and risers and offloading systems. The rules do not necessarily explain in detail how to interface classical tanker and offshore rules.

Reference	Title
American Bureau of Shipping	Guide for Building and Classing Floating Production Installations
Bureau Veritas	Rules for the Classification of Offshore Units
Bureau Veritas	Hull Structure of Production, Storage and Offloading Surface Units
NR 497 DTM R00 E	
Det norske Veritas OSS 102	Rules for Classification of Floating Production and Storage Units
Lloyd's Register of Shipping	Rules and Regulations for the Classification of a Floating Offshore Installation at a fixed location
IACS	Shipbuilding and Repair Quality Standard" (no. 47) dated 1996

Total General Specifications

Reference	Title
GS COR 100	Design of cathodic protection of offshore structures
GS COR 101	Design of internal cathodic protection of equipment and storage tanks
GS COR 351	External protection of structures and equipment by painting Floating Structures
GS LSO 100	Environmental effects considerations for helidecks
GS STR 001	Weight monitoring and weighing offshore units
GS STR 101	Design of Offshore Jacket and Subsea Structures
GS STR 102	Design of offshore topsides structures
GS STR 201	Materials for offshore steel structures
GS STR 301	Fabrication of offshore steel structures
GS STR 651	General design principles of a F(P)SO design
GS STR 653	F(P)SO - Hull fabrication requirements
GS STR 661	F(P)SO - Design requirements for mooring and anchoring

3. Definition

To avoid misinterpretation, the following definitions are used in the rest of this document:

- Hull: in general this correspond to the shipyard scope of work including hull, marine systems and living quarters
- Topsides: this corresponds to the process facilities, utilities and other related functions. FSOs do not have topsides
- Turret: this corresponds to the structural, mooring and riser support parts of a turret.

- Appurtenances: FPSO specific elements including their foundations which are protruding from the hull not normally existing on ships (such as risers supporting structures, boat-landings, mooring support structures, topsides stools, protectors, flare foundations,...). These elements are designed to Offshore Standards.

4. General arrangement

4.1 Hull shape

Consideration of a ship-shaped hull versus a box-shaped hull shall be given at the early design stage of the project. Possible areas of optimization using a ship-shaped hull are bending moments, hydrodynamics on site / during tow, behaviour under collisions for tandem offloading..

4.2 Tank arrangement

Regulation 24 of MARPOL shall apply.

Double-side configuration along the cargo tank area is required on new units. Double bottom is not recommended.

In addition to the requirements of the selected Classification Society, a special attention has to be paid on the operational aspects of the FPSO.

- The hull subdivision shall be designed to match with the references. However stored crude oil shall always be **segregated** from seawater.
- The hull subdivision shall be such that the variations of stresses in the structure are minimised.
- The hull subdivision shall be designed to allow an easy maintenance of the shell plating that is alternatively exposed to air or seawater.
- Crude oil pipes are not allowed in **bilge**.
- Crude Oil Washing (**COW**) shall be permanently fitted in each crude oil tank.
- **Sea inlets** or outlets shall be avoided as much as possible. Vertical risers fitted with their strainer running along the side shell are the preferred option. These risers shall be protected against collision and designed for an easy maintenance.
- **Plastic piping** shall be used as extensively as possible for other products (mainly seawater) than crude oil as per the references.

4.3 Tanks and tank capacities

All tank capacities shall be reported in ullage and sounding tables showing the gross and net volume of the tanks at each trim angle between -1 and 2 degrees.

4.3.1 Cargo storage capacity definition

The net capacity of a tank is defined as the net storable and recoverable volume of fluid in the tank at 98% filling, excluding volume of internal structures and unpumpables.

Unpumpables are defined at the maximum operating trim when pump flowrate decreases to less than 50% of nominal capacity.

When exact pump arrangement and geometry of tank is unknown (ie before detailed engineering), estimation of unpumpable shall not be less than 3% of the overall volume of the tank.

Thermal expansion of oil between storage temperature and trading reference temperature (15°C) shall be accounted for when defining the net tank capacity.

The net cargo capacity (excluding slop tanks) shall be checked at level trim of the F(P)SO.

4.3.2 Cargo area arrangement

The cargo tank configuration shall fulfil the following requirements:

- The cargo tanks shall be approximately of equal size.
- Loss of required storage capacity shall not exceed 10% in case of any one tank becomes unavailable. More generally, the loss of required capacity shall not exceed 20% when two tanks are unavailable for repair or maintenance, 30% when 3 tanks are unavailable, etc...

The density of cargo oil to be considered in all calculations will be specified in project particular specification. The crude oil storage temperature is to be considered in particular for paint selection and cathodic protection design.

4.3.3 Ballast tanks

Water ballast tanks will be situated along the sides, in fore and aft peaks and possibly within central cargo area to reduce still water bending moments. The required capacity shall be determined by the Shipyard such that the F(P)SO fulfils the hydrostatic and global strength requirements for all F(P)SO loading conditions. The minimum width of the ballast tanks should be three metres. The density of sea water shall normally be taken as 1025 kg/m³, except when actual values are known with high level of confidence (permanent ballast with river-water)

4.3.4 Slop tanks

Two equally sized slop tanks shall be located at the forward (flare) end of the cargo tank area. The capacity of each slop tank shall be determined according to [GS STR 651](#).

4.3.5 Potable water tanks

Two potable water storage tanks shall be located in the vicinity of the Living Quarters each with a capacity specified per the Project Specifications.

4.3.6 Fresh water tanks

At least one fresh water storage tank shall be located in the vicinity of the Living Quarters with a capacity specified per the Project Specifications.

4.3.7 Diesel Oil tanks

Two Diesel oil storage tanks shall be located in the vicinity of the Living Quarters. The capacity of each diesel oil storage tank shall be specified per the Project Specifications.

4.3.8 Methanol tanks

The methanol tanks (if any) should be isolated from tanks containing fluids at high temperature. Need for isolation by cofferdams shall be investigated.

4.3.9 Hydraulic oil storage tanks

When required, hydraulic oil storage tanks shall be provided each with a capacity at least equal to the capacity of the hydraulic distribution systems.

5. Stability and watertight integrity

5.1.1 Hydrostatic characteristics

The stability and strength of the F(P)SO shall be assessed according to the requirements of the Classification Society and regulatory bodies.

The vessel is to be provided with an on-line loading computer. An identical off-line loading computer with intact and damage stability capability is to be provided to allow for loading sequence simulation.

5.1.1.1 F(P)SO loading conditions

As a minimum the following loading conditions shall be considered:

- Light ship
- Ballast condition
- Full load condition defined as the configuration where the cargo storage is full (unpumpable required cargo), the bunker is 100% full, the slop tanks are 98% full of water and the ballast is such that the required trim is achieved, all risers are filled with their operating fluid, mooring lines are all connected and pre-tensioned)
- Loading conditions representing at least two normal loading and off-loading sequences
- Loading conditions will be developed so as to minimise the ballast operations
- Loading conditions necessary for tank Inspection, Maintenance and Repair (IMR cases). The following IMR cases shall be considered:
 - Any one tank empty.
 - Any two adjacent tanks empty.
 - Four (4) tanks with a common corner empty.

In the case of four tanks empty, a restriction in oil storage (in addition to the emptied tanks) shall be applied to limit the structural and stability impacts.

The free floating stability verification shall be performed to reflect:

- The initial phases of construction (with and without topsides as required), towing to the site and installation on site
- The final phases of decommissioning (with topsides and fluids).

Preliminary Topsides weights and centres of gravity are considered for global design, including minimum and maximum operating conditions and transportation conditions. The intact stability, damaged stability and strength requirements shall be satisfied for the full range of Topsides conditions, given including provisions for future extensions.

In addition, CONTRACTOR shall investigate whether these requirements can be satisfied for the following Topsides sensitivity cases:

The maximum weight of any pair of modules is 30% greater than the values given, with the remaining module weights and CoG's at the values given.

The weight of any pair of modules is set to zero, with the remaining module weights and CoG's at the values given.

The vertical centre of gravity of the overall Topsides is raised by 1.0 meter above that given, with module weights and horizontal CoG's at the values given.

The transverse centre of gravity of the overall topsides is moved ± 1.0 meter athwartships from the position given, with module weights and longitudinal and vertical CoG's at the values given.

The longitudinal centre of gravity of the overall Topsides is moved ± 5.0 meter fore and aft from the position given, with module weights and transverse and vertical CoG's at the values given.

5.1.1.2 Load line

Load lines requirements shall be established for the different conditions (tow, operation).

The maximum draught will be calculated according to **IMO 1966** Load Line Convention for ship type A: tankers or latest revision.

5.1.1.3 Freeboard

Bow/aft freeboard and bow flare with high bulwarks shall be provided to ensure that the occurrence of green water at the bow/aft is minimised (as close as possible to zero probability of occurrence).

Similarly freeboard shall be provided amidships to minimize the occurrence of deck wetness in the design extreme storm while fully loaded.

CONTRACTOR shall perform analytical predictions and/or model tests to demonstrate the effectiveness of the freeboard and bow configuration chosen.

It is also necessary to deal with equipment or ways on deck or access to riser balcony under normal operating conditions.

5.1.1.4 Trim

For all operational loading conditions a nominal trim by the flare shall be maintained. When possible the desired trim is obtained by an appropriate loading/unloading sequence. Additional ballasting shall be possible to reach the trim or to minimise the bending moment. Normal trim of the F(P)SO will be by the bow to allow proper draining to the flare Knock-Out drum. The normal operating trim will be -1% (by the bow) within a $\pm 0.5\%$ tolerance. For stripping purposes or extreme conditions a trim of -1.3% (by the bow) shall be allowed. Suction pipes for cargo pumps should be located in accordance with normal trim.

Location of the PV Breakers should be chosen in accordance with normal trim.

5.1.1.5 Heel

Normal operating conditions shall be with no nominal heel within a $\pm 0.5\%$ tolerance.

5.1.2 Intact stability

5.1.2.1 Free-floating stability

The intact stability shall be verified in accordance with Classification Society requirements. Stability calculations shall be performed with an approved software allowing free trim analysis. It shall satisfy **IMO Resolution A749** (18), Chapter 3, Regulation 3.1 (general intact stability criteria for all ships) and Regulation 3.2 (severe wind and rolling criterion), (or any later revision at effective date of Contract) for all conditions anticipated during operation. It shall be verified that the F(P)SO can withstand the environmental conditions during sea transport and at site.

Openings giving access below decks, like machinery space entries, ventilation intakes, vent pipes, etc., are to be considered in the stability calculations.

5.1.2.2 On site-stability

For the site stability verifications, MODU code shall be used. However it is mandatory to consider site specific data when they could be higher than those stated in code, such as in typhoon or hurricane areas. The use of values lower than those stated in the codes can only be considered if fully documented and has to be approved by COMPANY.

Risers and mooring positive actions (if any) shall be ignored in the stability verification, negative effects shall be included.

When not inspectable, positive actions of external buoyant addition (skegs, riser support caissons, etc.) shall be ignored as if they were flooded.

5.1.3 Damaged stability

The damaged stability shall satisfy the requirements of ICLL 1966 as modified by the 1988 Protocol, Annex I, Ch III, Reg 27 and MARPOL 73/78 Annex I, Ch III, Reg 25, but without considering bottom damage. The calculations shall be performed using the conventional method of a maximum KG curve. If this results in conditions with large correction for free surface effects, direct calculations with an actual shift of the liquids may be used.

Influence of damages to mooring lines or risers shall be assessed.

Calculations shall identify the normally closed vents or openings (doors, hatches, etc.) which would become critical under such circumstances if left open either for operation or by human error. This information shall appear clearly in operating manuals.

5.1.4 Inclining tests

Inclining tests shall be performed to confirm the hydrostatic calculations and the general weight information.

These tests shall be performed at different steps of the construction and at least at:

- Delivery of the hull
- Before connection of any mooring line or riser (before departure if the installation is reasonably complete).

Inclining tests shall be performed according to procedures approved by COMPANY and Class Society.

The tests shall allow for the estimate of lightweight, centre of gravity location and confirmation of vertical position of CoG (KG or VCG).

Inaccuracy on the results shall be estimated and documented. Discrepancies with predictions shall be analysed and explained, as necessary and if a fair explanation is found, updating of data and curves will be performed.

Final T&S and load master shall be revised and approved on the basis on the inclining experiment results.

6. Hydrodynamic characteristics

A hydrodynamic analysis shall be performed to assess the effects of vessel motions on human and equipment performance, to assess hydrodynamic and inertia loading, and to provide input

to the mooring and riser analysis. The F(P)SO behaviour shall be evaluated both on station (normal operating, survival and damaged condition) and during temporary phases such as tow. Motion analysis in damaged cases shall be performed under the 1yr return period environment. The damage cases to be considered are the ones leading to the maximum heeling angle from the estimated damage cases of each load condition. The main goal is to provide hull motion after MARPOL breach to verify the topsides stools structural integrity and hull structural integrity. The structural verifications after MARPOL type damage shall allow stress up to yield, and are not to be considered as design cases, unless consequences results in progressive collapse. The optimum draft of the F(P)SO shall be determined for the tow with respect to towing resistance, course stability, static stability and ship motions. Environmental data at site and along the towing route shall be used to calculate the hydrodynamic characteristics.

The analysis may be limited to the unit's first order motions and drift forces, but excludes the mooring analysis. The effect of the mooring and riser system on the first order motion behaviour can generally be neglected.

The following issues shall be addressed:

6.1 Vessel motions

Response Amplitude Operators (RAOs) are to be compiled for a sufficient number of drafts and wave headings. Special consideration shall be given for the appropriate amount of roll damping. As a minimum motions and accelerations shall be calculated for the following locations on the unit:

- F(P)SO centre of gravity
- Fore- and aftmost, highest corner of topsides process plant envelope
- Flare Tip
- Living Quarters and helideck

Results shall be presented for extreme and operational environmental conditions. Directional spread of waves for each mean wave direction shall be taken into account. The motions in extreme conditions shall be used for structural design. The motions in operational conditions shall be used to determine operational up time of process equipment (by the Topsides CONTRACTOR), human performance, helicopter and crane workability.

Tools used for analytical modelling shall be adequately calibrated against model tests in similar environmental conditions and on similar floater. If not, model tests shall be performed.

6.2 Waves Hull Loading

Hull girder wave loadings are to be checked against Classification Society and regulatory body requirements.

It shall be demonstrated that fore and aft ship structures are adequate with respect to bottom slamming and bow flare impact, and a minimum safe draft shall be established for the towed voyages.

The probability of occurrence of green water shall be assessed.

Confirmation of the structure of the cargo tank internals with respect to sloshing shall be given.

Outfitting on side shell shall be designed on the basis of hydrodynamic results.

6.3 Course stability

Course stability during tow shall be investigated, taking into account the anticipated environmental conditions during the tow.

The vessel shall have positive directional stability while under tow from the bow at speeds up to 6 knots, in the light and ballast conditions. Need for steel skeg(s) shall be investigated during model tests.

CONTRACTOR shall establish the towing resistance of the vessel for tows from the bow at speeds up to six knots for a range of drafts covering the towing conditions.

6.4 Seaworthiness

Pending on limits on the level of accelerations listed in the process data or resulting from a compromise made during basic engineering between sea-keeping analysis and process studies, roll and/or pitch damping appurtenances may be requested. In that circumstance, they shall be integrated in the hull design.

7. Loads

7.1 Load cases for stability and/or scantling

In addition to load cases already identified in the references, attention shall to be paid to:

- Static and dynamic load cases from anchor legs and risers
- Static and dynamic load cases from process modules
- Blasting impact from explosion from process modules
- Collision
- Dry-docking with Topsides

The risks of collision with supply vessels and export tankers must be evaluated, and consequences assessed.

In damaged conditions, the structure must withstand design conditions representative of the time required for the vessel to resume safe operating conditions (not less than worst seasonal conditions). Corrective actions may be considered, provided they are easy and ordinary actions such as ballast emptying or filling; voluntary cargo release to the environment is for example not acceptable.

7.2 Environmental loads

Environmental loads are to be determined for the stability and the strength calculations.

Waves and current effects have to be determined according to the Classification Society rules. (In particular for slamming, green water, local pressures, etc.).

In addition the wind loads have to be specifically looked at as follows:

7.2.1 Wind loads

CONTRACTOR shall establish the wind loads on the vessel and topsides. The procedure for establishing wind loads may involve model tests and/or calculations using qualified software. The procedure and the resulting loads shall be submitted to Project.

Wind tunnel tests with an adequate model of the entire FPSO (hull and topsides at different drafts and headings) may be required to evaluate the local airflow around the helideck, machinery exhausts, air intakes, and flare tower if no similar experience cannot be referred to.

7.3 Accidental Loads

The hull and accommodation structure shall be designed with due regard to the possibility of loads arising from accidental events such as collision, dropped objects, fire, explosion and other abnormal events such as mooring line failure or a riser bursting inside an I-tube.

Structural enhancements and/or protective structures shall be designed and provided by the CONTRACTOR ensuring that the consequences of accidental loads do not compromise safety on the installation.

In all post-accident scenarios the damaged structure should be verified by CONTRACTOR as capable of withstanding combined dead, imposed and environmental loads with a return period of at least 1 year.

The CONTRACTOR shall refer to Classification Society Rules for Offshore Units and Total General Specification **GS STR 101**, concerning design requirements for accidental loads.

7.3.1 Collision

The hull shall be designed to withstand accidental collision with supply vessels, methanol tankers and off take tankers. Protective structures shall be incorporated around the appurtenances fixed to the hull shell (moorings, risers, caissons, etc.) and on the bow (refer to section 10.11). Unless otherwise stated in the project particular specifications, the following requirements shall apply:

Two (2) levels of impact energy shall be considered in order to characterise the required resistance for hull plating and protective structures, according to the location of impact on the FPSO:

Criteria	Impact energy (MJ)	Impact energy (MJ)
Location	side shell hull plating, stern hull plating, protection structures	bow hull plating
Operational	2.75/3.5	3.5/4.5
Accidental	11/14	18/23

Collisions on side shell, stern and protection structures are assumed to be caused by a 5,000t supply boat:

- at 1 m/s speed (operational): bow/stern on (2.75MJ) and side on (3.5MJ)
- at 2 m/s speed (accidental): bow/stern on (11MJ) and side on (14MJ)

Collisions on bow are assumed to be caused by a 10,000t methanol tanker:

- at 0.8m/s speed (operational): bow/stern on (3.5MJ) and side on (4.5MJ)
- at 1.8 m/s speed (accidental): bow/stern on (18MJ) and side on (23MJ)

In case of “operational” impact, the hull plating or protective structure shall not suffer more than minor damage from collisions. Platform operations should not be interrupted, and immediate

repair should not be required. Energy absorption shall be obtained by elastic deformation of the structure.

In case of "accidental" collision, the shell plating or protection structure may be subject to significant plastic deformations. However, no leak shall occur in the hull for an accidental impact on shell plating and the protected appurtenance shall remain untouched for an accidental impact on protection structures.

A third level of impact energy, called "critical", shall be evaluated, but it is not to be used as a design case. The following critical energies shall be evaluated:

- Energy required to breach into cargo oil containment due to supply vessel impact on side shell.
- Energy required to touch the protected appurtenances.
- Energy required to breach into machinery space due to supply vessel impact at stern.
- Energy required to breach into collision bulkhead due to off take tanker impact at bow.

Guidelines for the assessment of collision damage:

The extent of hull damage due to the different collision scenarios and impact energy levels shall be determined using the guidelines contained in the HSE document "Collision resistance of ship shaped structures to side impact – MSL Engineering Limited, 2001" and the NORSOK document "Design of steel structure N-003".

The method to determine the extent of collision damage shall first be based on a simplified analytical method, such as Kinkad or other recommended method by above HSE document. Non linear Finite Element analysis, using large deformation FEM software package such as DYTRAN, shall then be applied only to the most critical scenarios found with the analytical method.

As a first approximation, the bow of the impacting vessels shall conservatively be considered infinitely stiff compared to the FPSO structure (all energy absorbed by the FPSO).

The amount of kinetic energy absorbed as strain energy may be assessed as per NORSOK above document, section 1.2.1. Rupture strain percentage shall be determined as per above NORSOK document, according to steel grade.

The acceleration on topsides and flare due to worse accidental impact shall be evaluated.

Post-collision studies to confirm the damaged hull structural integrity under the 1 year Return Period environments shall be performed. The reduction of hull girder strength associated to the worst damage shall be evaluated and accounted for in these studies, assuming no further propagation of the damage.

7.3.2 Dropped objects

The Main Deck shall be protected from potential impact of dropped objects. The CONTRACTOR shall demonstrate by analysis that the Main Deck plating does not suffer collapse or penetration by the dropped object and that any deformation of the Main Deck does not cause collapse of the supports to topsides equipment or breakage of cabling or piping systems.

Critical areas for dropped objects shall be determined on the basis of the actual movement of loads. Areas of open deck adjacent to laydown areas will receive particular attention. The weights of the dropped objects to be considered shall be taken as the operation hook loads of the cranes. The heights of the dropped objects shall be taken as the hook heights above the

structure under investigation. Details of the movement of loads will be presented in the mechanical handling study to be provided by COMPANY.

7.3.3 Fire

The CONTRACTOR shall carry out an analysis of the structural response to fire with consideration to the locations and temperature profiles identified in the topsides fire scenario analysis agreed with COMPANY. For each fire scenario the following structural requirements shall be met:

- The resultant stresses in the structure shall not exceed the reduced yield stresses of the structure
- Deformation of the structure shall not impinge on any safety critical operational equipment or lead to escalation of the situation
- The deformations shall not cause collapse of any part of the structure that supports any temporary safe refuge, escape route, or embarkation point within the required endurance period
- The structure of and supporting fire/blast walls and insulation material to critical areas shall maintain its integrity for at least the required endurance period.

7.3.4 Explosion

The hull and accommodation structure shall be capable of withstanding pressures resulting from explosion in combination with other loads imposed on the structure. In particular, the Main Deck and accommodation superstructure front shall be capable of resisting the blast pressure. The blast over pressure shall not cause progressive collapse or penetration of the cargo tanks. The design pressures shall be obtained from the results of explosion analysis to be provided by COMPANY or approved design guidance documents.

For initial design development, CONTRACTOR shall assume design blast over pressures of 1 bar for the Main Deck (0.2 s) and topsides support structures, and 0.5 bar for the accommodation superstructure front bulkhead and adjoining blast walls.

At basic engineering stage explosion analysis shall be performed to define blast pressure (peak and duration) for detail design.

The explosion resistance of Main Deck, topsides support structure and accommodation shall meet the following requirements:

- Unless the effects of plastic deformation can be shown to be acceptable, the stresses in the structure should not exceed the increased yield stress associated with explosion resistance
- Deformation of the structure shall not impinge on any safety critical operational equipment or lead to escalation of the situation
- The deformations shall not cause collapse of any part of the structure that supports any temporary safe refuge, escape route, or embarkation point
- The structure of and supporting fire/blast walls shall maintain its integrity.

7.3.5 Combined fire and explosion

If the risk assessment demonstrates significant probability of a combined fire and explosion scenario then assessment of the structure to the combined loading must be made.

The structural analysis required from the CONTRACTOR shall evaluate the effects of the identified scenarios, e.g. a fire following an explosion, or an explosion following a fire. In these cases any reduced structural strength or plastic deformation that has occurred during the initial phase of the accident must be taken into account in the analysis of the subsequent phase.

8. Structural design

8.1 Strength

The hull and associated structures shall be designed and built to meet the demands of continuous service as an F(P)SO without dry-docking for maintenance, inspection or foreseeable repair. The design shall minimise the requirement for in service maintenance.

Tank structures shall be suitable to permit unrestricted filling and this shall be verified for maximum tank pressure caused by tank overflow via the piping system headers in the marine systems pipe racks. The design shall be checked for sensitivity to sloshing loads. The design shall also allow for and facilitate a program of in water inspection requiring each tank to be accessed for survey, maintenance and repair.

The F(P)SO will be required to continue unrestricted operation with any tank being inspected.

In case of repair of one tank, CONTRACTOR shall define admissible loading/offloading sequence within environmental conditions that shall not be less than 10 year return period on site.

Fluid temperature effects have to be assessed in the calculations (differential dilatations and potential thermal deflection).

For the repair of a tank corner, it shall be possible to neutralise (gas-free, clean/water fill, clean) all surrounding tanks in the area including the diagonally opposite. The strength shall be demonstrated to be sufficient for the still water loads arising in inspection conditions and in combination with 10 year return site specific wave loading.

The scantling draught shall exceed the maximum draught according to the International Load Line Convention (resulting from the tabular or geometric freeboard calculation with applicable corrections). Unless otherwise specified, the ICLL draught shall have a margin (typically 0.5 metre) on the design draught to allow for future equipment addition. The design draught is defined as the draught corresponding to the fully loaded condition or the maximum draught defined in the trim and stability Manual.

Environmental loads, including slamming and/or green water loads, are to be fully accounted for in the project (including during ocean transit).

Structures supporting machinery are to be designed with consideration to strength, buckling and vibration characteristics as well as loads imposed by connecting systems.

All penetrations through the hull structure shall be properly compensated. The details of structural compensation shall be submitted to the Classification Society and COMPANY for approval.

Additional thickness is to be provided as a corrosion allowance. (See § 4.2) Scantling plans are to clearly identify corrosion allowances applied and where these are in excess of Classification Society rule requirements.

The strength of the F(P)SO hull and accommodation structure shall be verified for at least the following conditions:

- Tow from the construction site to the topsides integration site (without topsides) in association with expected worst case environmental loading during transit
- Installation of topsides facilities
- Tow from the integration site to the field location (with topsides) in association with agreed design environmental loading during transit
- Hook up & commissioning in association with expected worst case environmental loading up to and including 10 year return period conditions
- Dry-docking with all topsides installed and in fully operating configuration (as after some operation period)
- Normal production with worst case environmental loading up to and including 100 year return period conditions
- offloading in association with design conditions
- Special conditions (e.g. tank inspections) in association with worst case environmental loading up to and including 10 year return period conditions
- Accidental conditions (e.g. explosion, collision damage) followed by worst case environmental loading up to and including 1 year return period conditions.

Environmental data pertaining to the tow operations is to be provided by the CONTRACTOR and agreed with the Classification Society and COMPANY. The effects of non-aligned swell and wind-driven wave systems shall be fully considered where necessary.

The strength of the hull shall be verified in accordance with the requirements of the Classification Society for classification with Deep Sea notation. Due consideration shall be given to hull girder wave loads for unrestricted service. In some cases, scantling reduction due to operation in a benign environment (Sheltered Waters notation) may be accepted by the COMPANY provided sufficient strength (including fatigue strength and margin on corrosion) for the intended service is demonstrated to the satisfaction of the Classification Society and COMPANY. To allow for future growth still water shear forces and bending moments in design conditions shall not exceed 95% of the allowable values approved by the Classification Society at any time. Loading and offloading sequences are to be approved by the Classification Society and COMPANY. Envelopes of the calculated still water shear forces and bending moments for all operating conditions are to be provided by the CONTRACTOR. Envelopes of wave induced shear forces and bending moments calculated for site specific wave conditions (100, 10 and 1 year return conditions), tow wave conditions and rule wave conditions for unrestricted service are to be provided by the CONTRACTOR. The CONTRACTOR is to provide information on hull deformations under still water, wave and combined conditions in a format to be agreed with COMPANY.

Strain at the Main Deck is a major input to ensure proper topsides structure and piping behaviour. Its nominal value is a requirement to be obtained through the vessel's structural strength.

The implications of static and dynamic loads arising from the mooring system, attached risers and topsides supported above the Main Deck and directly related to the use of the hull for F(P)SO service must be included and fully considered in the structural design.

In addition to Classification Society requirements, direct calculation procedures, including a detailed analysis of the vessel's structural response to applied static and dynamic loading using

finite element analysis (FEA), shall be used to verify the structural design for operation in extreme wave conditions during tow, installation and operation. The scope of the FEA shall be developed by the CONTRACTOR in accordance with the requirements of the Classification Society and COMPANY and shall have received prior approval. In particular, modelling assumptions, boundary conditions, load cases and analytical step increments to be considered are to have prior approval. At least the following key areas will be the subjects of FEA:

- A region of the main cargo tank length
- A primary transverse frame
- Stringers in cargo and ballast tanks
- Turret junction
- Topsides supports and under deck structure
- Flare tower integration structure
- Crane pedestal integration structure
- Riser I-tube and support integration structure
- Mooring integration structure
- Helideck support structure.

The results of the FEA shall also be used by the CONTRACTOR to verify the buckling strength of stiffened panels, plates and stiffeners. Checks are to be made in accordance with Classification Society rules and DNV Classification Note 30.1 using consistent sets of corrosion allowance and factors of safety to be agreed with the Classification Society and COMPANY.

8.2 Specific analysis

According to most rules the allowable stress σ is given by a relation such as:

$$\sigma < k * \alpha * R$$

where k and α varies according to the load case and the material, R being a limit depending of the ultimate strength or yield strength.

Should this relation not be satisfied (under accidental loads for example), specific analysis such as elasto-plastic calculations is to be performed to demonstrate the acceptability. This shall be approved by COMPANY.

8.3 Fatigue

The CONTRACTOR shall provide a design resistant to fatigue and suitable for the design service life as specified in the project specification.

COMPANY requirements for hull fatigue analysis are provided in annexe.

The CONTRACTOR shall verify the fatigue lives of structural details using spectral analysis techniques in conjunction with appropriate S-N curves and route and field specific environmental data with consideration to cumulative fatigue damage arising from all tow and operational evolutions.

The CONTRACTOR shall provide detailed procedures for the fatigue analyses in accordance with COMPANY requirements provided in annexe for approval by the Classification Society and COMPANY. Particular attention shall be paid to the following:

- Determination of fatiguing stresses

- Determination of stress concentration factors
- Selection of S-N curves
- Selection of wave energy spectra for tow and operation
- Selection of the vessel heading in operation
- Consideration of fabrication tolerances
- Consideration of corrosion effects
- Consideration of phase relationships between stress components
- Inclusion of all relevant stress contributions
- Determination of cumulative damage.

The procedures shall list the details to be assessed and indicate the S-N curve selected for each.

3-D diffraction methods shall be used by the CONTRACTOR to determine the global dynamic wave loads and local loads induced by external water pressure. Hull motions and the induced inertia loads on the hull generally and at support locations shall be determined similarly taking the weight distributions appropriate for tow and operational conditions fully into consideration.

Global and local finite element models shall be used to determine fatiguing stresses. Fine mesh finite element models or empirical formulae shall be used to determine stress concentration factors appropriate to the detail concerned. Stress concentration factors for critical structure shall be determined using the finite element method. The effects of corrosion on fatiguing stresses and stress concentration factors are to be fully considered.

The fatigue analyses shall incorporate all important contributions to the cyclic loading, among:

- Global loading causing overall hull girder deformation due to dynamic wave effects
- Inertia loads caused by vessel motions
- Local loads induced by external water pressure
- Local loads induced by internal fluid pressure and accelerations (including sloshing)
- Loads induced due to cargo loading and unloading
- Loading imposed at supports for topsides equipment, risers, moorings and other attachments
- Equipment vibration
- Temperature effects
- Local wind, wave or current effects on slender structure.

The effect of continuous loading and offloading during normal operation may be considered by associating certain proportions of operational time with representative loading conditions or any superior method approved by the Classification Society and COMPANY. A minimum of three conditions may be considered approximating to light, half and full load. The proportion of time associated with each condition is to be determined with consideration to the normal loading and offloading sequence to be approved by the Classification Society and COMPANY.

At least the following key areas will be the subjects of detailed fatigue analysis:

- Connection of side shell longitudinals at transverse bulkheads

- Connection of side shell longitudinals at transverse frames
- Connection of bottom and deck longitudinals at transverse bulkheads and frames
- Connection of vertical stiffeners on transverse bulkhead to bottom plate
- End connection of longitudinal brackets (on girders)
- Connection of deck and bottom transverses to longitudinal bulkheads
- Connection of transverse bulkhead stringers to longitudinal bulkheads
- Topsides supports and under deck structure
- Flare tower integration structure
- Crane pedestal integration structure
- Riser I-tube and support integration structure
- Mooring integration structure
- Helideck support structure.

Particular attention shall be given to connections to the side shell structure and verification of the fatigue life of the hull at such locations.

8.3.1 F(P)SO specific fatigue requirements

For the **fatigue acceptance criteria**, the following safety factor table applies for calculating fatigue life with the COMPANY requirements as per the notes:

Consequence of failure	Degree of accessibility for inspection, maintenance and repair		
	Not accessible (note 2)	Underwater inspection (note 3)	Dry inspection
Substantial (note 1)	10	4	2
Non substantial	5	2	1

Note 1: Substantial damage as per risk analysis including loss of life, uncontrolled pollution, collision, sinking, other major damage to the installations and major production losses.

Note 2: Includes areas that can be inspected in dry or underwater conditions but require heavy works such as dry-docking for repair.

Note 3: Includes areas that can be inspected in dry conditions but with extensive preparation and heavy impact on operation.

Unless justified by relevant drawing and welding specifications for relevant detail, SN curves not better than F2 shall be used for calculations.

This can be interpreted as follows for different elements:

Region	Safety factor
Hull longitudinal plating, butt welds	4
Shell butt welds below the ballast draught	10
Hull longitudinal, stiffener end connections	5
Deck penetrations and welded attachments	2
Shell penetrations and welded attachments	4
Shell penetrations and welded attachments below the ballast draught	10
Transverse structure, plating	2
Transverse structure, stiffener end connections	2
External details below the scantling draught and their connections to the hull	4
External details below the ballast draught and their connections to the hull	10

The fatigue safety factor is the ratio between the calculated fatigue life of a structural detail by the design life of the F(P)SO.

The categorisation of structural details into the regions defined above shall be agreed with COMPANY.

The fatigue life of structural details shall be presented in a manner that may be used to plan quality assurance and inspection priorities during construction and operation.

Unless alternative details are demonstrated to provide satisfactory lives, the following features shall be used:

- Penetration connections of longitudinal stiffeners at transverse webs shall be fitted with double lug/collar plates or shall be of double weld slot type connections
- Brackets shall be used on both sides of the transverse web at penetrations of longitudinals in side shell, bottom and main deck
- Full penetration welds at end toes (on longitudinal bulkheads) of transverse bulkhead horizontal stringers in cargo tanks
- Full penetration welds at upper toes (on longitudinal bulkheads) of transverse webs in cargo tanks
- The toes and heels of pillar stiffeners fitted to primary webs in line with side shell and bottom longitudinals shall be soft nosed and mouse holes made well radiused in line with good practice
- Toes of tripping and/or other large brackets shall be well softened
- Longitudinal stiffener should be of T-type.

8.4 Search for critical elements

The engineering phase should identify the critical elements for structural and sealing integrity. These deserve specific attention, and must be classed in the specific steel and welding details category.

For existing hulls, it is important to assess the initial construction quality in order to identify potential weak points. Reference to sister-ships is useful. The design of the original details should be examined to anticipate where repairs and/or reinforcements would be required. This should concern:

- Areas identified during previous surveys
- Fatigue areas such as end of brackets, piping penetrations
- Local details around sea chests.

The design of the new details has to be approved and information on the weld and the associated NDT requirement are to be provided.

It is important to identify the components that require special attention and should be built to offshore standards. These high-stress areas include:

- Mooring lines stopper attachments and supporting structure
- Riser support attachments and supporting structure
- Offloading hawser attachment and supporting structure
- Crane supports
- Flare stack support
- Modules foundations.

8.5 Structural details

The selection of structural details will have extensive impact on fatigue life and consequently on inspection requirements, and should be made prior to the contract:

- Preference for symmetrical elements (in particular T beams for fatigue sensitive area)
- Longitudinal to transverse welding attachments
- Bilge area
- Penetration in tight compartments (structure and pipes)
- Outfitting attachment on fatigue-prone areas
- Tolerances on materials such as T-bars, misalignment in cross sections.

9. Materials and Welding

The specifications **GS STR 201**, **GS STR 301** and **GS STR 653** shall be applied with the following additions:

9.1 Definition of structural categories

Detailed Classification of structural elements shall be defined during the design process, approved by Class and COMPANY, and clearly shown on fabrication drawings.

The definition of hull structural categories shall be as follows:

- **Special category:** structural elements and welds which are part of first category element located in way or at the vicinity of critical load transmission areas, stress concentration locations, or highly fatigue sensitive locations. Highly fatigue sensitive locations are defined in **GS STR 652** – Appendix Section 6.
- **First category:** structural elements and welds which are carrying main loads, essential to the overall structural integrity of the FPSO, or located in fatigue sensitive areas.
- **Secondary category:** structural elements and welds other than those classified in first or special category.

Important note: the above definitions of steel categories are different from the ones used in the BV Classification Ship Rules. However, the steel “categories” as per BV Ship Rules refer to different locations in the ship’s hull for the sole purpose of steel grade selection: to these categories / locations are attributed a certain Class number (I, II, III), which in turn determines the steel grade according to element thickness and required material strength. It is to be noted that DNV Ship Rules do not refer to “Categories” as BV, and only use “Class” for the selection of steel grades. Therefore, to avoid any confusion with the above definitions of steel Categories, it is recommended not to refer to the term “Category” when using BV Ship Rules for steel grade selection, and to only refer to the element location and corresponding “Class”.

The following table shows the category classification for different structural elements and welds of the hull. Other locations may be classified as special and/or first category, according to the results of strength and fatigue analyses.

Special	First	Secondary
Welds of web frames and stringers end connections to longitudinal bulkheads	Bilge, sheerstrake and stringer plates within the whole length of the FPSO.	others
On side shell: longitudinal stiffener penetrations into watertight bulkheads within splash zone.	Deck plating in way of superstructures ends.	
Non inspectable areas, if any.	Deck and bottom plating in midship region or a larger region if necessary on account of unusual weights or loads distribution.	
	Upper and lower strakes of longitudinal bulkheads in midship region or a larger region if necessary on account of unusual weights or loads distribution.	
	Welding of primary and secondary members to the shell under design waterline.	

Note: Steel member categories for appurtenances, including their foundations inside the hull, are addressed in COMPANY specification **GS STR 301**.

Owing to the expected life of 20 years on site without dry-docking, unless specified by project specification, following requirements shall apply in addition to the Classification as per Classification Society Rules:

Structural part supporting critical loads shall be considered as special category, and specially: topside supports stools, fairleads attachment, winch supports, crane pedestal, riser supports and riser protector, etc.

Structural parts in area of critical load transmission or stress concentration are considered as primary structure and specially: topside and flare supports, crane pedestal, winch foundation, riser support and protector, turret, mooring fairleads and stoppers.

Structural parts which cannot be inspected in dry condition are considered as special category.

Other parts which can be inspected only from one side in wet condition: first

Such items should normally not occur and shall be limited to the minimum possible extent by design.

Boundaries of production oil tanks (settling tanks) and methanol tanks: first

9.2 Steel grades

A structural design involving the minimum use of higher strength steels is preferred. However, high strength steel with 355 N/mm² maximum yield strength may be specified in the upper and lower regions of the hull primary structure.

Steel with yield strength above 355 MPa is not permitted for hull structure, but may be permitted for hull appurtenances only and corresponding local reinforcements by special permission, and subject to case-by-case COMPANY approval.

Mild steel of 235 N/mm² maximum yield has to be used on all elements between ballast and design draft in cargo hold region.

The share of High Tensile Steel (i.e. steel with yield strength of 315N/mm² or 355N/mm²) in cargo tank area is to be approximately 50%. HTS share in fore and aft part is to be approximately 40 to 50%.

Notch toughened steel (grades E, D, EH or DH) shall be used for the external plates: main deck, side shell, bilges, bottom shell sheer strakes, keel area.

Z 35 quality steel shall be used in assemblies whenever the following conditions are met:

$$1.5 e + s \geq 55 \quad \text{and} \quad e \geq 20 \quad \text{and} \quad s \geq 25$$

with s: main receiving member thickness in mm and e: branch incoming member thickness in mm,

- for cross assemblies with full /deep penetration on both sides, Z 35 quality with through thickness tensile testing required in specification GS STR 201 shall apply,
- for any other assembly configuration with the incoming member welded full penetration or so called "deep penetration", the sulphur and the phosphorus contents of the main receiving member ladle analysis shall not exceed 0.005% and 0.020% respectively. Z 35 testing will not be required.
- For any assembly with fillet welds, above requirements for Z quality and sulphur / phosphorus contents do not apply, subject to Class approval.

Steel of non structural parts directly welded to the hull shall be of same grade as the element on which they are welded.

Cutting, forming and welding procedures used shall be compatible with the grades of steel used.

9.3 Corrosion allowance

Corrosion protection systems are ensured by combination of coating and cathodic protection as described in **GS COR 351**. For a new built unit, a thickness addition (corrosion allowance) is required. The following table gives minimum additional values to be added **on each side** of the net scantling as calculated based on classification rules and for 20 years. In case where **GS COR 351** requirements are not fully satisfied, the following values shall be revised by the COMPANY.

The following values shall be considered instead of class corrosion margin unless class values are higher.

Reasons for deviations to these values shall be fully documented.

Items - Location of elements	Bottom	General	Top
Ballast	1,00	1,25	2,00
Cargo	1,00	0,75	1,50
Side Shell	1,00	3,00	1,00
Ballast tank permanently full	1,00	1,00	1,00
Void - cofferdam	0,50	0,50	0,50

Notes:

- When considering interfaces between 2 items, both corrosion margin shall be added to define the final plate corrosion margin

For example for side shell plating in the upper zone of a ballast tank, the global corrosion margin is 3 mm

- For ballast tank corrosion margin shall be increased by 50% for internal and horizontal structural plates

For example for a horizontal longitudinal flange in the upper zone of a ballast tank, the global corrosion margin is 6 mm.

- For hull outer shell corrosion margin, "Top" is the hull deck and the upper part of the side shell 3 m above the scantling draft, "Bottom" includes side shell up to the lightest ballast draft and "Elsewhere" is the side shell between the lightest ballast draft up to 3 m above the scantling draft unless specified in project specification

For converted units of a shorter site-life but with corrosion protection likely to be of lower standard, values can be scaled assuming that the previous table represents a requirement for 20 years life.

9.4 Critical locations

Critical Locations are defined as:

- Riser porches and supporting structure
- Riser protectors and supporting structure
- Crane pedestals and supporting structure
- Flare and module supports and supporting structure
- Mooring supporting structure
- Toes of bottom transverses
- Toes of horizontal stringers
- Toes of deck transverses.

10. Special areas

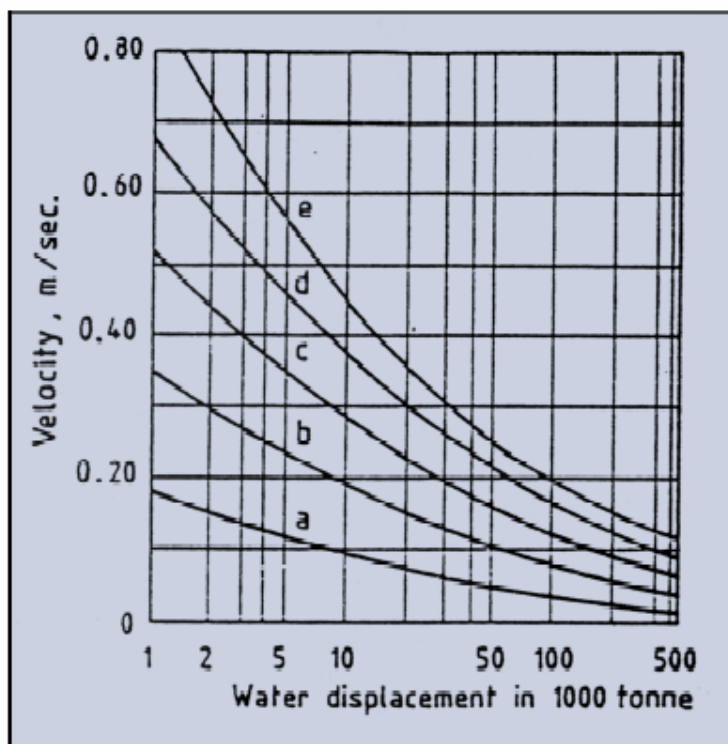
10.1 Supply boat berthing

Alongside mooring will be used to allow supply boats to transfer their cargo under on-board cranes. Attention shall be paid to the specific scantling and protection of the relevant shell plating and for any risers running along the hull.

In these regions, the side shell is to be reinforced and protected from damage by visiting vessels. Typical measures could include increased plating thickness and/or fenders, increased section modulus for longitudinal stiffeners and reduced web spacing over the operational hull draughts.

If fenders are used as a means of protection, a berthing speed of 0.35m/s shall be used for the design of rubber fenders for the supply vessel berthing areas. This value is based on the BROLSMA table (see Figure 1), with a category of navigation corresponding to curve c (easy berthing, exposed), for a 5000t displacement vessel.

Figure 1
Design berthing velocity as a function of navigation conditions and size of vessel (Brolsma et al., 1977)



10.2 Topsides supports

CONTRACTOR shall provide Topsides support structures (TSS) designed, verified and built to the satisfaction of the Classification Society and COMPANY. The design at the interface shall be developed by co-operation between the CONTRACTOR and the Topsides CONTRACTOR. The strength of the TSS and supporting hull structure shall be verified with consideration to fatigue, static and dynamic loads and thermal loads induced by the cargo oil temperature and flare radiation. The governing design cases for the TSS shall be identified with consideration to construction, tow and on-site conditions. Shear capacity, buckling integrity and welding to the deck shall be demonstrated to be appropriate for the service intended.

CONTRACTOR shall ensure that structures, piping and cabling crossing between hull structures and topsides can accommodate the relative deflections caused by hull deformations. To facilitate design of the mounting arrangement and determine the design requirements at the interface, CONTRACTOR shall provide data on hull deformations to the Topsides CONTRACTOR in a mutually agreed format. Due consideration shall be given to the effects of the static and dynamic loads associated with the topsides on hull deformations.

CONTRACTOR shall also provide vessel motion design data and inclination data for damaged conditions to the Topsides CONTRACTOR in a mutually agreed format.

The load on the topsides foundations is a function of:

- The mass of the Topsides
- The position of the Topsides centre of gravity
- The hull motions
- Angles of heel
- in damaged conditions

- Wind forces
- Thermal gradient between hull and topsides.
- Topsides geometry (and stiffness)
- Hull stiffness and deflection, etc.
- Future loads
- COMPANY reserve

The Topsides weights and centres of gravity, and the design loads for the TSS shall be provided by the Topsides CONTRACTOR.

10.3 Piperack

Vessel marine piping shall be supported, where appropriate, within a central longitudinal piperack above the Main Deck. The arrangement of vessel facilities within the lower hull-supplied section of the piperack shall permit access for personnel and equipment longitudinally and across the Main Deck. The piperack should be designed to allow easy maintenance without any hot work.

The configuration of the piperack and the arrangement of its supports shall be agreed with the Topsides CONTRACTOR.

10.4 Laydown areas

Laydown areas shall be designed and constructed to facilitate all stores and equipment transfer to and from the vessel in the following locations:

- Adjacent to the forward side of the accommodation superstructure.
- Indicated on the General Arrangement drawing.

The laydown areas and maintenance route shall be configured such that levels are aligned. CONTRACTOR shall provide a design that will accommodate hull deformations.

Laydown area deck plate, stringers and main beams shall be designed for a uniform loading of 25 kN/m² or point loads of 30 kN distributed over 0.1 m². The underlying support structure shall be designed for a uniform loading of 15 kN/m² over the whole of the laydown area. The structure shall be designed for dropped object loading to prevent penetrations.

Barriers shall be provided around the laydown area where required to prevent damage to surrounding facilities from impact by swinging loads.

10.5 Crane Pedestals

Crane pedestals to support cranes can be integrated with the side shell and transverse hull structure or in the topsides. If integrated to the hull, pedestals shall be predominantly cylindrical and positioned above the intersection of primary hull structure beneath the main deck. The primary structures shall be reinforced as necessary. Structural details shall be so arranged that the hull girder strength will not be impaired by fatigue. The pedestal structure shall be designed for fatigue effects produced by crane operation.

Boom rests for the cranes shall be provided.

10.6 Flare Tower Integration Structure

The design of the support of the flare tower shall fully consider the dynamic loads that may be experienced and, in particular, installation lift. Appropriate integration structure is to be provided on and beneath the Main Deck for the flare tower, associated pipework and facilities. CONTRACTOR shall obtain design data from the Topsides CONTRACTOR to develop an acceptable structural design.

10.7 Riser Integration Structure

Riser support structures shall be provided and the hull reinforced to support the subsea risers, umbilicals and the appropriate protective structures against accidental vessel collision.

Structural analysis shall be performed to verify strength and fatigue characteristics of each hull/riser interface to the satisfaction of COMPANY and Classification Society rules for offshore units. All essential loading and dimensional information for the design of the I-tubes, riser supports, riser protectors and associated hull reinforcement is to be confirmed by interface management between the CONTRACTOR, UFL CONTRACTOR and as necessary Topsides CONTRACTOR.

Normally, risers and umbilicals will be suspended externally on the side of the hull.

Support structure and hull reinforcement shall be provided to support risers and umbilicals suspended through I-tubes mounted externally on the hull. External protection structures shall be provided to protect the risers against vessel collision.

- A corrosion allowance shall be applied to the thickness of the I-tubes
- A protective coating highly resistant to abrasion and impact damage shall be applied to the internal and external surfaces of the I-tubes
- Anti-fouling shall be used to prevent marine growth on the support structures and protection structures.
- Cathodic protection shall be provided with sacrificial anodes or impressed current.

The internal surfaces of the I-tubes shall be flush with no weld penetration or obstructions into the minimum internal bore of the I-tube.

Subject to COMPANY approval, risers may also be suspended through I-tubes integrated within the hull wing ballast tanks:

- A corrosion allowance shall be applied to the thickness of the I-tubes
- A protective coating highly resistant to abrasion and impact damage shall be applied to the internal surface of the I-tubes
- Anti-fouling shall be used to prevent marine growth on I-tube surfaces exposed to sea water
- Coatings used for the ballast tanks shall also be applied to the surfaces of the I-tubes within the ballast tanks.
- Cathodic protection shall be provided with sacrificial anodes or impressed current.

The internal surfaces of the I-tubes shall be flush with no weld penetration or obstructions into the minimum internal bore of the I-tube.

External bottom hang-off can also be selected.

Support structure in the form of receptacles and hull reinforcement shall be provided to suspend risers externally on the hull near keel level. External protection structures shall be installed to protect the risers against accidental vessel collision.

- A corrosion allowance shall be applied to the thickness of the I-tubes
- A protective coating highly resistant to abrasion and impact damage shall be applied
- Anti-fouling shall be used to prevent marine growth on the support structures and protection structures.

10.8 Mooring integration structure

Structural analysis shall be performed to verify strength and fatigue characteristics of each hull/mooring interface to the satisfaction of COMPANY and Classification Society rules for offshore units. All essential loading and dimensional information for the design of the mooring supports and associated hull reinforcement is to be confirmed by interface management between the CONTRACTOR, UFL CONTRACTOR and Topsides CONTRACTOR.

The chain pull-in and tensioning equipment shall be located on the Main Deck and will require suitable foundations and local Main Deck reinforcement.

All the mooring equipment installed alongside the side shell shall be protected against accidental vessel collision by appropriate protective structure.

10.9 Seawater lift caissons

I-tubes shall be provided as indicated on the General Arrangement drawing. The design loads shall be confirmed by the Topsides CONTRACTOR.

10.10 Overboard discharges

Overboard discharge pipes shall be provided as indicated on the preliminary General Arrangement drawing. The location and dimensions shall be confirmed by the Topsides CONTRACTOR. The discharge pipes shall extend from the interface at deck edge to be agreed between CONTRACTOR and the Topsides CONTRACTOR to at least 1 metre below the lightest operating waterline of the F(P)SO taking into account the vessel operating trim/list and the FPSO motions in 1 year return environmental conditions.

10.11 Bow fender

Unless otherwise stated in the project particular specifications, permanent protection structure shall be provided at the bow to prevent minor damage to the hull structure from accidental collision of work vessels involved in tandem offloading or methanol loading operations, typically from supply boats.

The size and full range of relative draughts of the F(P)SO and supply vessels shall be fully considered. The fender shall be easily maintainable and shall not hamper installation, operation or inspection activities.

CONTRACTOR's design shall be verified by analysis to the satisfaction of the Classification Society and COMPANY.

10.12 Miscellaneous equipment foundations

Other items will need to be supported on the hull, including various pieces of topsides equipment and their associated services (in particular handling support structures), boarding

towers, ROV deployment stations, off-loading equipment, anchor-chain tension winches and towing and installation aids (which may include protection for equipment against green water).

Seatings and Foundations for equipment on or within the hull shall be fabricated according to COMPANY approved drawings. Design of seatings and foundation shall provide adequate support to the equipment, avoid any detrimental vibration or excessive flexibility and transfer the weight, dynamic and functional loads to the structure with low stresses.

Their location and design shall be such that they do not increase significantly the local structural stresses and do not reduce the local fatigue life.

They shall be fabricated according to same requirement of structural parts as per this Specification.

Seatings for rotating machinery of power in excess of 100 kW, or for vibration inducing machinery such as diesel engines or reciprocating compressors irrespective of their power shall be considered as primary structure/fatigue sensitive with respect to fabrication and erection quality & inspection.

10.13 Access in spaces & tanks, fittings for on-site inspection

Means of access and inspection of cargo tanks and other areas shall be provided as per IMO resolution [MSC133\(76\)](#) "Adoption of technical provisions for means of access for inspections" and [MSC134\(76\)](#).

In the course of the hull scantling process, areas subject to fatigue shall be identified in tanks.

If the hull is protected against corrosion by cathodic protection, devices allowing an easy survey and, if necessary, a replacement shall be fitted on.

CONTRACTOR shall design Access & Inspection paths in tanks and various spaces such as void spaces, cofferdams, etc.

Access paths shall allow to perform a complete structural inspection as per class requirements for special survey on Site and under production mode.

Such access shall be ensured with permanent access holes, ladders, handrails, and temporary equipment for which adequate positioning and supports shall be provided.

CONTRACTOR shall submit the access paths and definition of permanent/temporary means prior to any fabrication.

All accesses to be marked with the identification code of the space they serve, and with appropriate warnings for safety.

10.13.1 Access platforms/Walkways

All corridors and stair casings in the accommodation superstructure shall be provided with steel walls.

10.13.2 Helideck

A helideck shall be fitted. The strength and fatigue characteristics of the support structure shall be verified. Refer to [GS LSO 100](#).

The helideck may be integrated with the accommodation superstructure and may be manufactured from steel or aluminium.

11. Hull Structural details

11.1 Location of seams and splices

Number of seams and butt joints shall be made minimum consistent with supplied products and CONTRACTOR's production equipment and construction sequence.

Flanges and webs of built up beams shall be fabricated with the rolling direction of the plate in the longitudinal direction of the beam.

The minimum distance between butt joints shall be 5 times the plate thickness minimum 100 mm.

The minimum distance between one plate butt joint and the nearest stiffener fillet weld shall be 3 times the plate thickness minimum 50 mm.

11.2 Scallops & limber holes

Where necessary, Scallops of reasonable radius minimum 35 mm shall be provided at members connections. Fillet welds shall be carefully returned through the scallops and providing a smooth geometry without any undercut.

Limber and air holes shall be provided in members to ensure proper drainage and aeration. Such limber holes shall have elliptical shape or oblong in longitudinal members and their height shall not exceed 1/4 of the member web height.

All scallops and limber holes shall be shown on drawings, shall have a prior approval of Class and COMPANY approval and shall be accounted for in scantling analysis.

11.3 Lugs & collar plates

Lugs and Collar plates shall be provided in order to support efficiently the members, restore shearing resistance and water tightness when needed.

Lugs and collar plates shall be of same grade steel that the plating and in principle same thickness, unless properly justified by design calculations.

Lugs and collar plates shall be welded to the plating and the member by continuous fillet weld thoroughly returned all around.

11.4 Cut outs for access

Cuts outs for access shall be provided for easy access within any structural cell and to define convenient & safe inspection paths.

Such cut out shall be of minimum 800 mm diameter in horizontal members and 800 mm/600 mm in vertical members, except in few places where 600 mm dia or 600 mm/400 mm may be acceptable.

Cut outs for hatches, equipment removal paths... shall be as far as possible with their major dimension in the longitudinal axis of the vessel and with rounded corners with radius of 1/4 of the cut-out breadth minimum 200 mm.

11.5 Cut outs for pipes

Cut-outs for pipes shall be documented on drawings, accounted for in scantling calculations and arranged in order not to impair the strength of structural members.

As a rule, cut-outs for pipe(s) shall not exceed $\frac{1}{4}$ of the local section of any member. Cut-outs above this criterion shall be fitted with local reinforcement by flange or extra thickness insert welded to the plating by full penetration welds. No doubling plate permitted.

11.6 Fixations for outfitting

Non-structural parts shall be welded on doubler plates of the same steel grade as the Hull. Same welding procedures/qualifications shall be used for the welding of the doubler plate on the Hull. Non-structural member welded on doubler plates may then be of low strength steel. Non structural fixations shall be welded according to an Approved Welding Procedure Specification using identified and qualified welding products and parameters.

No fixation shall be made on or transverse to welded joints or closer than 100 mm to joints.

No attachment will be permitted in fatigue sensitive areas such as top flange of beams close to supports points, close to cut-outs or similar locations where such attachment would increase the hot spot stresses.

Where such an attachment position is unavoidable for functional reasons, the attachment shall be taken into consideration in the fatigue life analysis of the area.

12. Hull markings

12.1 F(P)SO identification marking

To be further developed in project specification

12.2 Draft scale, loadline marks

To be According to Load Line Convention:

Forward, middle and aft, port & starboard side draft scale

Weld line for design waterline

12.3 Markings for inspection

Following markings to be provided in order to assist for divers/ROV underwater inspections.

Marking as required for the notation underwater survey of the Classification society, without being less than:

- Marking on bottom of tank limits with tanks codes
- Marking at bilge (bottom part), on center line, at bilge (shell side), at waterline of tanks limits with tank codes
- Frame scale by welds lines on outer bottom at center line, under longitudinal bulkheads
- Transverse scale by weld line at every 5th longitudinal in way of transverse bulkheads with longitudinal number.

12.4 Other marks

Marks for delimitation of the safe area for supply boat operation: lines of bed welds for contours of painted areas.

13. Project

The proposed yard shall submit with its proposal a description of its standards. In particular, the following is required:

13.1 Yard experience

The proposed standards shall correspond to the real CS-approved practice of the shipyard. The personnel, equipment and facilities necessary to achieve the claimed performance should be available to the project.

If the proposed standards do not correspond to actual practice, an adequate qualification programme must be provided.

13.2 Tolerances and dimensional control

Fabrication tolerances must be as per Part A of IACS Shipbuilding and Repair Quality standards or Classification Society rules, whichever is more stringent, unless the design requires tighter tolerances, in which case these must be submitted to COMPANY for Approval.

CONTRACTOR must submit to COMPANY a dimension control procedure(s) and programme. The procedure must include the method(s) for obtaining measurements (during fabrication and final surveys) and their conversion into specified tolerances and controlled dimensions. Reported dimensions must be corrected to a standard temperature. The programme must describe where and when each type of control will be performed.

For all structural interfaces, fatigue calculation shall allow for tolerances of both parties and possible misalignment.

13.3 Weight control

A weight control procedure shall be established and followed according to the specification **GS STR 001**.

Additional requirements are:

- Follow-up of the vertical co-ordinates of the CoG
- Follow-up of wind screens for stability calculations. This shall deal with the windscreen information to determine the wind loads such as location (including orientation), magnitude and shapes
- Identification of compartments, caissons which are normally empty but whose unexpected flooding (leakage, cracks) cannot be detected due to poor access or/and lack of measurement.

13.4 Documentation

An adequate level of documentation must be given on design, materials and traceability and construction.

Final as-built documentation should include information on important repairs since these may be weak points in operation.

A baseline analysis shall be provided incorporating this information. Its documentation shall include:

- As built drawings
- Final weight reports



- Final stability reports
- Hydrodynamic analysis (including tandem offloading if any)
- Mooring analysis
- Geotechnical analysis
- Structural analysis for hull and topsides.

As per **GS STR 651**, a complete hydrodynamic and a complete detailed structural model shall also be provided as per **GS STR 652**. This model will include the structure and hull studies (scantling and stress, fatigue studies highlighting the critical areas) including bi- and tri-dimensional FE models performed by BV or DnV.

It shall be in a format useable later for planning inspection and maintenance (Veristar or equivalent).



Appendix Requirements for hull fatigue analysis



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This appendix to general specification "Steel hull design requirements" presents COMPANY requirements and methodology to be followed for hull fatigue strength analysis for newbuilt Floating (Production) Storage Offloading units. In addition, this Specification is intended to complete the classification rules of offshore units.

1. Reference documents

Reference	Title
IIW	International Institute of Welding - Recommendations on fatigue of welded components
HSE (previously DEN)	Offshore Installation Guidance on design construction and certification
DNV	Fatigue assessment of ship structures CN 30.7, dated Feb 2003
DNV FPSO	Fatigue methodology specification Report No. 99-3505 Rev 5, dated June 2000
IACS	Fatigue assessment of ship structures no. 56 dated 1999
IACS	Shipbuilding and Repair Quality Standard" (no. 47) dated 1996

2. General principles

CONTRACTOR shall perform a complete fatigue analysis in order to demonstrate to COMPANY that the F(P)SO comply with COMPANY requirements in terms of Fatigue Life.

Such Fatigue Analysis shall be planned and performed at design stage co-ordinated with respect to structural design and construction in order to incorporate in scantling definition, fabrication drawings and prefabrication/assembly stages all appropriate measures which are necessary for obtaining the required fatigue life performance.

CONTRACTOR shall develop its detailed procedure for calculation of the fatigue life and submit it to COMPANY Approval at early stage of design.

Such Procedure shall be based on the present specification considered as minimum COMPANY requirements and as a complement to the Classification Society Rules and Requirements.

Unless specified in the project particular specification, the F(P)SO shall withstand a production phase of 20 years without dry-docking and without needs for structural repairs, so any part of the structure shall be designed for a fatigue life greater than 20 years by a safety factor.

Fatigue damage shall include all steps from initial construction including towing(s) and site conditions.

The fatigue study subject of the present specification comprises the calculations of the behaviour of the F(P)SO at sea for the towing and the site sea conditions, the structural analysis of hull structure under the hydrodynamic loads and other fluctuating loads and the fatigue evaluation of selected structural details.

In case of dry tow, the fatigue analysis will in particular focus on the hull support areas on the transport barge.



The fatigue analysis shall be carried out for the hull ship type structural details and for the hull structural items in interface with the F(P)SO specific equipment (Topsides, Mooring system, etc.).

The subject of the fatigue analysis comprises the hull and the stools for Topsides Modules and is limited to the interface between the Topsides and the Stools located at the top of the Stools.

However, the Topsides shall be represented in the models as much as required to ensure correct hydrodynamic and structural behaviours.

3. Fatigue analysis basic data

3.1 Metocean data

Complete environmental data on site for fatigue analysis will be provided by COMPANY in the project specifications.

CONTRACTOR will define and submit to Class, COMPANY and Marine Warranty Surveyor for approval the metocean data, especially wave scatter to be used for tow(s) condition(s).

3.2 Vessel loading cases

3.2.1 Vessel operation profile

Analysis shall be performed for the significant vessel loading conditions according to planned operation. Specially for FPSO, CONTRACTOR shall be aware that loading configuration distribution for unit design life are significantly different from those of trading tanker and specified in classification rules fatigue strength of tanker.

Maintenance or other infrequent conditions may be omitted as far as the corresponding cumulative time does not exceed 5% of total time.

3.2.2 Intermittent wet surface

The effect of intermittent wet surface shall be considered for assessment of fatigue in plating and longitudinal stiffeners on side and bottom shell and tanks. The relative motion between the hull and the sea shall be considered taking into account incident, diffracted and radiated waves.

This effect shall be combined with hull girder deformations.

3.2.3 Dead weight

Static stresses resulting from permanent loads such as dead weight are ignored in the context of fatigue analysis.

3.2.4 Live loads

For the F(P)SO live loads such as deck variable loads and cargo loads are considered as negligible and can be ignored for fatigue evaluation of the hull.

CONTRACTOR will review the fluctuating loads associated with process equipment, lay-down areas, and will check that the above assumption remains valid.

3.2.5 Cyclic loading

The fatigue cyclic loading induced by the sea motion of the F(P)SO shall include the following main contributions:

- Global stresses induced by global hull girder bending moment
- Local stresses induced by the external wave, liquid cargo pressure and motion induced accelerations on structure & equipment, applied on stiffened panels
- Local stresses induced by any other fluctuating operational loads
- Secondary local stresses induced by the deflection of primary structures.

In the case of an analysis of the complete Hull body with appropriate load application technique and mesh, these three effects are included in the results as far as the modelling and loading pattern are adequate and need not be considered separately.

The loads variation induced by the spread mooring system, risers and caissons may eventually be considered as negligible for fatigue evaluation of the hull but they need to be considered for analysis of the mooring, caissons and risers supporting structure.

The dynamic loads induced at sea by all the deck equipment shall be considered. This deck equipment shall be modelled with their true mass and centre of gravity.

Wind induced fluctuating effect on Topsides modules shall be reviewed and taken into consideration as an independent fluctuating load to be added to wave induced loads.

3.3 Corrosion allowance - scantling

Corrosion allowance shall be considered according to the selected Classification Society Rules. To this respect, the two following approaches may be considered:

- Either the corrosion allowances are removed from plates and stiffeners thickness and the calculations are performed with the net scantling (preferred method as being conservative).
- Either calculations are performed with the plates and stiffeners thickness including their specified corrosion allowance (gross scantling) and the effect of progressive corrosion is taken into account within the damage calculation by a recognised method (agreed with Classification Society and COMPANY) such as for instance BV Fatigue Strength of Welded Ship Structures NI 393.

Shape & selection of the SN curve shall take into account the type of environment of the considered detail and the level of protection against corrosion.

3.4 Workmanship

For classified details, construction tolerances as defined in the IACS document "Shipbuilding repair and quality standard", are generally embedded in the SCF.

For details analysed through direct Finite Element Analysis, as the hot spot stress are usually calculated on the basis of an idealised, perfectly aligned structure, any possible misalignment needs to be taken into account separately and applied to the calculated stress to obtained the hot spot stress.

This is normally necessary for butt joints, cruciform joints and transverse fillet welds depending on loading.

Initial damage calculation shall be based on standard fabrication tolerances according to normal shipbuilding practice (Classification society standards/IACS standards: refer to general hull fabrication specification)

One of the expected results from the fatigue analysis will be a classification of various structural elements according to their fatigue damage level and potential consequences of failures in order to plan construction and in-service inspection and surveys.

In case where most stringent fabrication requirements are chosen as a solution to match the required fatigue safety factor, this would result in classification of the considered detail in a "fatigue sensitive" category as defined in § 6 of the present specification.

3.5 Mass and Inertia

Mass and inertia of the Vessel and of all the equipment shall be modelled in order to obtain correct hydrodynamic behaviour of the F(P)SO and loads at the interface between the Hull structure and the F(P)SO equipment.

The Topsides structure shall be modelled so as to represent the correct position of the mass and stiffness of the Topsides and ensure proper load transfer to the posts.

Moorings and risers are not supposed to influence first order motions significantly. However their contribution need to be included in as an equivalent mass and stiffness such that dynamic balance is preserved.

It shall be checked that mass and inertia's of structural and hydrodynamic models are coherent.

The maximum unbalance of mass, first order moments (position of CoG) and inertia between hydrodynamic and structural models should not exceed 2%.

3.6 Stress categories - SN curves

3.6.1 Definition of stresses

- Nominal stresses: resulting from the global 3-D Hull analysis, including local scantling and gross geometric effects such as holes, changes in element heights, geometric contours of primary structures.

Nominal stress includes the global (hull girder stress including all components of hull girder loads and stress distribution pattern in the hull section), local loads induced stresses and secondary stresses (induced by deflection of primary structures).

Nominal stresses are obtained through structural analysis models.

- Hot spot stress: nominal stress times stress concentration factor

The hot spot stress at a weld toe is defined as the geometric stress that includes rising effects due to structural discontinuities and presence of attachments, but excluding the localised stress due to the presence of the weld itself.

Hot spot stresses are obtained either through classified details hot spot factors (global & first stage analysis) or through direct stress analysis of details.

- The local notch stress increase is due to the presence of weld(s)

Notch stress may be accounted either by classified notch stress factors applied to the stress based on type of weld and weld profile, or by selection of SN curve corresponding to the weld and geometry type.

3.6.2 Definition of SN curves

The design SN curves shall be based on a probability of survival of test specimens of 97.5%, which means based on the “mean minus two standard deviation” curve of the experimental data.

SN curves obtained from Classification Society Rule and/or other recognised Codes and Standards such as IIW, DEN shall be normally used.

The fatigue curves shall be selected in adequacy with the construction details and the stress considered for the analysis as categorised here above.

Methods for accounting of thickness effects, compression effects, residual stresses and mean stress effect shall be used in a coherent way associating the basic SN curve and all subsequent corrections.

Depending upon the Classification Society, hot spot stress or notch stress are used for fatigue evaluation, together with the corresponding SN curve.

In the case of stress obtained by local Finite Element Analysis and provided that the model is fine enough, the results are directly the hot spot stress.

For global analysis, nominal stresses are obtained and stress concentration factors need to be applied. They can be obtained from Classification Society classified details. In general, SCF depends upon the type of loading (stiffener local bending or axial load resulting from Hull Girder bending moment). If the effects of these different types of deformations can not be separated, it is required to take the worst of the given SCF so that the final results are on the conservative side.

The stress to be considered for fatigue evaluation is the maximum principal stress adjacent to the potential crack location.

In case of complex stress state, the principal stress in the plate surface within $\pm 45^\circ$ of the normal to the weld toe should be used as the relevant hot spot stress.

3.7 Fatigue safety factor

The fatigue safety factor is the ratio between the calculated fatigue life of a structural detail by the design life of the F(P)SO.

Fatigue safety factors are to match following COMPANY Requirements without being less than that is required by the Classification Society.

Region	Fatigue factor
Hull longitudinal plating, butt welds	4
Shell butt welds below the ballast draught	10
Hull longitudinal, stiffener end connections	5
Deck penetrations and welded attachments	2
Shell penetrations and welded attachments	4
Shell penetrations and welded attachments below the ballast draught	10
Transverse structure, plating	2
Transverse structure, stiffener end connections	2
External details below the scantling draught and their connections to the hull	4
External details below the ballast draught and their connections to the hull	10

The categorisation of structural details into the regions defined above shall be agreed with COMPANY.

4. Selection of ship structural details for fatigue analysis

4.1 Principle

Many structural details exist on an F(P)SO that may be critical from a fatigue design viewpoint. Therefore, fatigue screening is a very important step in achieving fatigue control.

The final list of structural details is the responsibility of the CONTRACTOR and will ensure that all critical structural details meet the fatigue design requirements.

The following Table gives, for information, the locations of structural details to be considered as a minimum for fatigue evaluation.

Structural Members	Critical Structural Details	Typical Fatigue Loads
Longitudinal Hull Structural Members	Longitudinal Connections at frames & bulkheads Longitudinal connections at knuckles Insert plates Brackets toes and heels Rat holes and erection butts Deck openings Longitudinal girders Structural terminations Miscellaneous structure	Hull girder bending/shear loads Wave pressure loads Internal Loads (Tanks) Topsides loads
Transverse Hull Structural Members	Transverse frames and gussets, including cut-outs and various holes Transverse bulkheads	Wave pressure loads Topsides loads Sloshing
F(P)SO-specific Details	Topsides modules supports Flare tower foundation Riser porches Caissons Crane pedestal Mooring foundations Deck penetrations Helideck to deck connections	Hull girder bending loads Deck deformation loads Riser loads Mooring loads Topsides inertia loads Crane loads Winds loads Wave loads

This screening shall be based on:

Review of distribution curves along the vessel of:

- Dynamic hull girder loads (vertical and horizontal bending moments and shear forces, accelerations, etc.)
- Dynamic pressure charts on the hull for the various wave lengths and incidences, relative motion chart
- Slamming pressures and bow impact pressure charts.

Identification of structural arrangement types and position, patterns of full/void spaces, changes in span of main members.

Preliminary analysis of dynamic load induced by Topsides modules and other equipment.

Verification at screening level usually made considering nominal stresses (global and local) and SN curves F2 (BV NI393).

Final selection of the areas to be studied in details shall preferably be done after processing of a coarse mesh global model.



The list of locations to be considered shall be established by the CONTRACTOR and submitted to COMPANY approval.

5. Vessel fatigue evaluation methodology

5.1 Analysis planning

A direct stochastic fatigue analysis is to be performed, which consists in calculating the hydrodynamic loads in a complete model of the vessel and applying these loads to the structural model, then processing stress results using stochastic methods to provide long term stress distribution enabling the evaluation of fatigue damage.

Using this full-ship direct stochastic analysis, and provided that load application is adequately modelled, all linear local effects are automatically included.

However, non linear effects such as those due to wet and dry surface at the waterline, shall be accounted for separately.

For details in areas exposed to local lateral loads in addition to the global stresses, local models have to be utilised in order to assess the fatigue life accurately.

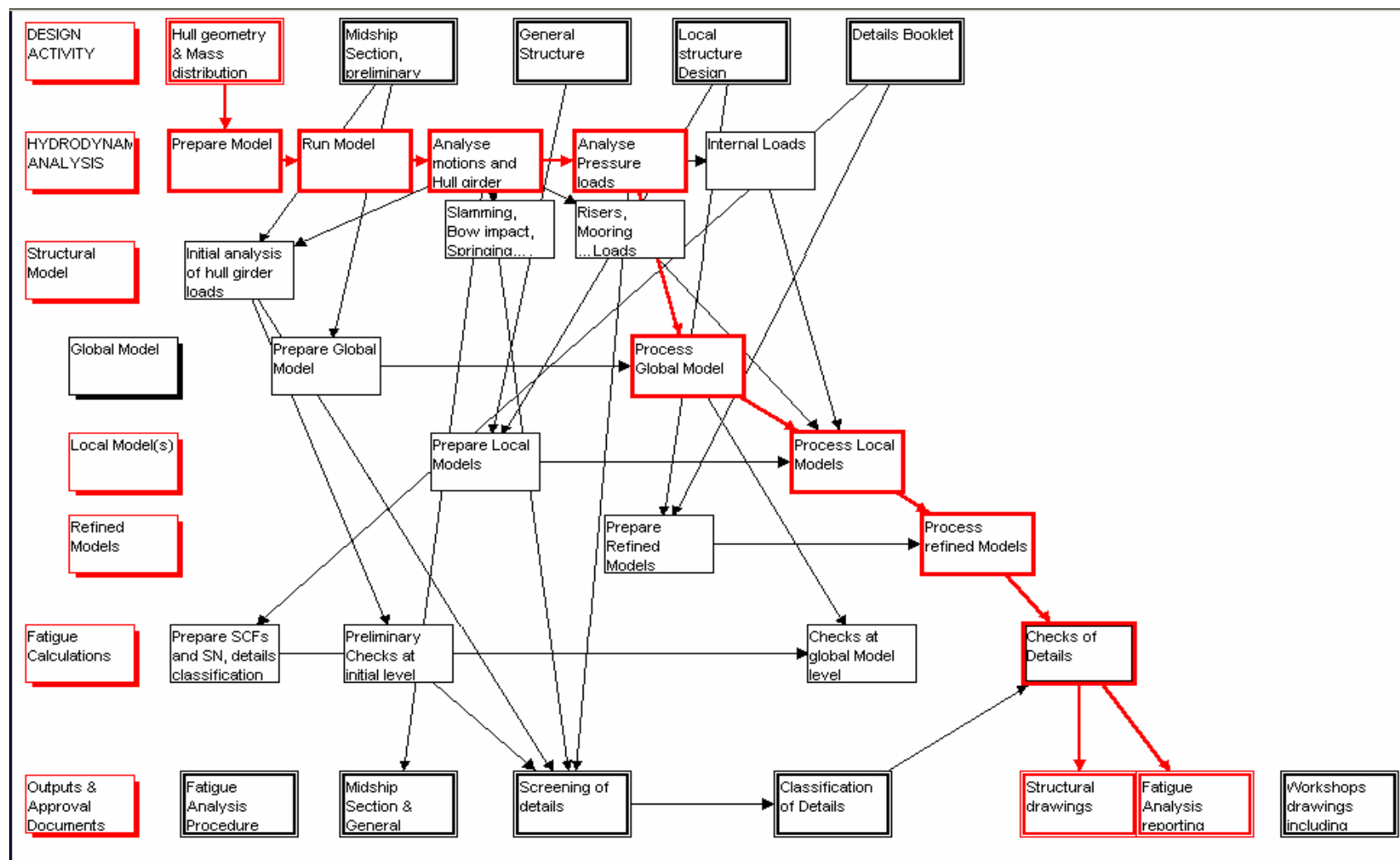
The following chart gives the principle of the tasks and steps required to perform the fatigue calculations according to this method.

Owing to the complexity of the analysis and numerous data transfer involved, careful check of each stage shall be implemented in the process.

In addition to main hydrodynamic and finite element analysis software, a number of computer processing of data is involved in such analysis.

CONTRACTOR will deploy a validation plan for each data processing step (such as pressure transfer between hydrodynamic and structural model, spectral response using stress transfer functions, long term stress response calculation and fatigue damage summation, etc.).

Validation of the process shall be submitted for approval to Classification Society and demonstrated to COMPANY together submission of analysis procedure.



5.2 Hydrodynamic model

The sea keeping and hydrodynamic load analysis is to be carried out by a recognised computer program, following well established and qualified modelling techniques.

5.2.1 Model meshing

Hydrodynamic loads shall results from an adequate model giving access to vessel motions, vessel hull girders loads and local pressures.

Calculation conditions shall be in sufficient number to cover the site and tow spread of waves period and relative incidence taking into account the yaw of the vessel (static and low frequency motion) and the directional spread of waves according to metocean data.

A higher density of panels around the bilge and close to the still water level should also be applied. Areas of hull knuckles at ends, if any, shall be of refined meshing.

As a rule it is recommended to have at least six elements per the shortest wave length in the lateral ship direction, assuming that the shortest length is approximately 10% of the ship length.

A complete model shall be used (no transverse symmetry) in case where the hull shape is not symmetric due to risers supporting structure.

5.2.2 Damping

Viscous damping shall be taken into account.

Non-linear roll damping on a ship hull is a function of roll angle and wave frequency.

Roll damping for fatigue analysis shall be based on Model Testing results to be performed for the relevant fatigue sea states.

5.2.3 Definition of wave heading and periods

Waves to be considered shall reflect the site scatter diagram, and to include for reference (and tow conditions eventually) at least 0 to 180° by steps 45°.

Owing to narrow spread in West Africa, incidences by steps 22.5° from stern (from 0 to 90°) should be selected as a minimum for site conditions.

The range and density of wave periods should be selected to ensure a good representation of all relevant response transfer functions (motions, sectional loads, pressures, drift forces) for the wave period range of the applicable scatter diagram), including peak values.

5.2.4 Hydrodynamic model Check and validation

The hydrodynamic loading model shall be compared to and validated through the model tests in waves as required by General Specification.

5.2.5 Motion Induced Acceleration and Inertia Force

Accelerations used in the derivation of loads in longitudinal and transverse directions shall include the g-component induced by the ships pitch motion and the ships roll motion.

The calculated design loads are to be applied as a combination of pressure forces on the hull and inertia forces. When this is done correctly, the global FE model will be close to equilibrium, and the reaction forces should be close to zero.

Internal Loads shall be derived from ship motions & accelerations according to Class Rules.

5.2.6 Internal Fluid pressures

Fluid pressures on tank boundaries shall be modelled including effect off local acceleration at tank CoG and hydrostatic pressure incorporating ship angular motions and effective tank top point.

This in particular applies to dynamic pressure on lower face of main deck in way of normally full tanks.

5.2.7 Partly filled tanks

A careful investigation of potential resonant conditions in normally partly filled tanks such as ballast tanks and cargo tanks shall be performed to assess the sloshing risk.

In case where the sloshing risk is not negligible, the particular condition shall be included as an individual case for damage evaluation with appropriate sloshing loading.

Sloshing loading pressures may be derived from Classification Society Rules when the sloshing condition has a low probability of occurrence.

In case where the occurrence of sloshing condition is not remote, either the design shall be modified (COMPANY preferred solution) or a dedicated sloshing analysis to be performed.

5.2.8 Slamming induced loads

The Hydrodynamic analysis shall include a review of potential slamming/bow impact effects and an evaluation of corresponding pressures and their probability of occurrence.

A particular attention to be given to local dynamic pressures induced by wind induced waves in bow and side area even in non slamming conditions.

Such loading shall be included in the fatigue damage evaluation of relevant elements.

5.2.9 Mooring induced loads

Hydrodynamic analysis shall evaluate the wave and vessel motions induced loads in mooring lines, risers and their correlation with main vessel hull dynamic loading in order to provide adequate input data for local models.

Such loads shall produce separate estimates for the high frequency induced loads and low frequency parts.

5.2.10 Interface topsides/stools

Special emphasise shall be put on the modelling of the interface between the Hull and the Topsides structure.

The hull girder deformation may induce very high forces on the Stools depending upon the types of connection selected at the interfaces between Topsides and Stools.

Assessment with regards to contact conditions between the top surface of the Posts and the bottom face plate of the Topsides structure shall be made clear.

The actual rigidity of the connection between the Deck structure and the bottom of the Posts shall be properly represented.

On this respect, the proposed method to take into account the various contact conditions depending upon the position on the Hull deck (sliding with friction, built-in, etc.) at these locations shall be documented. Simplified approach would be accepted provided they lead to conservative results.

5.3 Structure modelling using finite element method

5.3.1 General

Modelling shall be fine enough for assessment of stress for fatigue calculation.

The structural analysis can be performed in more than one step with the use of global and relatively coarse mesh in a first step followed by refined mesh analysis in a limited number of structural details.

A rationale and conservative procedure shall be used to evaluate fatigue damage of parts of the structure that are not properly loaded in the hydrodynamic model.

The detailed procedure to be developed by the CONTRACTOR shall indicate the number of levels of the analysis and the size of elements for each of them.

It is generally proceeded with three levels of analysis, as follows:

- Global model: complete ship structure for assessment of general stress level and deformations
- Local model: modelling of primary structure in a limited extent for assessment of nominal stresses of the primary hull structural members
- Refined model: to obtain hot spot stress for fatigue evaluation

The phase angle between the Hull deck deformation loads and the loads induced by the Topsides sea motion induced loads shall be properly analysed and taken into account.

5.3.2 Principles for defining mesh sizes

Definition of mesh and element types shall be in accordance with Classification Society standards.

The following principles can be used as a normal guideline for the minimum element sizes to be used.

5.3.2.1 Global structural model with use of 4-nodes shell elements

- General: One element between transverse frames/girders, minimum three elements in transverse direction between primary members/longitudinal bulkheads
- Girders: One element over the height in areas where stresses are to be obtained, flange may be modelled by beam. In other areas use beam elements
- Girders brackets: One element
- Stringers: One element over the width
- Bilge: Two elements over curved area
- Stiffener brackets: may be disregarded

Longitudinal Stiffeners may be grouped and modelled by beams.

5.3.2.2 Requirements for performing local model with use of 4-nodes shell elements

In general the size of element is 4 times smaller than for the global analysis with, as an example four elements in the height of Girders.

Combined with structural detail classified stress concentration factor, these stresses can be used for direct fatigue life assessment.

Slots & Cuts-Outs in primary members shall be taken into account either by modelling them in a simple way, or through post processing of results.

When eight nodes shell elements are used (preferred solution), a smaller number of elements may be used, without being less than 2 in webs of stiffeners.

5.3.2.3 Requirements for performing refined model

All aspects of detail construction are to be taken into account, such as stiffener asymmetry, lugs overlap, position and length of welds, scallops, etc.

In general the size of elements is about equal to the thickness of the plate.

Eight nodes thick shell or 20 nodes brick elements shall be preferred as far as possible.

5.4 Spectral calculations

5.4.1 Stress transfer function

The stress transfer function gives the local stress in the areas of interest for unit sinusoidal wave of variable period and for the wave headings considered and is the result of structural calculations under the wave loads. It shall be checked that the number of processed cases enables an adequate definition of the peaks of stress transfer functions for further spectral calculations.

Particularly, wave frequency behaviour and intermittent wetting shall be considered for near waterline components.

5.4.2 Short-term stress response analysis

The stress response spectrum shall be computed based on the linear model using the wave spectrum with appropriate definition according to metocean data.

For areas sensitive to non linear effects, such as side shell close or above the waterline, two/three intermediate conditions shall be used to represent the range of site and tow waves.

5.4.3 Wind-waves and swell combination

When relevant, the response to swell may be calculated similarly to the response to wind-waves.

The responses to wind-waves and to swell are interdependent, and the combined effect shall be calculated accordingly. This would be performed by an approved procedure.

5.4.4 Other sources of fluctuating loads

Other sources of fluctuating loads shall be considered as independent and analysed in order to define the corresponding long term distribution of stress ranges for the life of the unit.

5.5 Fatigue life calculation

5.5.1 Selection of SN curves

The selection of SN curves is performed in correlation with local/refined FE model or construction detail classification.

Thickness effect is to be taken into account according to the Class Rules.

5.5.2 Fatigue cumulating

The stress range response for ship structures can be assumed to be Rayleigh distributed within each short term condition. The stress range distribution for each given sea state and heading direction is then derived.

For each sea state, the cumulated fatigue damage is calculated according to the Palmgren-Miner hypothesis.

For other sources of fluctuating loads, the appropriate distribution shall be used, or direct numerical computation of damage shall be performed.

The accumulation of damage over the full set of sea state and other loads gives the usage factor of the structure.

The long term distribution of stress ranges shall be also computed, with at least values corresponding to 10^{-8} , 10^{-5} , 10^{-3} probability levels for sake of benchmarking, for both wave contributions and others effects.

Damage may be calculated either through analytical methods, that shall be carefully checked with respect to account of SN curve shape and various corrections, or through numerical computation by stress ranges intervals (preferred method). In of numerical integration, at least 100 integration steps between the 10^{-8} and 10^{-1} probability level shall be used.

6. Structural detail classification for Inspection & Control

The results of the fatigue analysis will be used for assessment of the construction details criticality.

Details shall be classed according the following principle, based on the Miner fatigue damage coefficient: and possibility & reliability of inspection

- Normal
- Fatigue sensitive
- Highly fatigue sensitive

Classification of details with respect to inspection is to follow following principles:

- Not inspectable: closed structures or such location and shape that inspection is not possible with conventional means on site. Such details should be avoided by design as far as possible
- Hard to inspect & repair: areas of the outer shell or other structural parts below the design waterline, which would require underwater inspection & repair.
- Inspection possible: areas/weld where inspection is possible either at any time or at least during programmed maintenance through emptying a tank.



The following table give the classification to be retained with regard to fatigue sensitivity:

Category of structure damage	Secondary or Inspection possible	First or hardly to inspect	Special or not inspectable
< 50% allowable	Normal	Normal	Normal
Between 50% and 75% of allowable	Normal	Normal	Fatigue sensitive
> 75% allowable	Normal	Fatigue sensitive	Highly fatigue sensitive

CONTRACTOR will submit to COMPANY approval the classification of details/welds with respect to inspection at same time as selection of details for fatigue damage calculations.

After analysis of fatigue damage results, CONTRACTOR will issue and submit to COMPANY approval a set of drawings showing the classification of details according to above table, to be used for inspection planning.

All workshop drawings will mention this classification of details / welds with respect to fatigue as well as with regard to structural category.