

GENERAL SPECIFICATION

SUBSEA SYSTEMS

GS EP SPS 038

Subsea Structures design & fabrication

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1. Scope

This document defines the technical design, material and fabrication requirements for all subsea steel structures and subsea structural components designated as non-pressure containing structures.

This document shall apply to subsea structure weighing less than 400 t in air.

The content of this document is applicable to the following equipments/systems (in line with **GS EP SPS 002** applicable scope) and their associated foundations and protection structures:

- Production and injection manifolds
- Pipeline end manifolds (PLEM)
- Pipeline/flow line end terminations (PLET/FLET)
- T (ILT)- and Y-connection
- Subsea isolation valve (SSIV)
- Subsea controls and distribution structures (SDU, UTA)
- Subsea Process (SSP) stations (e.g. compression, separation, pumping, chemical injection / storage, water treatment, electrical power distribution)
- PGB
- FCM
- HIPPS
- XT support structure
- Subsea Pig Launcher/Receiver (SPLR)
- Spreader beams and/or frames
- Sea fastening including grillages.

Structural design of skirted foundations and suction anchors shall refer to **GS EP STR 433**.

Note: The flow line riser bases and export riser bases (FRB, ERB) components and their applications as well as driven piles are outside of the scope of this document.

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2. Reference documents

This document shall be read in conjunction with **GS EP SPS 002**.

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published at the effective date of this document.

Reference	Title
AISC Manual of Steel Construction	Allowable Stress Design, 9th Edition
API RP 17A	Design and Operation of Subsea Production Systems - General Requirements and Recommendations
API RP 17P	Design and Operation of Subsea Production Systems - Subsea Structures and Manifolds
API RP 2A-WSD	Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design
API SPEC 17D	Design and Operation of Subsea Production Systems - Subsea Wellhead and Tree Equipment
ASME BPVC Section IX	Welding, Brazing, and Fusing Qualifications
AWS D1.1/D1.1M	Structural Welding Code - Steel
DNV-OS-H205	Lifting Operations (VMO Standard - Part 2-5)
DNV-RP-C204	Design against accidental loads
DNV-RP-C205	Environmental conditions and Environmental loads
DNV-RP-C208	Determination of Structural Capacity by Non-Linear FE analysis methods
DNV-RP-F107	Risk assessment of pipeline protection
DNV-RP-H103	Modelling and Analysis of Marine Operations
EN 10025-2	Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels
EN 10160	Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)
EN 10164	Steel products with improved deformation properties perpendicular to the surface of the product - Technical delivery conditions
EN 10210 (All Parts)	Hot finished structural hollow sections of non-alloy and fine grain steels - All Parts
EN 1993-1-8	Eurocode 3: Design of Steel Structures Part 1-8 Design of joints

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Reference	Title
EN 287-1	Qualification test of welders - Fusion welding - Part 1: Steels
IMO A.714	Code of Safe Practice for Cargo Stowage and Securing
ISO 10474	Metallic products - Inspection documents
ISO 15614 (All Parts)	Specification and qualification of welding procedures for metallic materials - Welding procedure test – All Parts
ISO 19900	Petroleum and natural gas industries - General requirements for offshore structures
ISO 19901-4	Petroleum and natural gas industries - Specific requirements for offshore structures - Part 4: Geotechnical and foundation design considerations
ISO 19902	Petroleum and natural gas industries - Fixed steel offshore structures
ISO 4063	Welding and allied processes - Nomenclature of processes and reference numbers
ISO 9712	Non-destructive testing - Qualification and certification of NDT personnel

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published.

Reference	Title
GS EP FP 410	Subsea Wellhead and Guidance Systems
GS EP SPS 001	Subsea Production Systems General Design Requirements
GS EP SPS 002	Design of Subsea Stations
GS EP SPS 009	Corrosion Protection of Subsea Stations
GS EP STR 433	Structural design of skirted foundations and suction anchors

3. Terms, abbreviated terms and definitions

The chap 3.1 of [API RP 17P](#) shall apply with additional terms defined in [GS EP SPS 002](#).

In addition, the following abbreviations are used in the Specification:

BOP	Blow Out Preventer
COG	Centre Of Gravity
CP	Cathodic Protection

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DAF	Dynamic Amplification Factor
ESDV	Emergency Shut Down Valve
EDP	Emergency Disconnect Package
EFL	Electrical Flying Lead
ERB	Export Riser Base
FPSO	Floating Production Storage & Offloading
FCM	Flow Control Module
FEA	Finite Element Analysis
FRB	Flow line Riser Base
GS	General Specification
HCS/VCS	Horizontal/Vertical Connecting System
HISC	Hydrogen Induced Stress Cracking
HIPPS	High Integrity Pressure Protection System
H_s	Significant Wave Height
ID	Internal Diameter
ILI	In-Line Inspection
LOA	Length Overall
LRP	Lower Riser Package
MQC plate	Multi Quick Connectors plate
MPFM	Multi-Phase Flow Meter
MSL	Mean Sea Level
MSS	Manifold Support Structure
MWS	Marine Warranty Surveyor
ND	Nominal Diameter
OD	Outside Diameter
PLEM	Pipeline End Manifold / Module
PQR	Project Qualification Record
PPS	Project Particular Specification
QC	Quality Control
RHS	Rectangular Hollow Section
ROV	Remotely Operated Vehicle
ROT	Remotely Operated Tool
SCM	Subsea Control Module

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SKL	Skew load
SPLR	Subsea Pig Launcher/Receiver
SSIV	Subsea Safety Isolation Valve
SSP	Subsea Process
SWL	Safe Working Load
TEF	Tilt Effect Factor
T_p	Wave Period
WOROV	Work Class Remotely Operated Vehicle
WSD	Working Stress Design
XT	Xmas Tree
YEF	Yaw Effect Factor

4. Structural Design requirements

Shall be designed in conjunction with **GS EP SPS 002**.

4.1 Structural members classification

During design stage, Contractor shall define for each member its criticality in accordance with [API RP 2A-WSD](#) or [ISO 19900](#) or [ISO 19902](#). The resulting classes shall be identified in a design basis document and noted on General Arrangement drawings, both to be submitted to Company for approval.

Table 1 below provides typical examples of structural members classifications based on criticality.

Table 1 - Classification of structural members based on criticality

High criticality	Medium criticality	Low criticality
• All components subjected to concentrated stresses during lifting/lowering, such as pad eyes, yokes, etc. • Cheek plate • Structures submitted to high stress and/or fatigue –during pre-service and in service phases (i.e., construction, load out, transportation, installation, retrieval) • Spreader beams and/or frames • Lift point and their supporting members (Tube, plate, etc.) • Main longitudinal chord • Diagonal bracing highly loaded • All joints in connection of a high criticality member (based on design) • Structural members that are critical during pre-service and in service phases (i.e., construction, load out, transportation, installation, retrieval) • Main transverse member highly loaded • XT support structure	• Elements submitted to high stresses (dynamic loads among other stresses) • Skid beam support tubular • Short and/or cranked transverse members • Secondary longitudinal chord • Long stiffener (thk $\geq$ 15 mm) • Transverse skirt • Diagonal bracing • Gussets (thk $\geq$ 15 mm) welded on Medium criticality members • Main components (bracings...) • Main transverse member • Lift point stiffener • Centerline and/or secondary longitudinal chord • Secondary transverse member stiffener • Guide frame • Main valve protection (ex. A-frame, etc.) • Buoyancy yoke support • Valve and tubular support • Suction piles (remaining parts)	• Other structural members • Guides and bumpers of lifting aids • Valve protection and hydraulic clamp support • Stiffener, support and/or skids plate • Structures submitted to low stress and/or fatigue • Mudmat, including stiffeners and/or outriggers • Docking beam (support, receptacle, stiffener, etc.) • End cap • Yoke support

4.2 Structural Member design

Allowable stresses for structural strength and stability check of cylindrical members, shall be evaluated with [API RP 2A-WSD](#): Section 6.0 (Structural Steel Design) or [ISO 19902](#).

4.2.1 Design of non tubular members

The nominal strength equations to be used in the design of non-tubular structural shapes are found in the [AISC Manual of Steel Construction](#) 9th edition. The resistance factors given in this standard are used to reduce the allowable stresses.

4.2.2 Rectangular steel hollow section design

With the fabrication method that could be used for the RHS profiles thickness, small cracks can occur in the longitudinal weld. It is therefore specified that the tension stress transverse the weld must be limited to maximum 50% of the general design resistance:

$$\text{Allowable stress transverse tension in the weld} \leq 0.5 \times (355 \times 0.6) = 106 \text{ MPa}$$

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4.2.3 Allowable Stress on Weld check

Reference shall be made to [AISC Manual of Steel Construction](#) 9th edition Section J2 or [EN 1993-1-8](#) with the following additional requirements:

Full Penetration Welds

The strength of the weld shall be controlled by the strength of the base metal (plate); therefore there is no need to check the strength of the welds.

Partial Penetration Welds

Allowance strength of the welds shall be calculated in accordance with [AISC Manual of Steel Construction](#) 9th edition: Table J2.5. [EN 1993-1-8](#).

The minimum weld size shall conform to J2.3 accommodating the requirements given in [AISC Manual of Steel Construction](#) 9th edition: Table J2.1 [EN 1993-1-8](#).

Fillet Welds

Allowable stresses of the welds shall be calculated in accordance with of [AISC Manual of Steel Construction](#) 9th edition: Table J2.5 [EN 1993-1-8](#).

The minimum weld size shall conform to [AISC Manual of Steel Construction](#) 9th edition: Table J2.4 [EN 1993-1-8](#).

4.3 FEA assessment requirements

4.3.1 Error Analysis

Error analysis and verification should be provided in support of the results of the FEA.

4.3.1.1 Procedural Errors

Procedural errors concern errors in the modeling process. Some checks against procedural errors are required, such as proximity checks for joints and element sides/faces, model drawings with material properties associations, thickness distribution (for shells), true views of beam profiles, with eccentricities, mass/density distributions, etc. (see form 2 in Appendix 1).

Incorrectly supported or connected structures may be identified through displacements plots, or through plots of the first few dynamic modes.

Incorrect action models could be identified through several means, but the first checks are for accurate equilibrium force and moment resultants from support reactions.

4.3.1.2 Numerical Errors

Numerical errors are associated with mesh and element type, iterations, round-off and approximations in the software. Discussion of numerical errors should be provided, including full warning/error list as generated by the software during the analysis.

Most finite element software systems generally have several built in checks to identify poor modeling and analysis practices. A warning or an error message is issued when built in criteria are violated. The correct practice is to resolve any such messages and take the appropriate remedial action.

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If the warning/error message is not applicable to the analysis, proper justification should be provided.

4.3.2 Model Validation

Model validation is a required task of the FEA. Its implications should be considered from the onset of the analysis. Several techniques could be used to provide confidence in the mathematical and numerical models, and results thereof, as follows:

4.3.2.1 Alternative Modeling

Developing a significantly simplified model preferably at a lower idealization level (analytical or beams) to validate load paths and magnitude of resulting quantities.

4.3.2.2 Sensitivity Analysis

Sensitivity analysis both from idealization and numerical points of views could be provided in particular around singularities, for boundary conditions, etc.

4.3.2.3 Error Assessment

Report expected level of uncertainties in the analysis results. This is a difficult objective but some level of confidence could generally be drawn by synthesizing the results from error analysis in section 4.3.1, benchmark data from section 4.3.2.4, and alternative modeling and sensitivity analyses as defined above.

4.3.2.4 Benchmarks

Reference known models or modeling strategies with validated structural response to support adequacy of model idealization and assess error levels. Benchmarks in support of model validation may be required by Company.

4.3.2.5 State of the Art

Reference recommendations in Standards, Codes or Rules that are applicable directly to the studied system, or to a similar system with different dimensions.

4.3.2.6 Similarity

Reference similar analyses for system or subsystems that are validated from analytical or experimental sources.

4.3.2.7 Convergence & Filtering

Assess mesh quality for the intended purpose of the analysis. This includes discussion of convergence for stresses within each of primary, secondary and local classes.

4.3.3 Assessment criteria

Without relevant guidance for the structure or design conditions under consideration, minimum requirements are provided below.

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4.3.3.1 Design Basis

Here we consider both WSD and LRFD assessment formats for stress levels. In either formats, design should be performed for strength against all predictable operational and extreme events, and most accidental events. Additionally, slender parts of the structure under compressive forces should be checked for stability.

4.3.3.2 Actions

4.3.3.2.1 WSD Format

For WSD format, design configurations include Operating, Extreme and Accidental states. To each of these configurations corresponds a set of actions and of allowable values of the basic variables. In this format, actions are taken with their representative values and are combined according to their likelihood of simultaneous occurrence under the considered design condition.

4.3.3.2.2 LRFD Format

For LRFD format, design configurations are to be checked, as the case may be, against Serviceability, Ultimate and Accidental limit states. To each limit state corresponds sets of factored actions and of factored strength basic variables. In this format, actions are taken with their characteristic values obtained by factoring their representative values on the basis of statistical analysis of such actions *on similar structures in similar environments*. They are further combined according to their likelihood of simultaneous occurrence under the considered design conditions *on similar structures in similar environments*.

Use of LRFD format in the present context applies when the structure being analyzed is a non-standard component or part of a structure for which LRFD format has been developed in applicable Codes, Rules or Standard and such format is being applied to the whole structure.

4.3.3.2.3 Fatigue Actions

Actions relevant for fatigue are those with high cycle content across the structure's lifetime (thus excluding low cycle, high amplitude actions that are relevant to extreme design conditions). Fatigue prone actions are generally not factored and should be taken with their representative values.

4.3.3.3 Linear Analyses

Linear analyses, static or dynamic, provide stress and distortion values that are relevant in assessing the structure strength.

4.3.3.3.1 WSD allowable criteria

The Von-Mises stress (σ_{vm}) obtained from finite element analysis (extreme fiber) shall not exceed the allowable stress (σ_a) defined below:

$$\sigma_{vm} \leq \sigma_a$$

With:

$$\sigma_a = 1.1 \times \alpha \times R_f$$

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Where:

R_f = minimum (σ_y , $\sigma_u/1.2$)

σ_y = minimum specified yield stress of the material

σ_u = tensile strength of the material

α = basic allowable stress factor

With:

$\alpha = 0.6$ load out, transportation, lifting/lowering/installation, operation, retrievability

$\alpha = 0.6 \times 4/3 = 0.8$ extreme conditions (in operation/weather)

$\alpha = 0.6 \times 1.7 = 1.0$ accidental & damaged conditions

4.3.3.4 Allowable criteria for peak stresses

The localized peak stress area shall be displayed on an element by element basis and not as smoothed (average fields) in order to demonstrate that the locally occurring stresses have the potential for plastic redistribution without general collapse.

The mesh density selection has an influence on the localized peak stress evaluation, for the very fine mesh region, it could be acceptable to have very localized peak stress, with stress greater than σ_a defined in section 4.3.3.3 provided the free following criteria are fulfilled simultaneously.

- a) The Von-Mises stress at the centroid of elements (extreme fiber, for a region corresponding to a square area no more than 2 times the thickness of the area of interest shall not exceed the allowable stresses below:

$$\sigma_a = 1.3 \times \alpha \times R_f$$

With:

$$\sigma_{vm} \leq \sigma_a$$

- b) The Von-Mises stress (extreme fiber) for the neighboring elements are to comply with the criteria given above.

- c) For areas where the stress is higher than (σ_{vm}), plastic stress redistribution shall be demonstrated.

4.3.3.5 Allowable criteria for non-linear analysis

In non-linear analysis, plastic strain shall not exceed 5% except for dropped objects (i.e accidental conditions).

For details not covered in the present specification as the Stress-Strain curves for ultimate capacity analysis, the [DNV-RP-C208](#) shall be used.

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4.4 Foundation structural requirements

4.4.1 Suction Pile

Foundations shall comply with the following specifications

- [GS EP STR 433](#)
- [GS EP SPS 002](#): Section 5
- [API RP 2A-WSD](#): Sections 9.1 through 9.11
- [ISO 19901-4](#).

In addition to the documents referenced above, the following requirements shall apply:

- The foundation shall be suitable for the installation and connection of the support structure, such that all loads imposed on the support structure are transmitted into the foundation and absorbed into the soil
- The foundation shall withstand the long-term static and dynamic loadings
- Natural settlement has to be estimated during the installation and field life.

4.4.2 Mud mat

Mud mat on bottom stability and design shall consider any module to be supported as ILT/FLET/PLET/etc. Mud mat could be integrated to the module or installed first separately.

In addition, jumper/ spool loads and tie-in loads shall also be considered.

The mud mats are required to ensure the stability (bearing / sliding when relevant and non-settlement) of the module resting on the seabed.

They may be either:

- Metallic (recommended base case)
- Or for particular case and after validation by Company, made of GRP (Glass Reinforced Plastic) with carrying frame
- Wood with density close to 1 may also be contemplated for temporary foundation.

In the case of metallic mud mats, the cathodic protection system of the module shall consider the mud mat areas for the calculation of the number of anodes.

Calculations shall be conducted according to either [API RP 2A-WSD](#) or [ISO 19902](#) requirements and based upon:

- Soil conditions at the seabed; maximum allowable settlement considerations shall be particularly addressed
- Geometrical shape of the mud mats
- Maximum environmental conditions in place and during installation
- Module gravity and buoyancy loads

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- Flowline displacement, expansion load, walking, buckling, shall be taken into account for the mudmat dimensions
- Jumper/ spool loads and tie-in loads.

Note: When required in Project Particular Specification, displacement monitoring shall be added.

4.4.3 Leveling

Reference shall be made to [GS EP SPS 002](#) Chapter 5.5.3.

4.4.4 Installation aids

Auxiliary lifting aids have to be prepared and installed as per the following:

- a) Cradles, lifting, and/or push-pull devices in such a position to ensure easy installation/removal of the pins, shackles, sheaves, etc.
- b) Easy and safe access to each area when necessary.
- c) Rigging device for supporting the rigging arrangement during the transportation phase and to ensure an easy access of the crane hook for lifting operation.
- d) The rigging device shall be designed to support the weight of the rigging (slings, shackles, spreader bar, etc.) plus an uniform distributed load equal to 5.00 kN/m².
- e) The connection of the rigging device on the object shall be performed using fast release bolted clamps to allow for an easy removal in one piece. The rigging device shall be self bearing when clamps are released.

5. Design criteria

All structural steel of the subsea structures shall be designed in accordance with [API RP 2A-WSD](#) which refers to the allowable stresses or [ISO 19900](#) and [ISO 19902](#). In addition, the most conservative resistance factors shall be used in the structural design.

Detailed FE analyses with the use of dedicated design software used by Contractors and approved by Company are required for design of highly stressed areas such as the pad eyes and complicated joints, if the traditional calculation do not give an acceptable answer to code.

Decommissioning and abandonment of the structures at the end of production life shall be taken into consideration when designing the equipment.

Material selection and Fabrication requirements are detailed in chapter 8.

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6. Structural analysis

6.1 General

As part of the design process, the various components of the subsea structural systems shall be analyzed to confirm that they are fit for purpose. During the detailed design of the subsea structures, as a minimum, all relevant load cases defined with [API RP 2A-WSD](#) or [ISO 19900](#) series in the following analysis shall be conducted in conjunction with the [GS EP SPS 002](#) section 5 requirements:

- a) Lifting Onshore analysis (handling in workshop): refer to section 6.2
- b) Load-out analysis: refer to section 6.2
- c) Transportation analysis (Loads apply to dedicated support locations): refer to section 6.3
- d) Offshore Installation (Through splash zone, submerged lift)
 - Lifting in air (weight entrapped water included): refer to section 6.2
 - Lifting through splash zone (slamming forces): refer to section 6.2
 - Lifting through water column: refer to section 6.2
 - Landing of the structures: refer to section 6.4.
- e) In-place analysis: refer to section 6.5
 - Sea-line connection
 - Operation scenario including thermal effect
 - Dropped object
 - ROV impact.
 - Snag loads
 - Trawling/fishing activities
 - Seismic.
- f) Structure retrieveability and decommissioning analysis.

6.1.1 Weight contingency factor

For the subsea structures, the weight to be modeled in global analyses shall be the weight of the structure, including allowance reflecting the uncertainty in the weight estimate.

This contingency shall be reflected in the weight allowance data given in weight control reports for the structures. Typically, this uncertainty shall decrease as the detailing of structure (secondary/outfitting steel) progresses. Considering this, appropriate weight contingency factor shall be applied in all the structural analyses as listed above.

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Table 2 - Percentages of contingency + tolerances

Phases Disciplines	Basic engineering	Detailed engineering		Construction	
	IFD	IFD	AFC	As-built	Weighed weight
Structural	20%	12%	7%	5%	3%
Mechanical	20%	12%	7%	5%	3%
Piping	20%	12%	7%	5%	3%
Electrical	25%	15%	10%	5%	3%
Instrumentation	25%	15%	10%	5%	3%
Safety	25%	15%	10%	5%	3%

IFD = Issue For Design

AFC = Approved For Construction

6.2 Lifting studies

6.2.1 General

The purpose of the lifting studies is to check the structural behavior of the packages to be lifted, and to calculate and design all the relevant lifting devices such as pad eyes, pad ears, trunnions, shackles, spreader bars or spreader frames, slings, bumpers and guides, etc.

This section defines the minimum requirements for any package lifting studies. Depending of the destination of the package, or of the selected installation Contractor, different methods and/or different acceptance criteria may be required by the Particular Specification.

Depending of the context of the study (basic engineering, detailed engineering, construction), the Contractor shall consider a more or less stringent contingency for the position of the center of gravity of the package to be approved by Company.

This section covers the lifting operations performed with single or double hook lifting systems, single or double crane vessel lifting system. Other systems shall be covered by the Particular Specification.

Unbalanced prongs loads on the hook shall be addressed and approved by the crane manufacturer.

6.2.2 Lifting analysis

6.2.2.1 Computer model

The computer model used to verify the package structure at lift shall reflect the exact location of the application point of the sling force on the structure considering the eccentricity of pad eyes and slings.

The model shall be such that the center of gravity of the package and the hook point are in perfect static equilibrium.

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Slings shall be modeled with the appropriate stiffness which should be obtained from the sling manufacturer or can be approximated using the following properties:

- The area of the sling member shall be 60% of the actual gross area of the sling based on the given sling diameter
- The modulus of elasticity of the sling member shall be $E = 80,000 \text{ MPa}$
- The slings, as tension members, shall not transfer end moments.

In most cases, horizontal dummy springs are required to stabilize the structure during analysis:

- Assumed spring stiffness shall be $K = F_{\text{sling}} / L_{\text{sling}}$ where F_{sling} and L_{sling} are the incoming sling tension and length at the node where the dummy spring is connected
- The generated reactions shall not exceed 5 t or 0.1% of structure total weight, whichever is smaller.

6.2.2.2 Loads

For any lifting analysis, the calculations carried out shall combine and include the following loads and factors:

- For an unweighed structure, the calculations shall consider the maximum expected weight, which includes the contingencies defined in the table 2 above.
- For a weighed structure, the calculations shall consider the weighed weight plus a tolerance factor of 3% due to weighing inaccuracy.
- When the maximum expected lift weight is above 90% of the maximum lift capacity, the maximum lift capacity shall be considered for the lifting analysis.
- Whenever the results of a weighing (if any) would show a weighed weight greater than the maximum expected weight and/or an excessive COG shift, the lifting calculations shall be revised to consider the weighed weight plus 3%, and the structure shall be reinforced accordingly if required.

6.2.2.3 Variation of COG

Lifting analyses during engineering phase shall consider:

- The variation of the calculated location of the centre of gravity within a rectangle whose sides are equal to 10% of the overall width and length for a structure/equipment.
- The variation of the **minimum** sling angle of $60^\circ \pm 5^\circ$.

Note: COG can also vary due to installation or removal of equipment without some of its retrievable components in place, e.g. installation of XT or MPFM without FCM or SCM or MPFM. Analysis shall consider all such potential installation cases driven by the fact that due to limits on installation vessel crane capacity, it might be required to install or retrieve a XT without some of its retrievable modules (e.g. FCM).

6.2.2.4 Dynamic Amplification Factor

Installation Contractor is responsible for verification and calculation of actual DAF for all the structures before and during installation.