PETROBRAS	**TECHNICAL SPECIFICATION**	Nº: I-ET-3010.2D-1400-140-P4X-001	
	CLIENT: AGUP		SHEET 1 of 43
	JOB: HIGH CAPACITY – GAS EXPORTATION ALL ELETRIC		-
	AREA: ATAPU 2 AND SÉPIA 2		
SRGE	TITLE: **TOPSIDES STRUCTURAL REQUIREMENTS**		INTERNAL
			ESUP

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SUMMARY

1 INTRODUCTION

This document presents BUYER requirements to be adopted by SELLER for the structural analyses and design of the topsides structures of the PETROBRAS HIGH CAPACITY FPSO – GAS EXPORTATION ALL ELETRIC, as part of engineering design development at the Detailing Phase. Topsides structures comprise, not limited to, topsides modules/pipe-rack, outfitting and flare tower. Upper riser support structure and pull-in structure are not part of topsides SELLER scope of work.

SELLER refers to DESIGN DETAILING COMPANY in this document.

In addition to BUYER requirements, SELLER documents to be delivered to the Classification Society (CS) contracted for the Detailing Phase shall fulfill the additional requirements agreed with this CS rules.

BUYER FPSO Units may be installed at some areas in Santos Basin, southeastern of Brazilian coast.

SELLER shall issue a new “Topsides Structural Requirements” document based on the present one, keeping the same philosophy in general, revising and including additional requirements for assembly and construction, detailing the scope of supply, and submit to BUYER for approval.

SELLER shall fulfill all design requirements specified in this document, but not limited to. Fabrication requirements shall be used by SELLER as information to guide the design.

SELLER shall present, for BUYER and CS approval, a detailed Topsides Structural Requirements showing the methodology and computational tools to be adopted. Topsides Structural Requirements carried out during the Detailing Phase shall be used as reference, updated and complemented.

All structural design reports and drawings, as well as all computer structural analyses models with loadings (input and output), design spreadsheets and computational tools adopted in the structural analysis, such as data importation/exportation tools or data manipulation tools not commercially available, shall be submitted to BUYER for approval. In addition, for equipment weights greater than 50kN, SELLER shall list in the design report

the corresponding SELLER reference document number with informations about the footprint/foundation type, center of gravity and total weight (dry/operational and test), as well as the equipment list shall also be attached to the design report. All structural drawings and design data shall also be submitted in due time for CS approval. SELLER shall answer CS comments.

This document is complemented by codes, rules and standards presented in Section 2 of this document, subject to approval of the CS of the Unit.

The latest revision of the CS rules shall be used for the design of structures, reinforcements and complementary structures. Additional relevant criteria can be used in the design, based on designer experience and requirements of the CS, since submitted to BUYER and CS for approval.

During the Detailing Phase, any change in the FPSO topsides main structures and details as well as any change of the design philosophy shall be submitted by SELLER to BUYER for approval.

By changes one shall understand, for example:

- Interference with structures;
- Changes of dimensions, cross sections and welds;
- Significant changes on weight and general arrangement;
- Attachments on structures;
- Material changes;
- Main non-conformities during detailing, fabrication, assembly and construction phases;
- Damages during fabrication and found after the inspections;
- Structures out of the specified tolerances, misalignments and deformations above the rules limits;
- Changes in Painting Schemes.

Besides those mentioned above, SELLER shall follow the same procedure for any other relevant modification or change.

The International System of units (SI) shall be used in the analyses, reports and drawings.

All 2-D drawings shall be provided in system formats compatible with the contractual software and shall be extracted from 3D model. The 3D Model shall be built according to TECHNICAL REQUIREMENTS FOR DIGITAL ENGINEERING [4]. SELLER shall guarantee the consistency for all engineering database.

2 REFERENCES, CODES, STANDARDS AND PROCEDURES

2.1 DESIGN DOCUMENTS

All documents listed in I-LD-3010.2D-1200-940-P4X-002 and I-LD-3010.2E-1200-940-P4X-002 shall be used as reference, with emphasis on the following:

[1] I-DE-3010.00-1400-140-P4X-004 – GENERAL NOTES FOR TOPSIDES STRUCTURES;

[2] I-DE-3010.00-1400-140-P4X-006 – TOPSIDES MAIN STRUCTURE – TYPICAL DETAILS;

[3] I-DE-3010.2D-1200-942-P4X-002 – GENERAL ARRANGEMENT;

[4] I-ET-3000.00-1350-940-P4X-013 - TECHNICAL REQUIREMENTS FOR DIGITAL ENGINEERING;

[5] I-ET-3010.00-1200-251-P4X-001 – REQUIREMENTS FOR BOLTING MATERIALS;

[6] I-ET-3010.00-1200-956-P4X-002 – GENERAL PAINTING;

[7] I-ET-3010.00-1300-140-P4X-001 – GUIDELINES FOR STRUCTURAL DESIGN AGAINST BLAST LOADS;

[8] I-ET-3010.00-1300-140-P4X-003 – FIRE-STRUCTURE ANALYSIS FOR PASSIVE FIRE PROTECTION DESIGN;

[9] I-ET-3010.00-1300-140-P4X-005 - GUIDELINES FOR STRUCTURAL ANALYSES FOR CRYOGENIC PROTECTION DESIGN;

[10] I-ET-3010.00-1350-960-PPC-001 – GUIDELINE FOR FPSO GREEN WATER ANALYSIS;

[11] I-ET-3010.00-1351-140-P4X-001 – HULL GLOBAL DEFLECTION;

[12] I-ET-3010.00-1400-140-P4X-002 – GUIDELINE FOR DROPPED OBJECT STRUCTURE ANALYSIS;

[13] I-ET-3010.2D-5266-630-P4X-001 – TOPSIDE'S MECHANICAL HANDLING PROCEDURES;

[14] I-ET-3A36.00-1000-941-PPC-001 – METOCEAN DATA – NORTHERN SANTOS BASIN PRE-SALT FIELDS (FOR ATAPU 2);

[15] I-ET-3A26.00-1000-941-PPC-001 – METOCEAN DATA –SANTOS BASIN CENTRAL CLUSTER REGION (FOR SÉPIA 2);

[16] I-LI-3010.2D-1200-940-P4X-002 – EQUIPMENT LIST;

[17] I-RL-3010.2D-1350-960-P4X-002 – MOTION ANALYSIS.

2.2 RULES, CODES AND STANDARDS

Rules, codes and standards from the list below shall be used for structural design of the topsides structure and attached structures, subjected to CS approval. Latest edition of each one shall be used, or, otherwise, contractual applicable edition, when specified. Rules, codes and standards other than those shall be submitted to BUYER and CS for approval.

[18] ABS - Floating Production Installations;

[19] ABS – Rules for Building and Classing Floating Production Installations;

[20] ABS - Rules for Materials and Welding (Part2);

[21] AISC 335 – 89 – Specification for Structural Steel Building - Allowable Stress Design and Plastic Design - June 1989;

[22] API RP 2A – WSD – Planning, Designing and Constructing Fixed Offshore Structures – Working Stress Design;

[23] API RP-2FB – Recommended Practice for the Design of Offshore Facilities Against Fire and Blast Loading;

[24] API RP-2MOP – Marine Operations;

[25] API Standard 537 – Flare Details for General Refinery and Petrochemical Service;

[26] BS 2853 – Specification for the Testing of Steel Overhead Runway Beams for Hoist Blocks;

[27] DNV CG 0128 – Buckling;

[28] DNV CG 0129 – Fatigue Assessment of Ship Structures.

[29] DNV OS C102 – Structural Design of Offshore Ship-shaped and Cylindrical Units;

[30] DNV OS C201 – Structural Design of Offshore Units (WSD Method);

[31] DNV RP C203 – Fatigue Design of Offshore Steel Structures;

[32] DNV RP C205 – Environmental Conditions and Environmental Loads;

[33] DNV ST N001 – Marine Operations and Marine Warranty;

[34] EN 1993-1-2 – Eurocode 3:Design of Steel Structures – Part 1-2: General Rules – Structural Fire Design;

[35] ISO 19901-3 – Petroleum and Natural Gas Industries - Specific Requirements for Offshore Structures Part 3 Topsides - Structure;

[36] MODU CODE 2010;

[37] NORSOK N-003 – Actions and Actions Effects;

[38] NORSOK Standard M-101 – Structural Steel Fabrication;

[39] Research Council on Structural Connections (RCSC) – Specification for Structural Joints Using High Strength Bolts;

[40] Text of The Resolutions Adopted by the 22nd General Conference on Weights and Measures.

3 DESIGN DATA

3.1 DESIGN LIFE

The Units shall be designed for 30 years minimum operation period without docking.

3.2 ENVIRONMENTAL DATA

Environmental parameters for in-place analyses and for transportation analyses shall be obtained from METOCEAN DATA [14] and [15].

3.3 STRUCTURAL CATEGORIZATION

All areas of the structures shall be categorized according to the application and consequence of failure.

Table 3.1 – Structural Categorization

A	**Special Design Area**	Those regions of the Primary Structure that are critical for the load transfer, and may be subject to critical stress concentrations. Examples for process plant modules are: module foundations, bottom gusset plate of multicolumn supports, lifting padeyes and all structural elements, such as beams, columns, braces and plates, directly connected to lifting padeyes.
B	**Primary Design Area**	Structural elements essential to the overall unit integrity, but less critical than the Special Design Area. This class is represented in process plant modules by main girders, columns and diagonals, major equipment supports (beams which supports equipment with > 50kN), deck plates and bulkheads that provide global resistance for module.
C	**Secondary Design Area**	Structural elements of minor importance, the failure of which is unlikely to affect the unit integrity. This class is represented in process plant modules by deck plates, stiffeners and bulkheads that are not taking part on global resistance, piping supports, laydown area bumpers and monorails (including their foundation).
D	**Tertiary Design Area**	Structural elements of minor importance, the failure of with is unlikely to affect the unit integrity. This class is represented in process plant modules by stairs, walk ways, handrails, gratings and others.

Further details can be found in GENERAL NOTES FOR TOPSIDES STRUCTURES [1].

3.4 UNITS

International System of units (SI) metric system shall be used throughout the project, including input data and results of structural analyses, and any other numerical information presented in design report, drawings or any other document.

The numerical notation adopted shall be as recommended in the 22nd General Conference on Weights and Measures [40] and presented below:

- The symbol for the decimal marker shall be dot ".";
- Numbers shall be divided in groups of three in order to facilitate reading; neither dots nor commas are ever inserted in the spaces between groups.

The following units shall be used as standard units on the project:

Table 3.2 – Standard Units on the Project

Description or structural characteristic	Unit
Member length, joint coordinates, etc.	m
Tube diameter and wall thickness, section prismatic properties, deflections, etc.	mm or cm
Angles	deg
Forces	kN
Moments	kN.m
Distributed loads	kN/m² or kN/m
Masses	kg or metric tons (tonnes)
Member stress	N/mm² (MPa)
Time	s (second)
Wind velocities	m/s
Accelerations	m/s²
Temperature	°C

4 MATERIAL

Material grades shall be in accordance with the requirements of the CS rules of the Unit for topsides structures. Grade selection shall consider the plate thickness, the structural

categorization and service temperature. Details on material grades can be found in GENERAL NOTES FOR TOPSIDES STRUCTURES [1].

4.1 STEEL DESIGN PARAMETERS

Steel design properties will be taken as:

- Young's Modulus → E = 206 000 MPa
- Shear Modulus → G = 79 200 MPa
- Poisson's Ratio → ν = 0.3
- Density → ρ = 7 850 kg/m³
- Coefficient of thermal expansion → α = 12.0 x 10^{-6} / ºC
- Steel design temperature: 0 ºC

If in any phase of the project (e.g.: construction, transport, integration) the environmental temperature is lower than the design temperature 0 °C, SELLER shall proceed all necessary adequation.

Service temperature shall not be taken higher than the design temperature.

Creep curves and heat effects shall be assessed for special application (e.g.: flare tower).

The flare tower structures temperature shall be kept bellow 350 °C, heatshield shall be used to do this.

4.2 MATERIAL THICKNESS

The SELLER shall avoid large amount of different thickness during the selection of the structural elements sections, in order to optimize the material supply and reduce expenditures.

To prevent laminar tearing, a minimum steel plate thickness of 15mm with ‘Z’ quality (through thickness strength - TTS) shall be used in locations with significant TTS or where required by CS (including TTS and minimum plate thickness requirements), the most restrictive requirements shall be applied. The significant through thickness tensile stress shall be considered greater than 25% of yield strength.

4.3 BOLT MATERIAL

Structural joints shall be welded. Bolted joints may be used for hook-up parts and removable parts only. Bolt material for structural elements shall be specified according to REQUIREMENTS FOR BOLTING MATERIALS [5].

Material to be:

- Bolts ASTM A325/A325M or ASTM A490/A490M, nuts ASTM A563/A563M, washers ASTM F436/F436M – where neither high pressure nor high temperature is an issue. Requirements in the respective standards to be complied with RCSC [39] and corresponding certified reports of required tests to be presented. (*);
- Bolts ASTM A193/A193M Grade B16, nuts ASTM A194 Grade 7 (see REQUIREMENTS FOR BOLTING MATERIALS [5]) - where high pressure and/or high temperature is an issue.
- Coating System to be: 8-12%Ni balanced Zn coating, for temperature less than 150o C (see REQUIREMENTS FOR BOLTING MATERIALS [5]).
- Threads shall be rolled type.

(*) Guidance for definition of joint type, installation requirements, such as possible requirement for specification of a minimum pretension, and other requirements, may be taken from RCSC [39]. Due to the cyclic nature of the loading, only pretensioned bolt shall be used.

5 WELDING

Welds shall be properly dimensioned for all design conditions. In addition, minimum requirements shall be used according to GENERAL NOTES FOR TOPSIDES STRUCTURES [1].

6 INSPECTION

Welds Nondestructive Testing (NDT) extension shall be in accordance with GENERAL NOTES FOR TOPSIDES STRUCTURES [1].

7 CORROSION CONTROL

The topsides structures shall be adequately corrosion protected by the coating system in accordance with GENERAL PAINTING [6]. No corrosion allowance needs to be considered for topsides structures.

8 PASSIVE FIRE PROTECTION

Based on Fire Propagation and Smoke Dispersion Study results, the need of Passive Fire Protection for the topsides structures shall be assessed according to FIRE-STRUCTURE ANALYSIS FOR PASSIVE FIRE PROTECTION DESIGN [8].

9 CRYOGENIC PROTECTION

Based on the High Content CO_2 Gas Leakage Embrittlement Study results, the need of Cryogenic Protection for the topsides structures shall be assessed according to GUIDELINES FOR STRUCTURAL ANALYSES FOR CRYOGENIC PROTECTION DESIGN [9].

10 STRUCTURAL ANALYSES

This section describes the design analyses to be performed during the Detailing Phase.

The SELLER shall design the topsides structures according to CS Rules and BUYER requirements.

10.1 SOFTWARE

The following software are acceptable for structural analyses.

For modules, flare tower and other frame structures:

- GT STRUDL;
- Sesam GeniE;
- SACS;
- SAP 2000.

For other structures, local and non-linear analysis:

- Sesam GeniE;
- ANSYS;
- FEMAP;
- ABACQUS.

Other structural software shall be submitted to BUYER for approval.

10.2 STRUCTURAL MODELING

A tri-dimensional space frame model shall be elaborated with unidirectional members (bars). The working points of the main elements (columns, beams and braces) shall be at the unique center of a frame joint according the Figure 10.1, therefore there are no horizontal eccentricities in the structural model.

SELLER shall not change the working point locations of the Basic Design unless submitted and approved by BUYER.

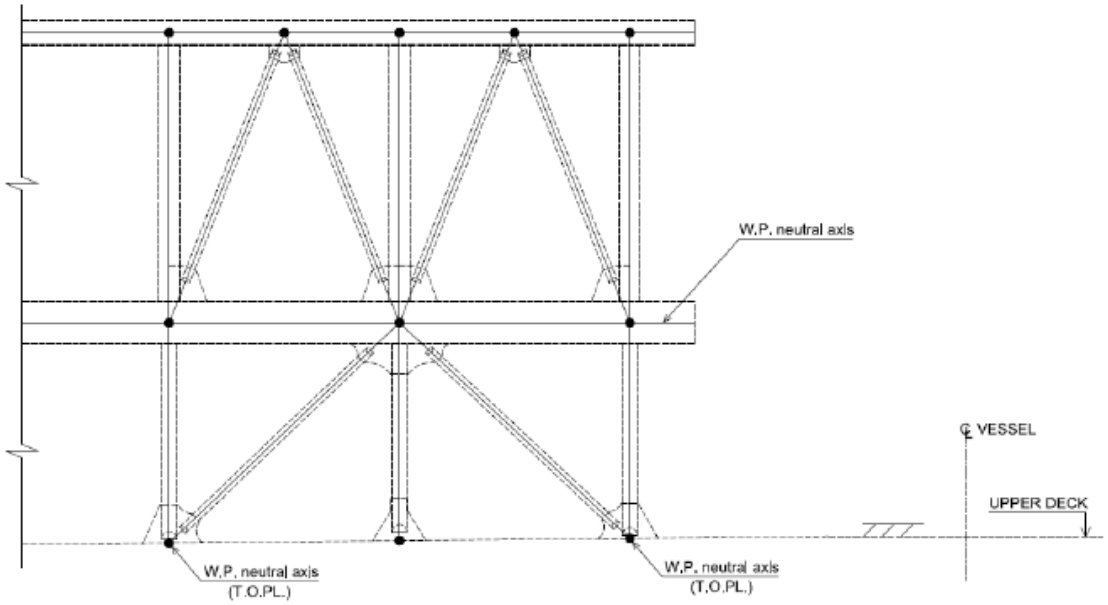


Figure 10.1 – Typical working point position

In general, beams are continuous, the columns and braces are interrupted. When necessary (e.g., avoid overlap, ensure the minimum space for welding etc.) non-competing work points may be adopted. In this case the offset shall be represented in the drawing and in the structural model, column-beam and brace-beam connection joints shall be defined separately to reflect actual load transfer (e.g., shear load, which is transferred from brace, might be the controlling factor for beam design). See Figure 10.2 and Figure 10.3.

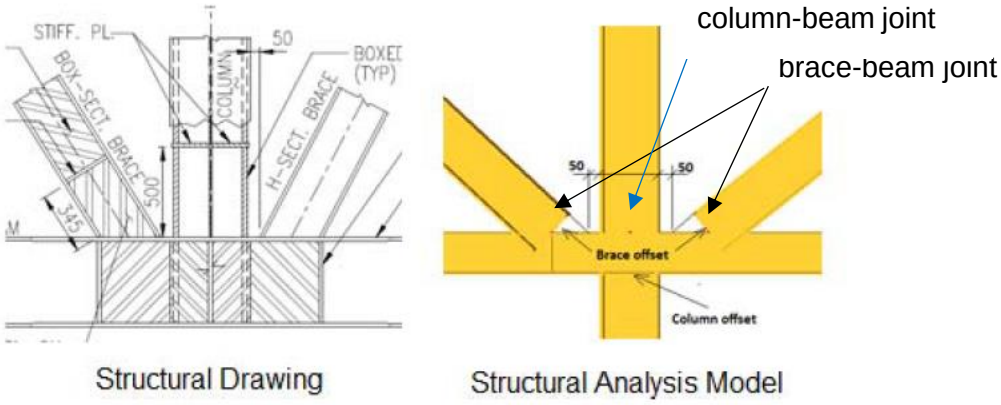


Figure 10.2 – Column/Brace Offset in Model

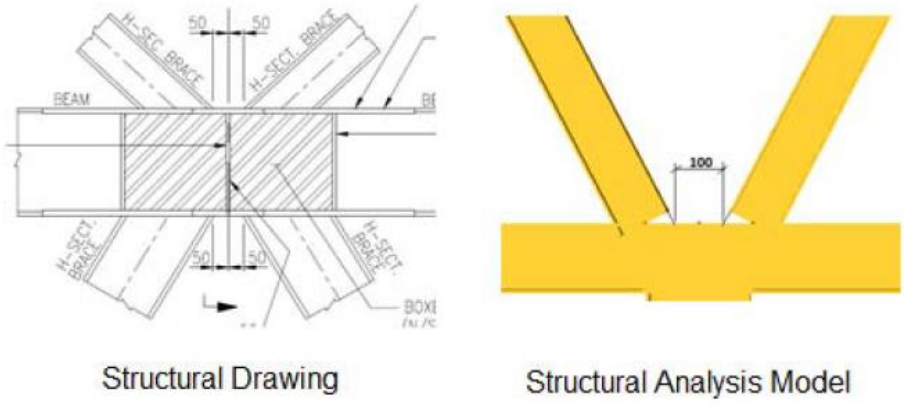


Figure 10.3 – Brace Offset in Model

Vertical offset of beam members at all deck levels shall be applied in the structural analysis model. The top flanges of beams shall be flushed to the top of steel (refer to Figure 10.4). In the event that bottom flush is required, the requirement shall be clearly stated in the relevant document/drawing.

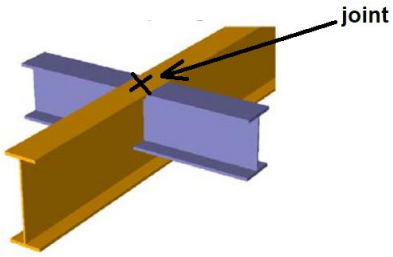


Figure 10.4 – Beam Member Flush in Model

Deck floor shall be modelled with shear only type Finite Element Method (FEM) elements connected at the structural joint in order to give lateral bracing to the whole model. In addition, the secondary structure, such as: stiffeners, brackets e.g., shall not be taken into account in the primary structure FEM model. The secondary structure shall be properly evaluated in the model for secondary structure analysis.

The concept of connections of module structures to hull shall be:

- Module supported on columns attached to the upper deck by means of gusset plates. These gusset plates are directed in transverse ship direction and are in line with under deck transverse web frame or transverse bulkheads. The function of the transverse gusset plates is to act as hinges, minimizing stress in the module structure due to hull deflections effects under wave loads and loading/unloading of the FPSO, which generates strain in the upper deck and make the bottom connection of the columns displace in longitudinal direction.

- In longitudinal direction braces are applied between two spans and three columns (two web frame spaces). At these locations, gusset plates are installed at vessel upper deck also in the longitudinal directions and in line with the ship's longitudinal stiffeners, in order to avoid punching of the upper deck plating.

- Besides bracing in longitudinal direction, braces are also required in transverse direction.

For connections between multi-columns supports and topsides structure, where only a single column is attached at the pancake level, this connection may be made by means of a gusset plate for a suitable load transfer of structural details subject to critical stress concentrations. It is recommended that the gusset plate be applied in the transverse ship

direction and also have a hinge function to minimize the installed stress in the topsides structure due to the effects of hull global deflections.

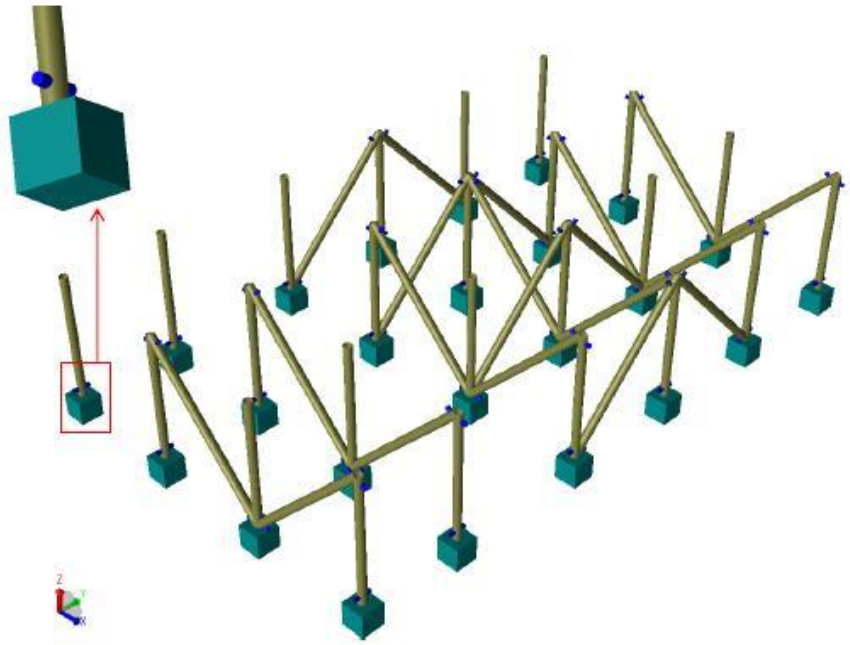


Figure 10.5 – Concept of typical connections of module structures to hull

The brace members located at the planes “xz” and “yz” which are connected to the hull structure shall be oriented as indicated in Figure 10.6 and Figure 10.8 respectively. Brace members at plane “xz” shall meet at common column support on main deck, as well as the brace members at plane “yz” shall meet in the pancake structure. The brace orientations indicated in Figure 10.7 and Figure 10.9 are not recommended due to the frame displacement restrictions, that implies higher stresses in the module structure. Any solution, different than Figure 10.6 and Figure 10.8, shall be submitted to BUYER approval.

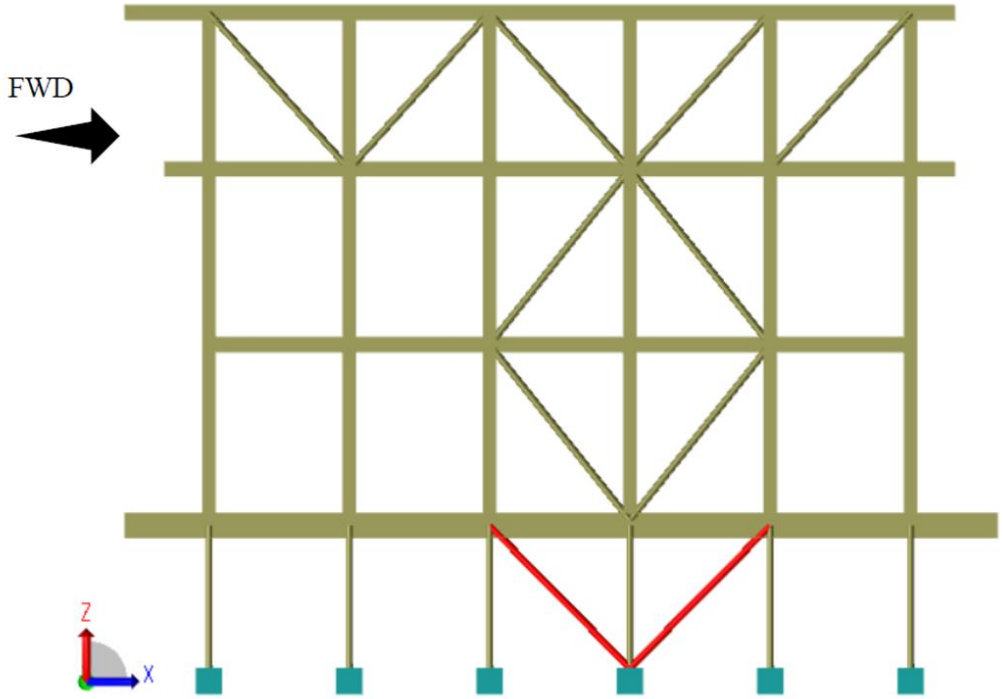


Figure 10.6 – Recommended orientation for the brace in “xz” plane (red marked)

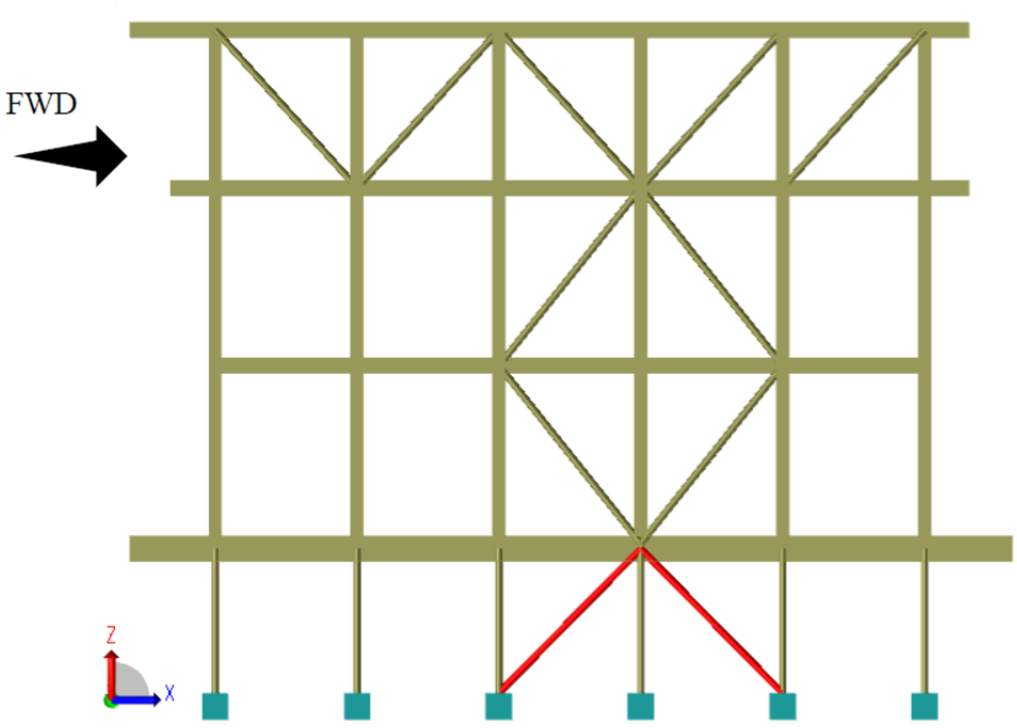


Figure 10.7 – Not recommended orientation for the braces in “xz” plane (red marked)

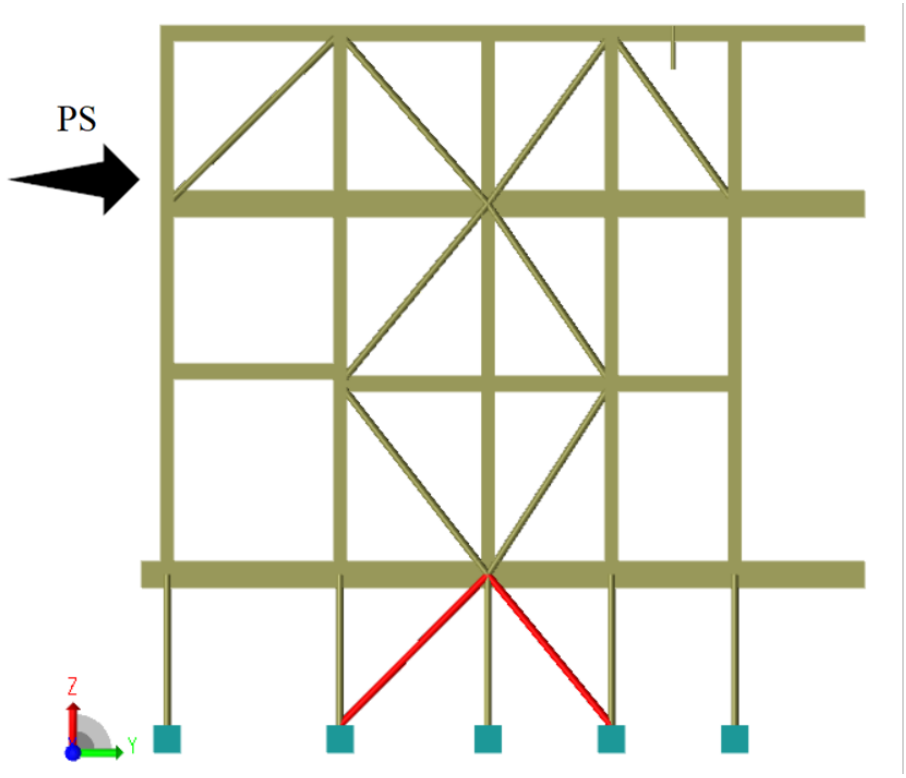


Figure 10.8 – Recommended orientation for the brace in “yz” plane (red marked)

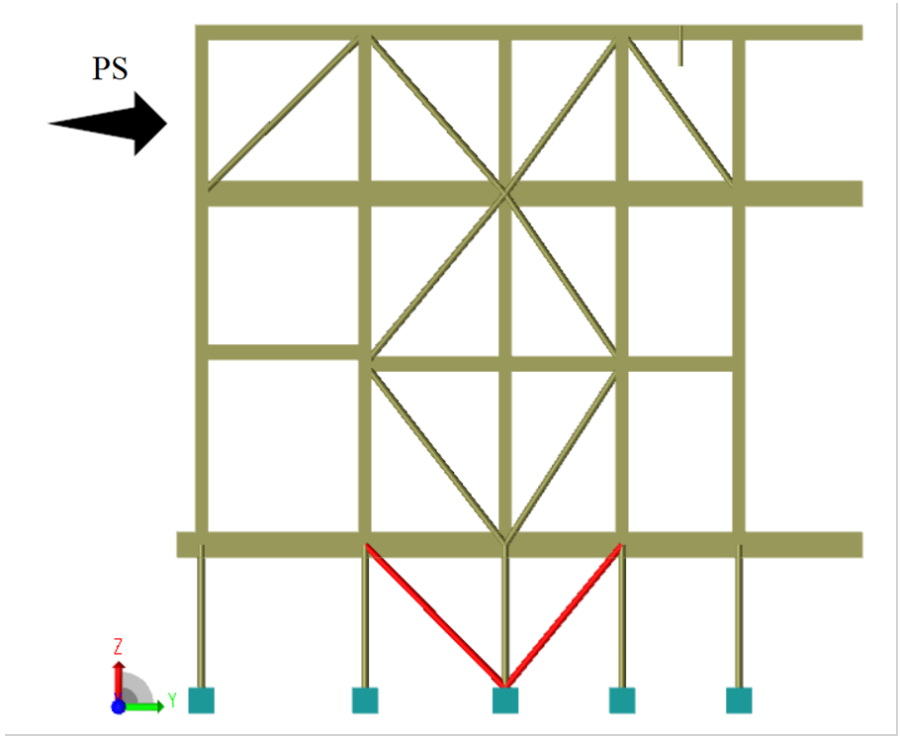


Figure 10.9 – Not recommended orientation for the braces in “yz” plane (red marked)

For module support columns mentioned above, the following boundary conditions shall be applied to the FEM model.

- All supports are restrained for translation in X, Y and Z direction.
- All elements braced with gusset plates shall have gusset in-plane rotations restrained and gusset out-of-plane rotations released.

If SELLER performs any modification in support columns connection details presented in [2] at detailing phase, or if required by CS, boundary condition used shall be justified considering the effect of out-of-plane stiffness for yielding, buckling and fatigue, and shall be submitted for Petrobras approval.

Stress concentration factors and other local effects are evaluated by means of plates and bi-dimensional FEM elements.

The stairs shall be supported in the module structure. Only the lower ends of the stairs beams shall be supported on the main deck structure with sliding teflon plate.

The flare tip and the flare headers for gas flow may be modelled as beam elements not for structural verifications but for the correct transference of loads from the piping lines to the flare tower structure.

Additional auxiliary structures for equipment support and electrical equipment room as well as walkway for maintenance and access shall be included in the structural model of Power Generation modules (M-12, M-13 and M-13B).

The CO_2 Removal package (M-04), Sulphate Removal package (M-11), Power Generation (M-12, M-13 and M-13B) packages and any other package structures shall be included in the modules structural models, including all packages loads as dead weight, live loads, equipment weight, inertial loads and wind loads. Structural verification of modules shall be performed using this complete model.

For analysis of gusset plates between pancake and hull main deck, FEM models with shell type elements, including an appropriate hull region (main deck and foundations) or pancake region, shall be executed. Mesh size shall be of the order of plate thickness at peak stress locations for hot spot stress derivation in fatigue analysis. For yielding and

buckling verification, mesh size shall not be greater than 50 mm at these locations, with limiting stresses according to CS rules. The gusset plates shall be verified for all in place load combinations.

Process pipe rack shall be included in the starboard modules structure and its loads, including dead weights, live loads, environmental loads, piping weights, miscellaneous and hull deflections. Module structure verification shall be performed using this complete model.

10.3 LOAD MODELING

All equipment shall be represented in the structural model considering the dimensions and Center of Gravity (CoG) position indicated on the Weight Control Report. The footprint indicated by the manufacturer shall be reproduced in the structural model to ensure the correct load transfer.

The gross dead weight of modeled structure shall be generated directly from the structural analysis software. The gross dead weight of not modeled secondary and tertiary structure (such as secondary beams, gratings, ladders, stairs, handrails, walkways, maintenance platforms and equipment support) shall be input as uniformly distributed or concentrated loads. All gross weights shall be taken from the latest revision of the Weight Control Report.

For the structural design of trolley handling way, a dynamic amplification factor (DAF) of 10% of (trolley capacity or handled load + self weight) shall be applied on structural model in vertical direction. The maximum permissible load pressure due to deck trolley, as well as the deck trolley footprint and the moving load type, shall be obtained from reference TOPSIDE'S MECHANICAL HANDLING PROCEDURES [13]. The value presented in reference [13] already includes the DAF and the load factor due to centre of gravity inaccuracy (CoG), where the CoG load factor for deck trolley of 5ton and 10ton capacity is equal to 10%, while 15% for deck trolley of 40ton.

For monorail support structure design, a dynamic amplification factor of 25% of monorail capacity shall be applied on vertical direction. In horizontal (longitudinal and transversal) directions a load of 10% of (monorail weight plus lifting capacity) shall be applied.

For reaction load at boom rest structure, the information provided by crane manufacturer shall be considered.

Live load on deck area shall be applied in accordance with the Table 10.1 or with CS requirements, the most restrictive requirements shall be applied. The Table 10.1 shall be considered as BUYER minimum requirements:

Table 10.1 - Functional Loads on Deck Area

VARIABLE FUNCTIONAL LOADS ON DECK AREAS OF TOPSIDE STRUCTURES				
AREA	Local Design (note 1)		Primary Design (note 2)	Global Design (note 3)
	Distributed load kN/m²	Point Load kN (note 4)	Distributed Load kN/m²	Distributed Load kN/m²
Storage	q = max(γ x H; 13)	1.5q	q	q
Lay-down	40	40	30	30
Free area between equipment (note 5)	5	5	5	may be ignored
Walkways, staircases and platforms	4	4	4	may be ignored
Walkways and staircases for inspection only and escape routes	3	3	3	may be ignored
Storage room and workshop	15	15	15	15
Maintenance areas (note 5)	15	15	15	15
Roofs (note 6)	2.5	2.5	2.5	may be ignored

γ = specific weight of storage material; H= storage height; q = max (γ.H; 13)

(1) Local Design is used in the local analysis of plates, gratings and support beams of secondary structure. Inertial loads shall be disregarded in local analysis.

(2) Primary Design is used in the structural design of the primary and secondary structures. Primary structures are defined as the main structural elements of topsides that ensure the strucutral integrity, such as: beams, columns, braces, structural joints and bulkheads. Secondary structures are defined as structural elements that in an eventual failure do not affect the structural integrity, and are defined as: stiffened deck plates, elements to bear the floor gratings, special piping supports, bumpers and bulkheads that are not applied in topsides global resistance;

(3) Global Design is used in the structural design of topsides foundations. Global design condition shall be disregarded for the structural design of the topside foundation with design concept in multi-column supports;

(4) Point loads shall be applied on an area 100 x 100 mm, and at the most severe position, but not added to wheel loads (from cargo handling equipment) or distributed loads. For laydown area with wooden deck, the point loads shall be applied on an area 220 x 220mm. For floor grating (steel or pultruded material), the point loads shall be applied on an area 150 x 150mm;

(5) The variable functional loads shall not be applied at free area between equipment and maintenance areas for the DEC, Damage and Fatigue Conditions. For free area definition see Figure 10.10 below;

(6) For roofs with no access, 2.5kN/m² shall be applied. For roofs with access, the free area value shall be applied.

The bumper structure in laydown areas shall be designed for a combined vertical and horizontal impact load equal to 2% and 20% of the maximum crane capacity, respectively.

The primary structure which the bumper is directly attached shall be designed according to the impact loads prescribed in DNV ST N001 [33], considering the bumper vertical cow-horn type.

For both cases, no increase in allowable stresses is permitted.

All lay-down areas, on main deck and topsides, shall have their total (primary structure) and local distributed functional load capacities marked at visible locations of the handrails or bumpers (between 1.10 m and 1.50 m from floor), at all the entrances (minimum 2 (two)), inside and outside, according to the values of the Table 10.1.

Trolley's handling ways capacity shall be properly indicated by means of floor painting or any other clear indication approved by BUYER.

A Load Plan shall be issued providing information on loading capacity of all areas presented in Table 10.1. The drawings for the different structural levels, with the respective indication of limiting load, shall be included in the Load Plan.

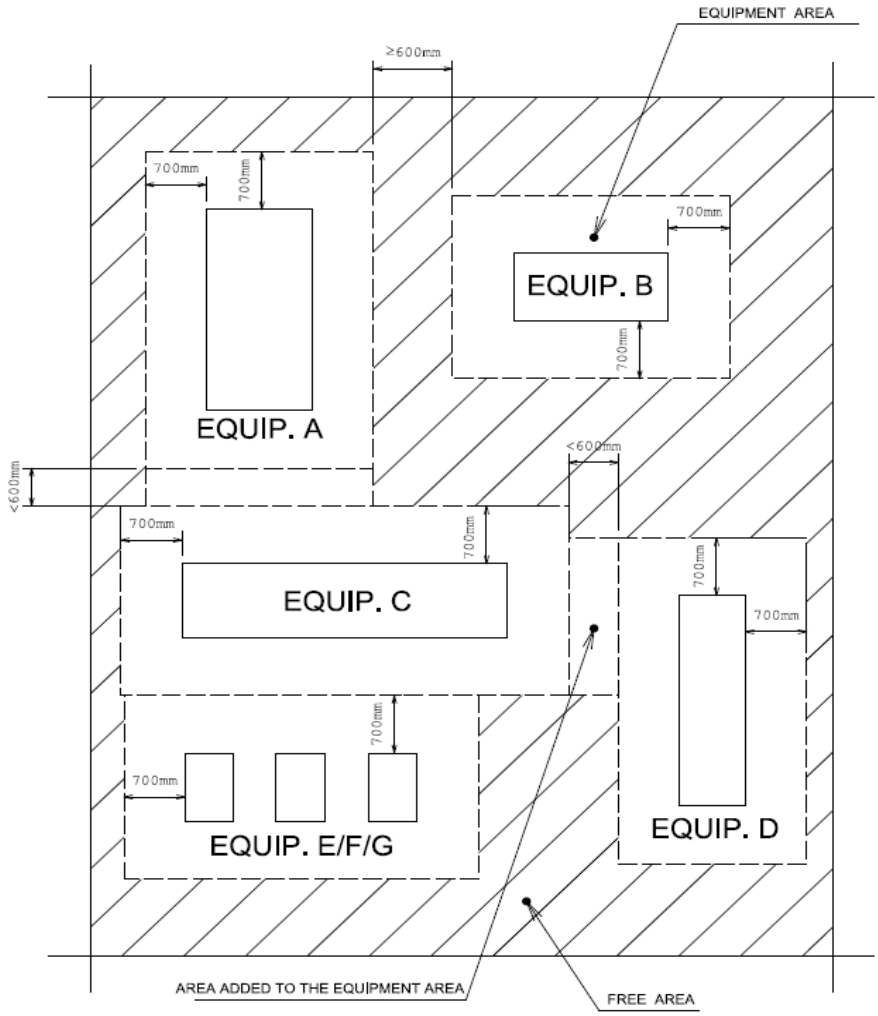


Figure 10.10 – Free Area

Wind and vessel motions directions shall be combined to produce the most unfavourable stresses and support reactions for those parts of the structures being designed. The structures and equipment areas shall be considered as area of obstruction for the wind loads.

Hull deflections shall be properly considered at structural analyses of modules supported by columns in order to obtain the effect of relative support displacement at columns bases as well as correct relative displacement between support points of piping at adjacent modules or modules/pipe rack.

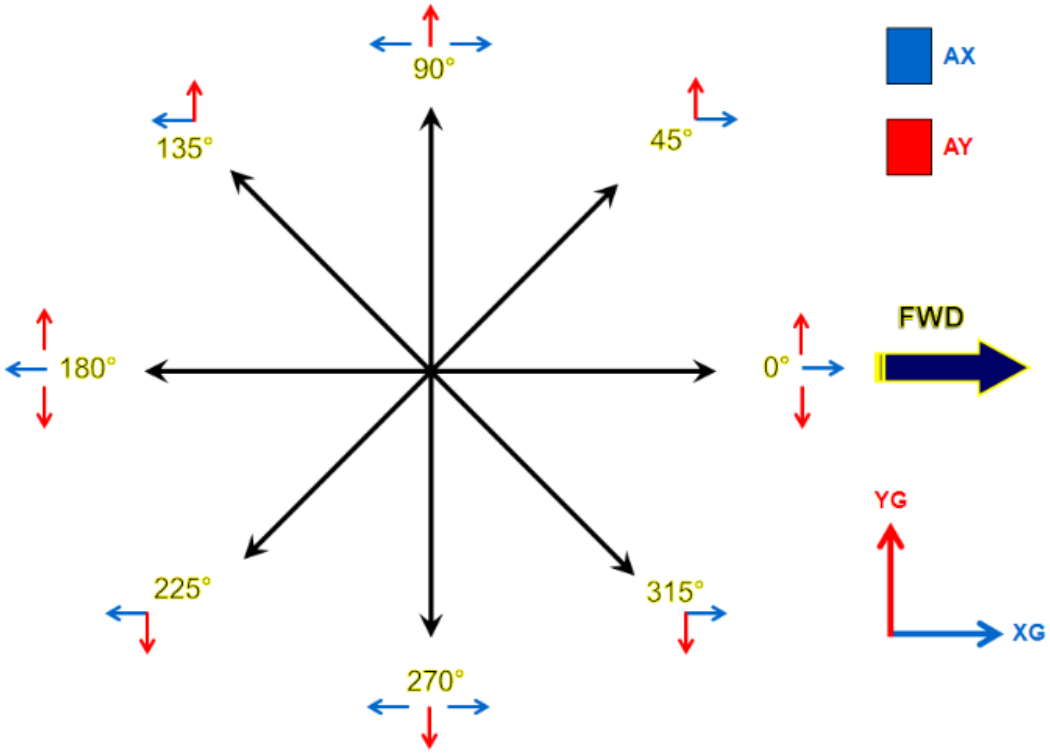
Structural analyses of other structures connected to the hull main deck shall include hull deflections effect according to SELLER Hull Global Deflections Calculations.

The acceleration indicated in the MOTION ANALYSIS [17] is a basic design information.

Inertial loads, due to ship motion, shall be calculated according to the following procedure and with the accelerations extracted from the motion analysis report to be issued in the detailing phase.

- For head seas conditions maximum longitudinal accelerations shall be used with associated transversal and maximum vertical accelerations;
- For beam seas conditions maximum transversal accelerations shall be used with associated longitudinal and maximum vertical accelerations;
- For oblique conditions, longitudinal accelerations shall be taken as the maximum longitudinal acceleration * 0.707, transversal acceleration shall be taken as the maximum transversal acceleration * 0.707. Maximum vertical acceleration shall be used.

The following eight directions, as indicated in Figure 10.11, shall be adopted: 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°. Directions 0° and 180° shall be associated with head sea accelerations, 90° and 270° directions with beam sea accelerations, the remaining directions with quartering seas accelerations.



0° ➡ $a_{X,max} + a_{Y,Corresp.} + a_{Z,max}$
$a_{X,max} - a_{Y,Corresp.} + a_{Z,max}$

45° ➡ $a_{R,max} + a_{Z,max} = a_{X,max} \times \cos\frac{\pi}{4} + a_{Y,max} \times \cos\frac{\pi}{4} + a_{Z,max}$

90° ➡ $a_{X,Corresp.} + a_{Y,Max} + a_{Z,max}$
$-a_{X,Corresp.} + a_{Y,Max} + a_{Z,max}$

135° ➡ $a_{R,max} + a_{Z,max} = -a_{X,max} \times \cos\frac{\pi}{4} + a_{Y,max} \times \cos\frac{\pi}{4} + a_{Z,max}$

180° ➡ $-a_{X,max} + a_{Y,Corresp.} + a_{Z,max}$
$-a_{X,max} - a_{Y,Corresp.} + a_{Z,max}$

225° ➡ $a_{R,max} + a_{Z,max} = -a_{X,max} \times \cos\frac{\pi}{4} - a_{Y,max} \times \cos\frac{\pi}{4} + a_{Z,max}$

270° ➡ $a_{X,Corresp.} - a_{Y,Max} + a_{Z,max}$
$-a_{X,Corresp.} - a_{Y,Max} + a_{Z,max}$

315° ➡ $a_{R,max} + a_{Z,max} = a_{X,max} \times \cos\frac{\pi}{4} - a_{Y,max} \times \cos\frac{\pi}{4} + a_{Z,max}$

Figure 10.11 – Directions of incidence for Inertial Loads

10.4 IN-PLACE ANALYSIS

The in-place analysis shall include the following design conditions:

10.4.1 STATIC OPERATIONAL CONDITION (SOC)

Just dead weights in operation (structural, equipment, piping, electrical, instrumentation, safety and others), live loads and hull deflections (still water) shall be considered. Wind and wave loads shall not be considered.

This condition shall be used for monorails and trolley loads verification.

No increase in allowable stresses is permitted.

10.4.2 DESIGN OPERATION CONDITION (DOC)

The Design Operation Condition (DOC) refers to the structure under 1-year return period motions accelerations and wind. Operational dead weights (structural, equipment, electrical, instrumentation safety and others), live loads and piping loads, hull deflections, wind pressures and accelerations due to vessel motion shall be considered.

No increase in allowable stresses is permitted.

10.4.3 DESIGN EXTREME CONDITION (DEC)

The Design Extreme Condition (DEC) refers to structure under 100-year return period motions accelerations and wind. Operational dead weights (structural, equipment, electrical, instrumentation safety and others), live loads and piping loads, hull deflections, wind pressures and accelerations due to vessel motion shall be considered.

Use of one-third increase in allowable stresses is permitted.

10.4.4 DESIGN SERVICEABILITY CONDITION (DSC)

This condition shall be used to verify the deflections of the structure. Dead weights in operation, live loads, with DOC wind and DOC wave loads shall be considered.

No increase in allowable stresses is permitted.

10.4.5 BLAST ACCIDENTAL CONDITION (BAC)

Based on topside overpressure design results obtained in the Explosion Study, the topside structure shall be assessed according to GUIDELINES FOR STRUCTURAL DESIGN AGAINST BLAST LOADS [7].

Use of two-third increase in allowable stresses is permitted.

10.4.6 DROPPED OBJECT CONDITION

Dropped object verification shall be carried out according to GUIDELINE FOR DROPPED OBJECT STRUCTURE ANALYSIS [12].

10.4.7 VORTEX SHEDDING

This analysis aims to verify vortex shedding effects caused by the wind in the structure. To avoid resonance due to vortex shedding, the structural tubular of topsides modules and flare tower members shall be verified using the procedures presented in DNV RP C205 [32].

Vortex Induced Vibrations (VIV) under frequent fatigue conditions shall also be verified and avoided.

No increase in allowable stresses is permitted.

10.4.8 DAMAGE CONDITION (DAC)

This condition refers to the structure verification for an accidental even. Damage condition shall be verified using the procedures presented in ABS – FPI [18]. The structural design for damage condition shall be performed for the following scenarios:

(1) Unintended flooding shall be based on the deepest equilibrium waterline in damaged condition obtained from damage Preliminary Trim and Stability Booklet. Damages angles indicated below were used during basic design. The structural design shall be calculated according to the heel and trim angles report to be issued in the detailing phase, associated with 1 year motions and accelerations.

- Heel: 15.799°
- Trim: 1.184°

(2) Static cases (environmental loads shall be disregarded) according to MODU CODE [36]:

- Static Heel Angle: 22.5°
- Static Trim Angle: 10.0°

For static cases Heel and Trim angle shall be applied separately, i.e., two different loading conditions shall be considered, one for the heel angle and another for the trim angle.

Use of one-third increase in allowable stresses is permitted for unintended flooding.

Use of two-third increase in allowable stresses is permitted for static cases.

10.4.9 UPLIFT CONDITION (ULC)

Uplift condition is used to obtain minimum reactions (possible occurrence of tension force) at columns bases.

This condition refers to the structure under 100-year return period motions accelerations and wind. Only structural dead weights, equipment operational weight, piping operational weight and electrical, instrumentation and safety weights shall be considered during this condition.

No live loads shall be considered.

10.4.10 HYDROTEST CONDITION (HTC)

All structures, in the region of interest, shall be verified for Hydrotest Condition (HTC) before being lifted, transported and installed onto the FPSO and after installation, during platform operation. Only structural dead weights, equipment test weight, other equipment weight (dry and/or operational condition), piping test weight, other piping weight (dry and/or operational condition) and electrical and instrumentation weights shall be considered during this condition. No live loads nor environmental loads shall be considered. Each equipment shall be individually verified for HTC after being lifted and positioned in its final location.

No increase in allowable stresses is permitted.

10.4.11 GREEN WATER CONDITION

Green water verification shall be done according to the motion analysis report to be issued in the detailing phase and the GUIDELINE FOR FPSO GREEN WATER ANALYSIS [10]. A distributed hydrostatic pressure combined with all loads considered in Operation (DOC) and Extreme Condition (DEC), if during the detailing phase confirm the occurrence on these conditions. Otherwise, this analysis for one or both conditions can be disregarded.

Use of one third increase in allowable stress is permitted.

10.4.12 FATIGUE CONDITION (FTC)

For the simplified fatigue approach, the maximum double amplitude dynamic loads for fatigue condition are determined with 100-year return period motions and accelerations and no wind, to be associated with proper long term response Weibull distribution parameters. Operational dead weights (structural, equipment, electrical, instrumentation safety and others), live loads according to item 10.3, piping loads, hull deflections (only wave hull-girder bending moment) and accelerations due to vessel motion (without the gravity effects in Z direction) shall be considered.

The Weibull shape parameter considered for elements above pancake level may be taken equal to 0.70, as well as the number of cycles equal to 9.38×10^7. If another Weibull shape parameter or number of cycles are used in the detailing phase, or if required by CS, this new value shall be justified and submitted to Petrobras approval.

- **MODULES STRUCTURES / PIPE RACK**

For modules/pipe rack and main deck structures, fatigue analysis shall be performed. The simplified approach may be used as presented in DNV RP C203 [31], considering a 30 years design life.

If any reinforcement is required based on simplified fatigue analysis, a full stochastic analysis shall be performed in order to avoid local fatigue reinforcements.

In the specific case of PIG Launchers / Receivers and Production & Injection Manifolds module M-09, a full stochastic fatigue analysis shall be performed.

For the simplified analysis, loading and stress variation shall be obtained from in-place analysis. S-N curves and Stress Concentration Factors (SCF) shall be assumed based on DNV RP C203 [31] recommendation.

The Weibull shape parameter *h* may be obtained from CS rules or based on a specific calibration submitted to BUYER and CS approval.

Target fatigue life shall be in accordance with the next table.

Table 10.2 - Target Fatigue Life

Structural Components	Safety Factor	Target Fatigue Life (years)
Secondary Structure Joints	1.0	30
Primary Structure Joints	2.0	60
Module / Hull Connections	2.0	60
Module/ Hull Connections Non-Inspectable Parts	10.0	300

For structural joints where passive fire protection (PFP) is necessary, intumescent paint shall be applied as a PFP coating to avoid module/hull connections non-inspectable parts.

- **FLARE TOWER STRUCTURE**

For flare tower the fatigue life of the main structure shall be determined using a Spectral Fatigue Analysis approach.

The same 30 years design life shall be considered with safety factor according to Table 10.2 above.

Flare tower fatigue analysis shall consider the damage due to wind gustiness and the damage due to vessel motions. Total fatigue life shall be determined by their combination according to DNV RP C203 [31].

10.5 INSTALLATION ANALYSIS

This section describes the installation design analyses to be performed during the Detailing Phase.

Installation analysis shall include the following design conditions:

10.5.1 LIFTING CONDITION (LIC)

Lifting analysis shall be according to DNV ST N001 [33].

The structural model CoG shall be monitored and aligned with the project Weight Control Report. During the Detailing Phase, acceptable limits of deviations shall be defined, above which actions deemed necessary shall be taken.

Design of temporary guides and bumpers, or auxiliary structures to make the lifting procedure feasible for module or flare tower installation, shall be according to DNV ST N001 [33] in detailing phase. Modules columns and other members chosen to support guides and bumpers shall be temporarily braced accordingly.

If the module weight, measure after the weighing, is greater than the sum of loads applied on the lifting analysis, including weight contingency factor, the analysis shall be updated in order to check the structural adequacy for new loading scenario. Otherwise, no analysis update shall be done. The same procedure shall be considered for CoG position. In any case, the weighing report shall be attached to the lifting design report. The lifting design report will be only considered approved after the module weighing.

The factor of Centre of Gravity Inaccuracy (CoGI) may be taken as 1.10. If SELLER adopt any different factor than 1.10, or if required by CS, this new CoGI factor shall be justified and shall be submitted for Petrobras approval.

The modules and flare tower lifting analyses in the Basic Design considered the use of:

i) one hook;

ii) a single crane;

iii) four vertical cables (except flare tower);

iv) spreader bars (except flare tower);

v) inshore condition;

No horizontal and in-plane loads are applied to the referred structures.

If any different condition for the lifting of modules and flare tower is adopted the SELLER is responsible for all structural adjustments required.

No increase in allowable stresses is permitted.

10.5.2 DESIGN TRANSIT CONDITIONS (DTC)

For topsides structures, design transit condition shall be verified for two different phases:

- Transport from the construction site to the shipyard on a transport barge (DTC 1);
- Transit of the FPSO from the shipyard to the installation site, with all structures installed onto (DTC 2).

If it is necessary to include sea fastening elements for (DTC 1) phase, in order to reproduce the real condition, SELLER shall analyze the structure in two steps. The 1st step only with module self-weight and without sea fastening elements. The 2nd step, only with environmental loads (wind pressures and accelerations due to transport barge motion), including the sea fastening elements in this analysis.

Use of one-third increase in allowable stresses is permitted.

For Design Transit Conditions (DTC 2) fatigue damage shall be accounted for.

10.5.3 LOAD OUT CONDITION (LOC)

To cover the load out operation, the maximum expected vertical deflection of one support of the module shall be considered combined with the dry dead weights (structural, equipment, piping, electrical, instrumentation, safety and others).

The value defined above is the maximum allowed misalignment between the barge and shore skid ways, and shall be confirmed by SELLER based on the load out procedure to be developed during the Detailing Phase, according to recommendations from CS.

No increase in allowable stresses is permitted.

10.5.4 SET DOWN (Modules Assembly on Hull)

10.5.4.1 STATIC DRY CONDITION (SDC)

Just dead dry weights (structural, equipment, piping, electrical, instrumentation, safety and others) and hull deflection (still water) shall be considered.

Live loads, wind and wave loads shall not be considered.

This condition shall be used to assess the contact between the pancake beams and the top of the columns, during lifting operation. If the traction on the supports is verified, the SELLER shall adopt a structural solution to prevent this situation.

No increase in allowable stresses is permitted.

10.5.4.2 PREMISES TO BE ADOPTED DURING THE LIFTING CAMPAIGN

The structural analysis assumes that all support points to main module beams (top of columns and diagonals) are levelled to a level of tolerance such that the main module beams are expected to touch all those points at set down operation. If, during the integration phase, the SELLER verifies that this condition will not be completely reached, additional structural analyses shall be carried out to evaluate the effects of settlement on members of the structure and possible solutions.

In order to minimize reinforcements during the integration phase, the unity check in any of the multicolumns and diagonals shall be limited to 0.85 for in-place analysis (see item 10.4). If a different limit is proposed, it shall be submitted to BUYER approval.

SELLER shall provide special devices and installation procedures in order to mitigate misalignments and mismatch effects between module structures and multicolumns.

The construction tolerances for the support points of the topsides structures are defined in GENERAL NOTES FOR TOPSIDES STRUCTURES [1].

11 ACCEPTANCE CRITERIA

11.1 GENERAL

The structures are designed such that all the structural members shall comply with the permissible allowable stresses as specified by AISC 335 - 89 [21] and API RP 2A - WSD [22].

11.2 PLATES, BRACKETS AND STIFFENED PANELS BUCKLING

Plates, brackets and stiffened panels shall be checked for buckling in accordance with DNV CG 0128 [27].

11.3 PADEYES

The following allowable stresses shall be used for the design of padeyes in accordance with DNV-ST-N001 [33].

Tension/Compression	0.60 Fy
In-Plane Bending	0.66 Fy
Out of Plane Bending	0.75 Fy (for stiffened padeye; for simple padeye 0.66 Fy)
Shear	0.40 Fy
Bearing	0.90 Fy

In addition, design factors are applied according to AISC 335 - 89 [21] recommendation.

11.4 STRUCTURE MAXIMUM DEFLECTIONS CRITERIA

11.4.1 VERTICAL DEFLECTIONS

Girder deflection shall be limited to L/360 for primary structure, L/250 for secondary structure and 2L/360 for cantilever beam, where L is the girder or cantilever length, according to AISC 335 - 89 [21].

For monorails, the vertical deflection shall be limited to L/500 between its supports and L/250 for cantilever beam, where L is the monorail span, according to BSI [26].

Floor plate deflections shall comply with ISO 19901-3 [35].

11.4.2 HORIZONTAL DEFLECTIONS

Horizontal deflections shall be verified in according with ISO 19901-3 [35].

For module columns, horizontal deflections shall be limited to 0.3% of the height between floors.

For multi-floors modules, the total horizontal deflection shall not exceed 0.2% of the total height of the topsides structure.

OBS: If horizontal deflection criterion is not complied with, structures designer shall verify with other disciplines (e.g.: piping and mechanical) if the deflections are acceptable.

12 GENERATION OF MODULES REACTIONS AT HULL DECK

SELLER shall attach a table at the respective module design report, containing all the reaction forces (in global coordinate system) for all loading combinations in the point P_0, according to

Figure 12.1. In addition, at the results item of design report, summary tables shall be presented with the envelope of maximum support reactions for Fx, Fy, Fz, Mx, My and Mz,

taking into account the concomitant support reactions, for each design condition according to item 10.4. The Figure 12.2 shows an example of the summary table.

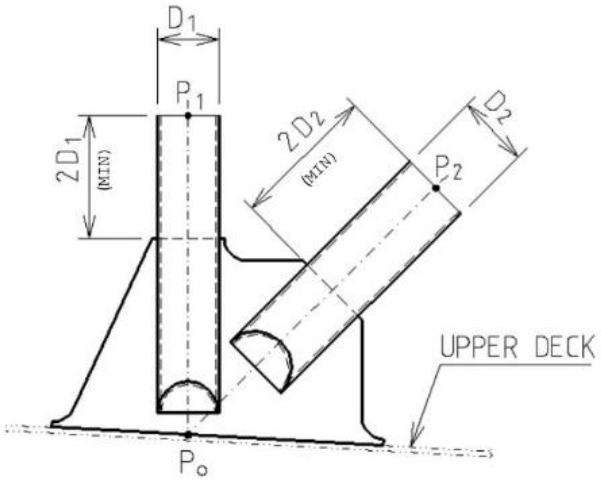


Figure 12.1 – Typical Section

MAXIMUM DEC REACTIONS								
MAXIMUM	SUPPORT	LOAD	F_X [kN]	F_Y [kN]	F_Z [kN]	M_X [kN*m]	M_Y [kN*m]	M_Z [kN*m]
F_X	A	100	- 773	2	1 809	- 10	- 37	0
F_Y	B	101	3	1 475	3 380	- 29	- 6	- 6
$F_{Z,MAX}$	C	102	- 491	15	4 086	- 38	- 27	1
M_X	D	103	- 23	40	661	- 93	0	2
M_Y	E	104	720	- 8	661	18	54	- 1
M_Z	F	105	7	- 731	840	65	- 7	- 9
$F_{Z,MIN}$	G	106	12	- 8	- 977	34	0	2

Figure 12.2 – Summary table for each design condition

For yielding, buckling and fatigue analysis of the hull foundation of modules and flare tower, SELLER shall attach a table, in respective module or flare design report, containing the member forces Fx, Fy, Fz, Mx, My, and Mz (in global coordinate system) at the points P_1 and P_2 according to

Figure 12.1 for all in-place load combinations.

13 EQUIPMENT FOUNDATIONS

Besides normal verification, all equipment support shall be verified for the maximum heeling and trim, as well as the extreme loading, according to the motion analysis report to be issued in the detailing phase and the values defined in the CS Rules.

Functional loads, test loads, equipment vibrations and environmental loads shall be taken into account. If an equipment vibration frequency is close to a natural frequency of the structure, a dynamic analysis shall be performed, considering the contribution from Anti-Vibration Mountings (AVM).

It is SELLER responsibility to supply and install any wedge or plate needed to level the equipment skids that will be installed directly over the hull and modules decks.

14 FLARE TOWER

These structures, including the necessary supports and hull structural reinforcements, shall be evaluated for all design conditions, including the Unit's transit from the shipyard to installation site.

The structural analysis shall consider the Unit's motions, accelerations and wind loads.

For flare tower, the horizontal lifting and the upending shall be considered. The entire flare tower, including empty equipment and piping, shall be lifted from the quayside or transport barge and installed onto Units by means of an inshore lift by the top of Flare Tower (lifting padeyes at the top of structure). If SELLER performs any modification in this lifting analysis philosophy in the detailing phase, it is SELLER's scope of work to make all necessary adjustments to the structural elements to ensure that the Flare Tower withstands the imposed loads by the new design lifting condition.

SELLER shall provide and supply any additional auxiliary and temporary structure, outfitting and access required for the lifting installation and integration of Flare Tower. After lifting campaign, the additional auxiliary and temporary structure applied only for lifting operation shall be removed.

For the flare tower structures, the structural analysis shall also consider thermal loads.

Temperature gradients along flare tower length shall be taken from a Flare Radiation Report, to be issued during the detailing phase, in order to confirm the dimensions of the heat shield.

No live loads shall be considered in the flare tower structural analysis.

15 PIPING SUPPORTS

Piping supports shall be designed according to static and dynamic loads provided by the piping discipline at the Detailing Phase.

SELLER shall perform the structural analysis according to the steps shown below.

1. The structural analysis of primary structure shall be performed with the piping loads (including inertial loads), obtained from Weight Control Report, applied as loads distributed along the topsides module structure levels. Piping supports and flexible piping loading shall be disregarded;

2. Applying the numerical model used in the primary global analysis, piping supports and their structural foundation shall be added, designed and detailed considering the flexible piping loadings (thermal, inertial and static loadings), where the loads from the static loadings (piping stress loadings) shall be deducted from de loads indicated in step #1 (primary global analysis). In this case, after all deduction, the loadings of step #1 shall remain equal to values presented in Weight Control Report;

3. Only piping supports with loading greater than 50 kN shall be take into account in the numerical model;

4. The module primary structure also shall be assessed by the numerical model presented in step #2;

5. In the step #2, only the stiffness of the secondary structure which the piping support is directly attached may be considered in the strength analysis. If any other secondary structure is applied in the numerical model, these structural elements shall be considered as primary structure;

6. Flexible piping loading shall be in accordance with the environment condition applied in the structural analysis, e.g., DOC, DEC etc;

7. Flexible piping loads may be disregarded for damage and fatigue conditions;

8. Loading combinations regarding to water hammer effect and friction loads shall be foreseen in the structural design of piping supports only;

9. It is recommended that the piping loads components that rules the design, be aligned according to the environmental load condition (head sea, beam sea and quartering) used in the strength analysis.

16 DOCUMENTATION

Each design report issued by the SELLER shall contain at least the following items, but not restricted to:

- Strength Analysis (In-Place and Transit):
  - Documents used as reference (rules and design documents);
  - Design criteria;
  - Material properties;
  - Boundary conditions and member releases;
  - Geometric properties of elements;
  - Basic load (Description and applied value);
  - Load combination;
  - Load case and load combination summary;
  - Summary of reactions (forces and moments);
  - Maximum and allowable deflection (vertical and horizontal);
  - Members code-check list and pictures;
  - Gussets and main connections design;
  - The complete structural model with loadings and load combinations (electronic file) shall be attached to the design report;
  - Sea-fastening design (only for transportation analysis);
  - Design spreadsheets and computational tools adopted in the structural analysis, such as: data importation/exportation tools or data manipulation tools not commercially available.

- Fatigue Analysis:
  - General description;
  - Fatigue loads and combinations;
  - Fatigue curves defined for the analysis;
  - SCFs adopted from literature or calculation;
  - Stress range and damage calculation;
  - Results;

- The complete structural model with loadings and load combinations (electronic file) shall be attached to the design report;
- Design spreadsheets and computational tools adopted in the structural analysis, such as: data importation/exportation tools or data manipulation tools not commercially available.

- Lifting Analysis:
  - Design criteria;
  - Lifting factors;
  - Boundary conditions and member releases;
  - Weighting report;
  - Sling reactions;
  - Members code-check and pictures;
  - Padeye and attachments design;
  - The complete structural model with loadings and load combinations (electronic file) shall be attached to the design report;
  - Design spreadsheets and computational tools adopted in the structural analysis, such as: data importation/exportation tools or data manipulation tools not commercially available.

BUYER can ask for other items that judges necessary.