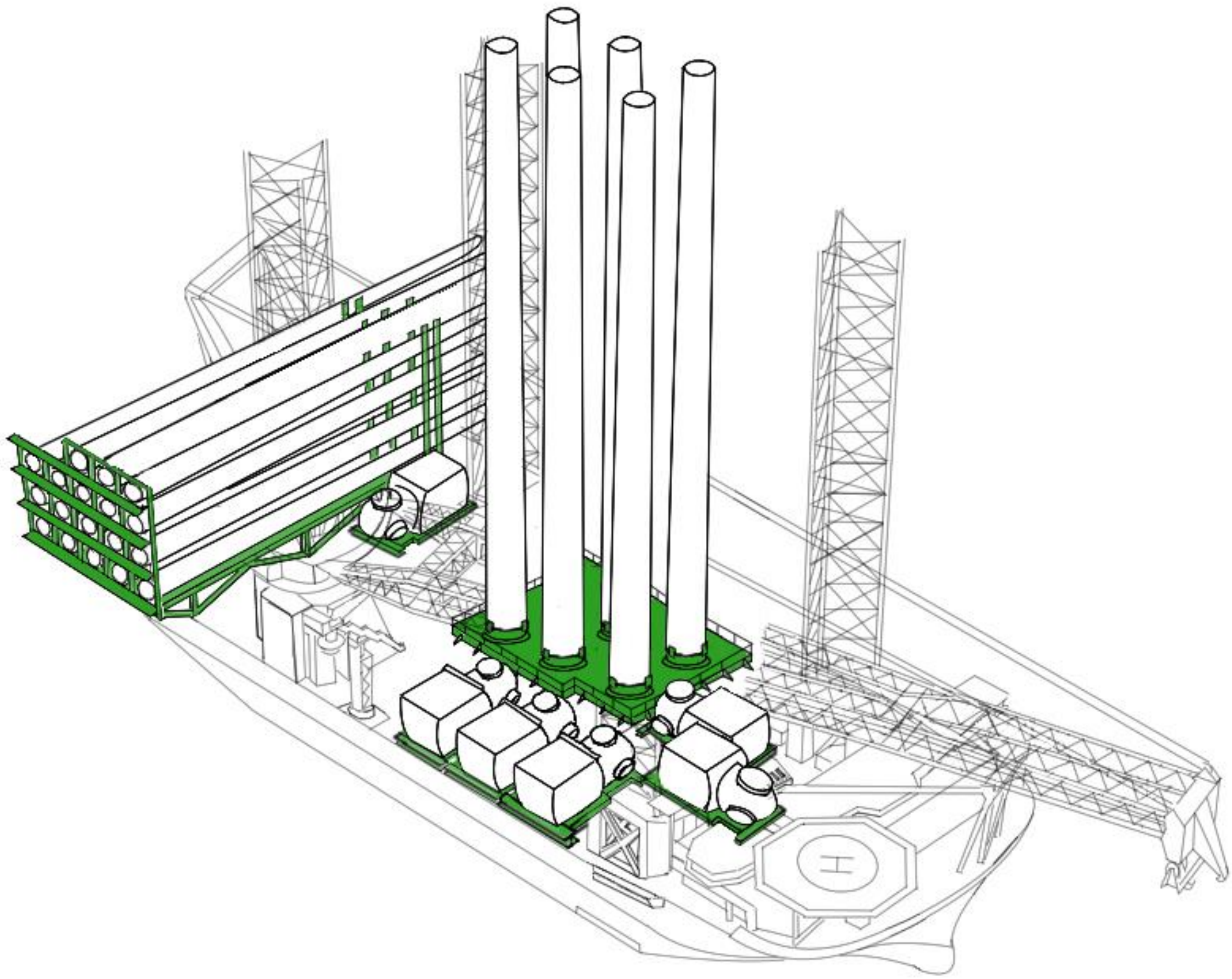

Seafastening Design Guideline
SG 14-222 DD & SG 14-236 DD
Vestas V236

Energy Cluster Denmark
Wind Industry Standardization
Installation Vessel Seafastening

Siemens Gamesa Renewable Energy
Vestas Wind Systems

Revision

Rev	Date	Remarks	Description
01	March 2025	First issue	

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CHANGES – CURRENT

New document

1. Introduction

1.1. Purpose

Due to the fast-paced WTG platform development and associated changes to the logistics setup & installation methods, WTG OEMs are required to procure a of new mission equipment, forcing large CAPEX for items that have limited re-usability and require a significant amount of steel & manufacturing works.

Energy Cluster Denmark (ECD) Wind Industry Standardization (WIS) project has looked to alleviate this problem by establishing a set of aligned sea fastening requirements, allowing Installation Vessel Owners to design and procure common seafastening and subsequently offer lease of the standardized project equipment to different OEMs, leading to industry-wide savings and operational improvements.

The primary goal of the project is to establish standardized sea fastening design requirements for tower grillages, blade racks, blade rack substructures and nacelles, leading to potential savings stemming from reusing and not having to mobilize/demobilize mission equipment to & from the vessel deck between projects.

The associated time & cost optimization shall lead to industry wide emission reductions and an increased number of available installation days for the WTIV's.

This document presents the design guideline for the development of all seafastening used for turbine components on the installation vessels for the following turbine types:

- SG 14-222 DD
- SG 14-236 DD
- V236

The component specific rigging instructions are always the prevailing documents with respect to the mass properties data. The data is provided and maintained by a technical committee consisting of SGRE, Vestas and ECD representatives.

Local legal requirements and/or standards must always be considered, and should any contradictions occur between this guideline and the applicable local regulations, then local legislation shall take precedence. If, however, the guideline requires higher demands than local legal requirements, then the guideline should be applied.

The seafastening responsibilities are specified in [A1] Scope and Responsibility Matrix.

Important Notes to this revision

- The pictures, drawings (masses, COG and dimensions) of components and equipment in this guideline are to be taken as examples and rough estimations.
- If accelerations are expected to exceed the accelerations shown in the acceleration table of each equipment/component, the respective OEM must be informed and consulted.

1.2. Abbreviations and definitions

Abbreviation	Description
B108	Blade 108m long (SGRE)
B115	Blade 115m long (SGRE)
Blade yoke	Blade installation tool
CoG	Center of gravity
D_{bot}	Bottom tower outer diameter
DNV	Det Norske Veritas
EHS	Environment, Health and Safety
Employer	Client to OEM and/ or Vessel Owner engaged by Employer
FLS	Fatigue limit state
ft	Feet
IG	Interference Galloping
LRFD	Load and Resistance Factor Design
Nacelle yoke	Nacelle installation tool
mt	Tonne (metric)
Must/shall	Mandatorily obliged to
MWS	Marine Warranty Surveyor
OEM	Wind Turbine Generator Suppliers (SGRE, Vestas, etc)
SG 14-222	Siemens Gamesa Direct Drive 222m rotor diameter WTG (MKVI type)
SG 14-236	Siemens Gamesa Direct Drive 236m rotor diameter WTG (MKVI+ type)
SGRE	Siemens Gamesa Renewable Energy
Seafastening	Grillage, supporting frames, racks, slings, lashings, bolts and any other equipment designed to and required to secure the WTG components and other equipment
Should	Indicating expected course of action to be followed unless it is deemed inappropriate for the particular case
TDD	Tower Design Document
TSA	Turbine Supply Agreement
TP	Transition piece
ULS	Ultimate limit state
VIV	Vortex induced vibrations
V236	Vestas 15 MW turbine
WTG	Wind Turbine Generator
WTIV	Wind Turbine Installation Vessel

1.3. Common Annexes

[A1] Scope and Responsibility Matrix

[A2] Power Supply Requirements

[A3] High Level Deliverables List

[A4] Blade Rack Design Load Manual

1.4. OEM Specific Annexes

[O1] Wind load template for towers

[O2] Main Components Weights and Dimensions Specification

[O3] Installation & transportation tools and solutions

2. General design criteria

For the sea transport of turbine components and equipment, normally an installation vessel will transport the components from harbour to the installation site. During transport, the vessel will be in motion reacting on waves, own speed, and buoyancy. Motion induced loads and wind action will affect components stored on the deck.

Unless otherwise specified, following coordinate system and motion designation is being introduced:

- X axis = longitudinal axis, positive forwards
- Y axis = transverse axis, positive towards port side
- Z axis = vertical axis, positive upwards.
- positive surge is translation in the X-axis direction (positive forward)
- positive sway is translation in the Y-axis direction (positive towards port side of ship)
- positive heave is translation in the Z-axis direction (positive upwards)
- positive roll motion is positive rotation about a longitudinal axis through the COG (starboard down and port up)
- positive pitch motion is positive rotation about a transverse axis through the COG (bow down and stern up)
- positive yaw motion is positive rotation about a vertical axis through the COG (bow moving to port and stern to starboard), see Figure 2-1.

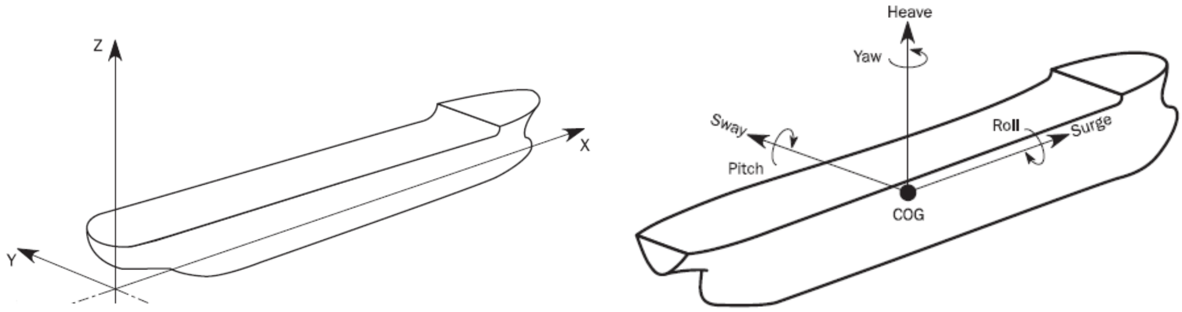

Figure 2-1 – Designation of directions and motions

General design criteria are listed below:

- In order to define loads, a dynamic motion study with a hydrodynamic program should be performed for the specific installation vessel planned to be used in the project. The accelerations from the study shall be compared with the component design accelerations and proven to be below component limits. If motion induced accelerations appear to be greater than component's limits described in this document, OEM shall be notified.
  The accelerations limits described in this document reflect the resistance of turbine components and its equipment. Values are to be treated (unless otherwise stated) as characteristic with probability of exceedance of 10^{-4}, Alpha factors not considered.
- Only light spray water on components during sea transportation is acceptable, as in general, components like nacelle do contain e.g. electrical modules and should not be exposed to sloshing water.
- Clearance between individual components must fulfil requirements described in DNV-ST-N001. A clearance of minimum 1.5 meter is recommended combined with the use of guides and bumpers to protect the components. Please, note, that the clearance is not only driven by the access but also play a key role in the initial phase of lifting.
- Seafastening for all turbine components and its equipment shall be designed, verified, and fabricated according to DNV-ST-N001 by using LRFD method. Other region-specific requirements to be taken into account by Sea Fastening designer.
- The Seafastening designer must provide relevant technical documentation according to [A3] High Level Deliverables List. All seafastening interfaces must be coated. All steel structures are recommended to be painted according to section 4.8.

3. Deck layout

Components should be placed on the vessel to optimize the pick-up angle between components axis and the main crane's boom measured in horizontal plane, whilst maintaining the clearances around the lifted object according to DNV-ST-N001 *16.13 Clearances around lifted object – jacked up crane*.

In all scenarios the path of the taglines between component and the crane boom must be accounted for so that: there are no clashes, and to ensure that the tagline angles are acceptable so OEM can control the components during lifting. Furthermore, due to large weight of the tagline's sheave blocks, manual handling of these is difficult and it is preferred to have all lifting yokes close to the minimum crane radius and positioned close to each other on the deck to reduce slewing, hoisting, and rigging time.
Deck or auxiliary cranes should be available to support the following operations:

- Handling of sheave blocks
- Handling of large tower bolts for the tower seafastening

The main crane, towers & blades should be positioned in a way to enable a safe & efficient installation process. When picking up components close to the crane minimum radius, additional deck capstans may be used in the deck layout arrangement.

Number of containers on deck is projects specific and related to the number of WTGs on deck and scope. These containers are to be placed in locations best suitable for the relevant use e.g., back load, spare parts etc. The number of containers shall be specified in Annex [A1] Scope and Responsibility Matrix.

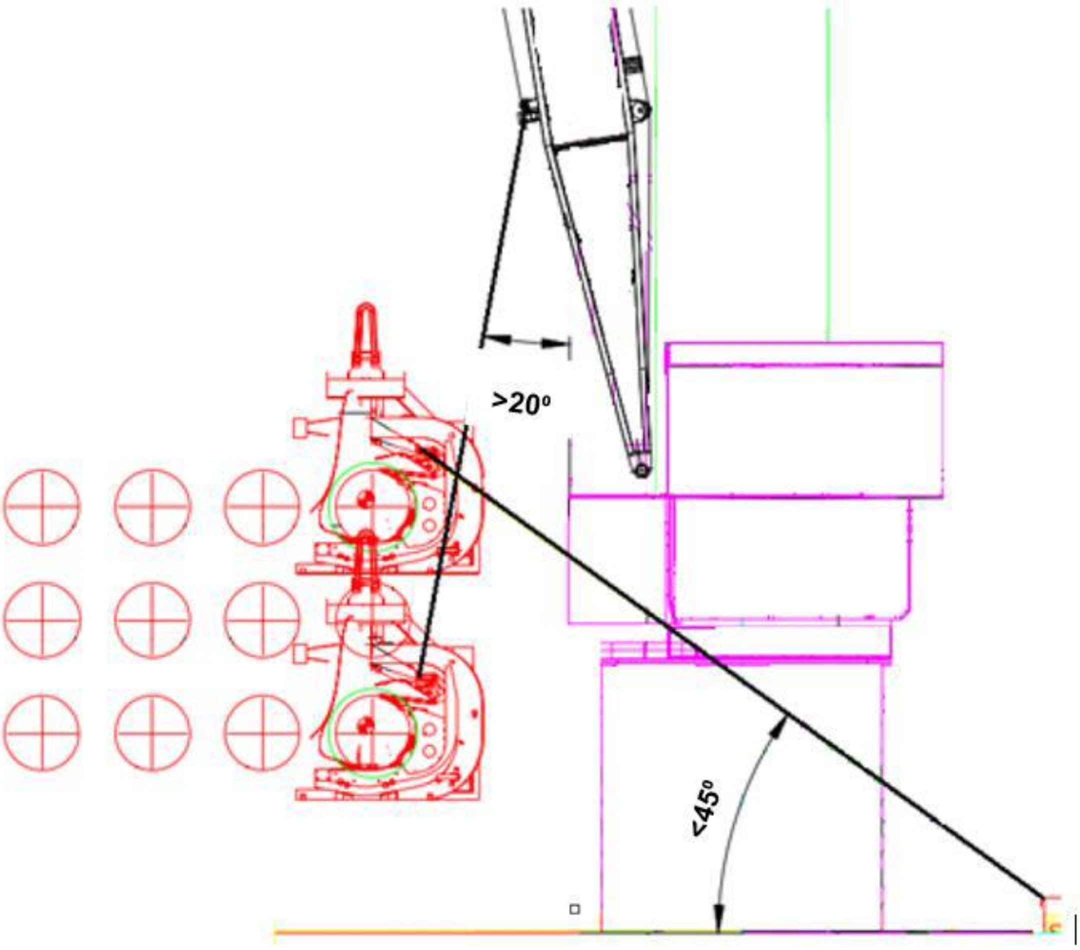

Figure 3-1 - Preferred blade pick up tagline angle

4. Design criteria for towers

4.1. Dimensions and centre of gravity

Since each tower design is project specific, the Tower dimensions, CoG and mass (including contingency) will be provided by OEM on per project basis.

For information only, below in Table 4-1 and Figure 4-1 are the Dimensions, Centre of Gravity and weight envelope of nominal SGDD-222, SGDD-236 and Vestas 236 towers, the figure & values are will be updated when the project specific design is finalised. Provided values are including all internals, temporary dampers and excluding any contingencies.

Table 4-1 – Mass, Tower

Structure	Weight [tonne]
Tower Min. [tonne]	750
Tower Max. [tonne]	1300

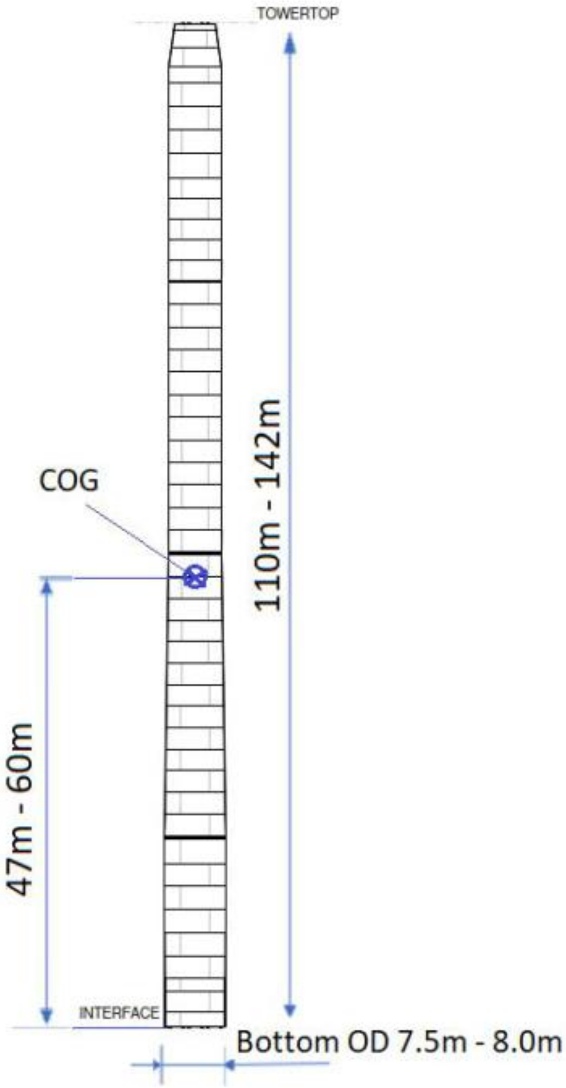

Figure 4-1 – Schematic of tower CoG

4.2. Tower transport accelerations

The towers are transported vertically on WTIVs. The towers will interface directly with the grillage on the vessel or by use of project specific tower adapters. The seafastening structures must be designed to withstand the loads from the vessel motions and wind during transit and survival conditions.

There is no specific orientation predefined for the towers in sea-fastened position and as structural strength is axisymmetric, the towers maximum allowable transport accelerations are defined in Table 4-2.

Table 4-2 SGDD-222&236 and V236 design limits for towers – characteristic values

Elevation*	Max Horizontal Acceleration $a_{x,y}$	Vertical Acceleration a_z	Roll	Pitch
[m]	[m/s^2]	[m/s^2]	[deg/s^2]	[deg/s^2]
40	4.5	3.3	3.5	2.3
50	5.0			
60	5.7			

* Elevation reference is located on the tower bottom flange

The designer is allowed to interpolate between elevations.
If actual accelerations extracted from the motion analysis are exceeding the accelerations shown above, OEM must be informed and consulted. Vertical acceleration presented in Table 4-2 is provided excluding the gravity.

Please note that the values given in Table 4-2 are generic and upper bound values which are calculated based on the entire tower portfolio. However, the project specific design limits are calculated based on real tower design in specific projects which is given in the TDD attached to TSA. It is vessel responsibility to ensure that the motion accelerations are not exceeding the project specific tower design limits. If the motion analysis indicates acceleration values higher than design limits given in TDD, OEM must be contacted.

FLS loads originating from motion during transit need to be taken into account for specific project evaluations.

4.3. Wind loading

The wind loading at transit, pre-lift and survival condition is based on project specific data. The seafastening must be designed for both static and dynamic effects from the wind, based on DNV-RP-C205. Wind loading cases for transport and survival shall be confirmed in all directions acting on the vessel and the equipment. More details are provided in Section 4.3.2

The following table is presenting the ULS wind loads expected for the towers during survival. The load partial factors are already included as per Eurocode requirements. Upon evaluation, it has been concluded that gust buffeting is the governing scenario for ULS during survival. Presented loads are occurring at tower bottom flange level. Nonetheless, the upper bound condition is not considered in the below values and therefore, a contingency factor of 10% must be applied on top of the loads.

Table 4-3 – Wind loads

Leading action	Moment (MNm)	Shear (MN)
Gust Buffeting	224.3	3.1

Values calculated for wind speed of 40 m/s (10 minute mean wind at 10 m height).
Annex [O1] Wind load template for towers is applicable for project-specific evaluations. FLS loads originating from wind loads needs to be considered for specific project evaluations.

When transporting full towers, a significant dynamic response (resonant effects) is expected for the tower, since it is a flexible structure with natural frequencies in the frequency band of the wind turbulence and vortex shedding (VIV).

Consistently with DNV-RP-C205 (Section 5.1), all dynamic components of the wind load shall be evaluated and included in the design loads if relevant. This must be considered for along-wind (due to wind turbulence) as well as cross-wind directions. In this case EN-1991-1-4 provides a simple and consistent method to evaluate static and dynamic wind loads acting on a vertical slender structure.

Seafastening designer should consider dynamic and static loads due to wind acting on the towers for seafastening design. OEM will provide the load verification on the towers during transport and storage on the vessel, when the seafastening design has been frozen and when the grillage stiffness has been submitted by the grillage designer including a finalized deck layout.

Vortex induced vibrations (VIV) can occur at a specific wind speed. The project specific VIV analysis shall determine if VIV reduction equipment is necessary for the specific tower design. OEM, based on grillage designer input, will verify that the project-specific tower can withstand the vibrations in the transport and storage period. This is an iterative process which is defined below. If the feasibility study concludes that VIV reduction equipment is required, VIV mitigating solution, or a damping system will be used on the towers.

The VIV loading shall be included in the verification of the tower frame strength. The VIV loading with corresponding tower frequency vibration and duration is calculated by OEM based on the tower design and seafastening frame stiffness. The procedure to be followed is outlined below:

1) Seafastening designer establishes a preliminary realistic design considering the towers arrangement, weight and associated loading from wind and sailing (FE-beam model is acceptable)
2) Seafastening designer establishes rotational stiffness of tower grillage
3) OEM supplies VIV loading, frequencies and durations based on the stiffness matrix
4) Seafastening designer verifies ULS and FLS strength of the frame

See [A1] Scope and Responsibility Matrix for a detailed split of responsibility of the aforementioned process.

Preliminary feasibility design will be discussed at the end of the first iteration of the design loop, i.e. point 1) to 4). Based on this feasibility study the parties can conclude if VIV mitigating solution or other damping method is required for the project.

Requirements presented below are required to mitigate and/or prevent high vibration amplitudes of the towers.

Table 4-4 – Design requirements for bending stiffness and tower distance

Minimum rotational grillage stiffness [GNm/rad]	>58
Center to Center tower distance [m]	>11.25

Note: low stiffness will lead to high VIV induced fatigue loads.
The stiffness provided is including optional the tower adapter.

4.4. Seafastening

Everything below the bottom tower flange is considered seafastening of towers, this includes:

1. Grillage including
   - Platforms and rails
   - Guiding pins and bumpers
   - Safe working areas including manholes
   - Lights and power sockets according to electric spec
2. Adapter ring/plates
3. Bolts / guide pins

The pictures below are examples, and any text or values in the drawing should **NOT** be treated as valid.

Figure 4-2 –Tower seafastening example

The staircase on the towers must be considered when the clearance is determined. Evacuation routes between towers are required.

The tower internals should be kept in an environmentally controlled state during sea transportation by using dehumidifier provided by the OEM. In order to accomplish this, the seafastening hatches design must be weather-tight around the base of the tower, see Figure 4-3. Hence, all hatches in the tower seafastening shall be sealed in order for OEM to run the dehumidifiers during storage onboard the installation vessel and transit.

For access to the towers and in the event of evacuation, manholes must be provided through the base of the seafastening, see Figure 4-2 and Figure 4-4. General access requirements are specified in "*EN 547 part 1 to 3: Safety of machinery, Human body measurements. Principles for determining the dimensions* required for access openings". Minimum size of the manhole is W800xH600mm. The EN14122 standard is applicable to design accessways, railings, platforms etc. unless otherwise specified.

Figure 4-3 – Sealed access manhole and water drainage example

Figure 4-4 – Grating inside tower seafastening example

The floor inside the seafastening must have anti-skid and drainage properties, ensuring friction and a dry surface, see Figure 4-4. The working level height inside the tower seafastening must be adequate for a normal person height when handling the bolts/pin-bolts, tools etc. on the tower flange. Furthermore, plain surface is required to avoid tripping, and all grating is preferred to be in one level.

The TP bolts are stored in Euro pallets on the grillage. The grillage floor inside and outside of tower positions is required to withstand 2000 kg/m^2 during transport and installation.

The purpose of standardising the interface to tower grillage is to allow for tool interchangeability between vessels, reducing potential delays stemming from long lead times for case-specific equipment.

4.5. Tower adapter

In cases when the tower grillage flange doesn't match the tower bottom flange, it is necessary to utilise a tower adapter to interface the tower with the vessel, see Figure 4-5 for an example adapter.

Figure 4-5 - Tower adapter example

The tower seafastening will have to adapt to various types and sizes of towers based on considerations listed below:

- Due to project-specific flanges, a tower grillage adapter might be needed to interface between the tower grillage and the project-specific tower bottom flange.
- The tolerances for waviness, roundness and angular displacement must be considered. The fabrication dimensional tolerances shall be in accordance with section 4.5.1

The distance from top of tower bottom flange to grating shall be min. 1.2m and max 1.5m, see Figure 4-6 -.

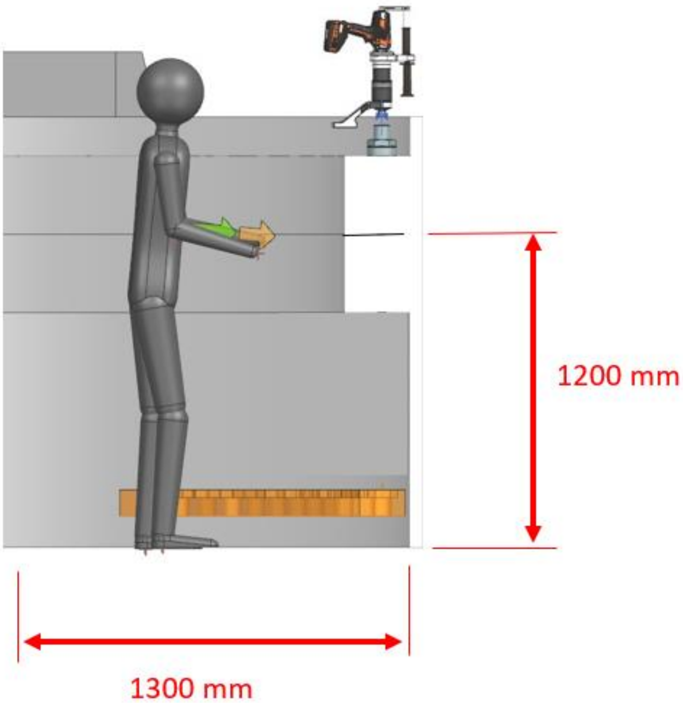

Figure 4-6 - Working height requirement for tower adapter

4.5.1. Interface requirement for tower bottom flange

The tolerances for waviness, roundness and angular displacement must be considered. The fabrication dimensional tolerances for erection of constructions shall be in accordance with DNV-OS-C401. Furthermore, OEM requirement shall be followed in fabrication tolerances, see below:

- **Surface waviness**
  The overall and local waviness shall be within the tolerance shown below, see Table 4-5. Overall waviness is calculated by subtracting the minimum local waviness value from the maximum local waviness value using only the outer measurements, see Figure 4-7.

Table 4-5 – Waviness tolerance

	Overall [mm]	Local [mm/m]
Waviness tolerance	2.5	1.2

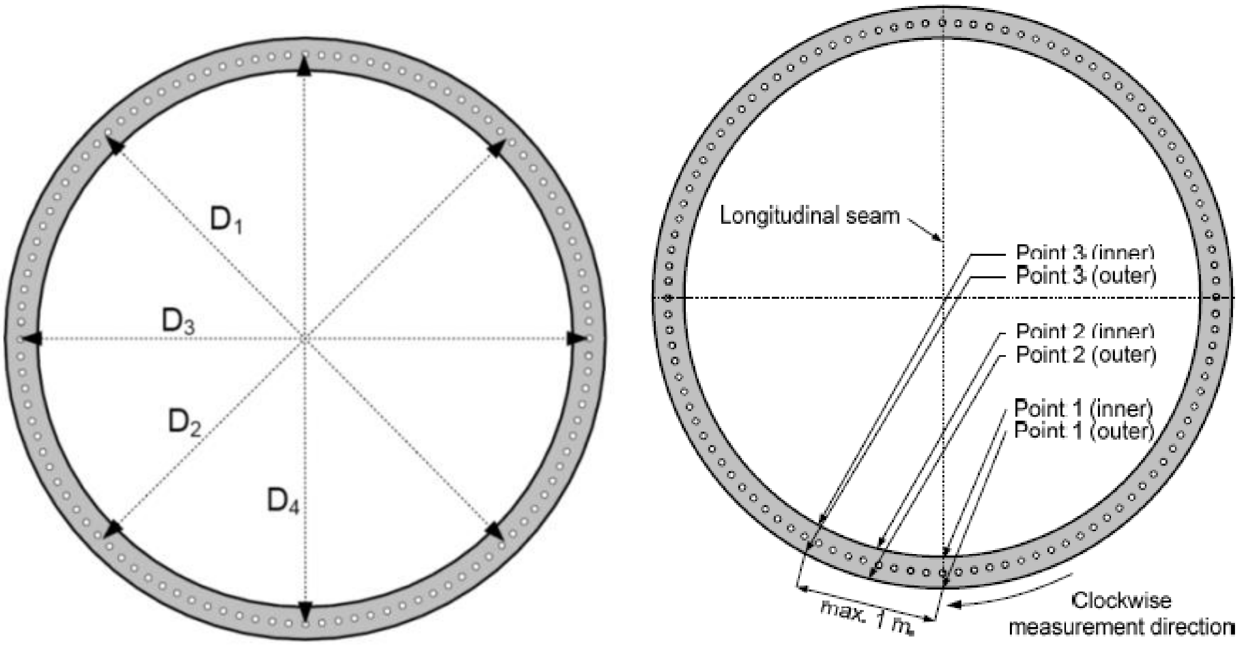

Figure 4-7 – Waviness and Roundness definition

- **Roundness / Ovality**
  The bolt hole reference diameter (D1, D2, D3 and D4) must be measured for each flange to ensure sufficient roundness, see . In total, there are two pairs that need to be measured: D1-D2 and D3-D4. The bolt hole reference measurements shall comply with the following requirements, see Equation 1.

$D_1, D_2, D_3, D_4 = D_{nom,\ hole} \pm 3$ mm,

$$\left[\frac{\max(D_{1,2,3,4})}{\min(D_{1,2,3,4})} - 1\right] * D_{nom,\ hole} \leq 5 \text{ mm},$$

, where $D_{nom,\ hole}$ is the nominal diameter of the tower flange from center of the bolt hole to the center of the bolt hole directly across.

Equation 1 - Roundness

- **Angular displacement**
  The angular displacement of the flange is the angle that the top surface of a radial cross-section makes with the normal surface to the tower axis. The angular displacement for the flange is calculated as the difference between two opposite measuring points on the flange. Only negative angular displacement (downward) is allowed as shown on below schematics, see Figure 4-8.

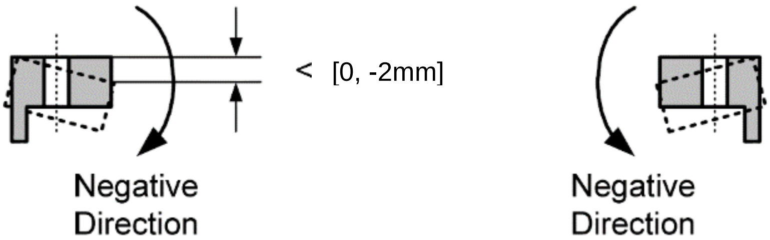

Figure 4-8 – Angular displacement definition

- Designs where the interface surface are not bolted directly together (e.g. using “bolt boxes” which transfer the loads to, or close to, the neutral axis of the support structure) need special considerations in respect of fatigue to bolts.

If it is not possible to meet the requirements listed above, alternative ways of correcting for the misalignment can be implemented. The specific solution is to be agreed between OEM and seafastening provider. The seafastening provider will deliver the correction equipment.

4.6. Positioning and guidance of tower

To align the tower on the tower grillage/adapter, bumpers are needed to guide the tower in place. The minimum number of bumpers is three and shall be designed with different heights to land the tower properly, the bumpers are recommended to be 200mm longer than the longest guide pin and equispaced at approximately 120 degrees. Distance from bumper to tower is min. 30mm.

For guiding the tower to the correct position onto the sea fastening, it is recommended to use two different lengths of guide pins (non-threaded bars), on opposite sides of the flange. Size of guide pins depends on tower hole diameter, the size of threaded bars used as guide pins shall be no more than 5 mm smaller than the hole size. First guide pin must be 100 mm longer than guide pins. Second guide pin must be 50 mm longer than guide pins.

Seafastening for towers must consist of a continuous flange ring.

Figure 4-9 - Tower Sea fastening bumpers example

4.7. Bolt interface

For connecting the seafastening and tower adapter (L type only), OEM accepts using threaded rods or bolts, see Figure 4-10. OEM prefers to use a threaded rod or bolt size smaller than the TP bolt size. The maximum bolt size for manual handling is M56, however if the bolt size for seafastening is larger, then a mechanical handling system shall be incorporated in the design to limit manual handling.

A smaller bolt size will give larger clearance in the bolt hole (between the bolt and hole) which is to ensure a guided landing of the tower on the seafastening and to ensure that during mounting and tensioning, of washer and nuts, can be done by only one person. The bolt assembly is to suit the type of hole used in the design between seafastening flange and tower flange. The washer, if not used for a normal round hole type acc. to EN1090, is to be designed specifically towards the specific bolt joint. The seafastening designer has to verify the fitness and strength of washers and present it in the relevant documentation. However, in order to avoid paint damages and unnecessary repair works, such an oversized washer should be always smaller than the washer used later to execute TP to tower connection. The bolts have to be distributed evenly (as much as possible) over the tower flange for sea fastening.

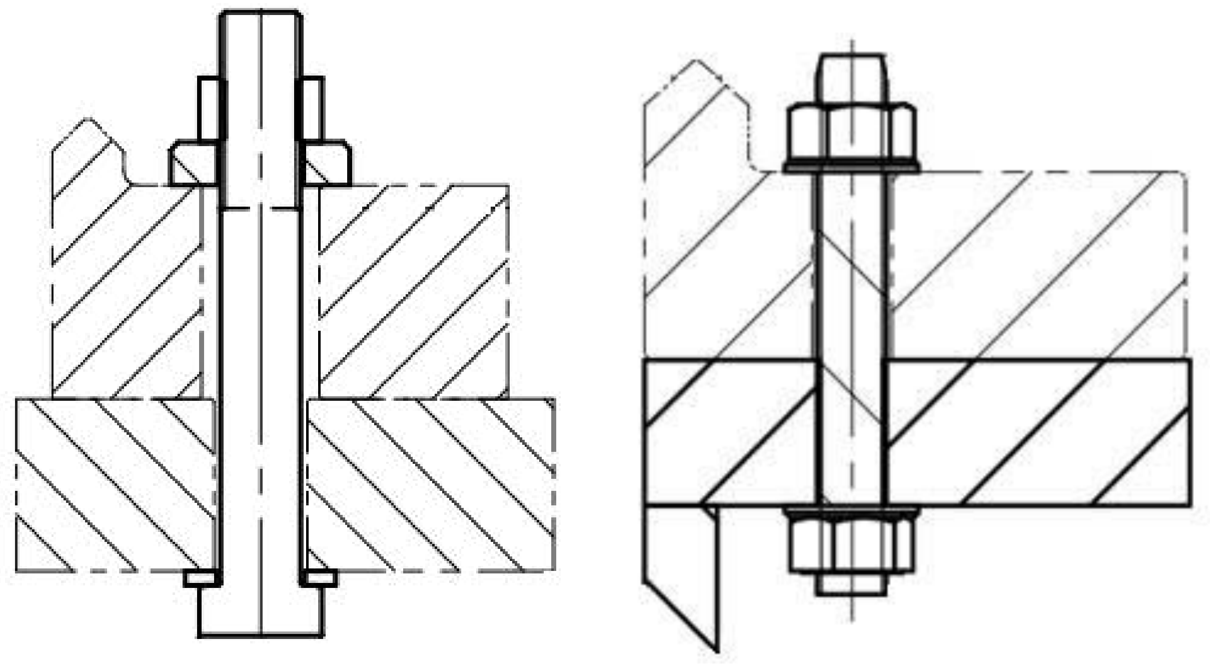

Figure 4-10 – Stud bolt –preferred solutions example

The tower guide system is to be mounted on the tower flange prior to installation from the vessel. This system requires an amount of free bolt holes for mounting and preferably these should remain free during transit to avoid demounting of seafastening studs/bolts. See Annex [O3] Installation & transportation tools and solutions for details.

The following scenarios are to be investigated:

1. Jacked-up condition (Pre-lift/load out) with minimum number of bolts with a maximum wind speed of 16m/s (10 minute mean wind at crane boom height).
   This is to optimize the loading and unload time of towers. During jacking up OEM intends to loosen and remove the nuts leaving only a minimum number of nuts required to hold the tower in the seafastening. OEM intend to loosen and torque the remaining bolts with a 1400-1800Nm torque wrench (Ex. PLARAD DA2-3600).
2. Transit and survival conditions with required number of bolts. Normal scenario for project specific environmental and loading conditions.

The provider of the grillage will determine the tower seafastening bolt pre-tension force and calculate a corresponding theoretical torque value as part of the seafastening procedure (e.g. bolt patterns, inspection plan to be provided).

The recommended scatter factor is 1.40 (applicable for torquing), this can further be reduced if value is accepted by client or MWS. Lubrication type "Never-seez Kema RG-1100" is used by OEMs. A friction coefficient of 0.13 can be used with lubrication.

The torque value has to be as low as possible in order to reduce operational time for tightening and loosening the nuts as well as being able to use smaller tools.

The theoretical torque values require validating by conducting a test. The intention of the test is to verify how much torque is required to reach the calculated pretension value in the real conditions. Usually, it is recommended to test 20-25 bolts.

Bolt connection has to be made to make bolt reusable. Requirement of reuse of bolts is stated in DNV-ST-N001 appendix E.2, also alternative standards can be applied subject to OEM approval. A fatigue assessment shall be made for the tower grillages and bolts. Reuse of bolts with respect to ULS and FLS shall be assessed. Finally, bolt pattern and the fatigue evaluation of the bolts must be delivered to OEM for review and final approval.

When relevant, the requirements for the bolt insertion system will be given separately in Annex [O3] Installation & transportation tools and solutions.

Pipes to hold the nuts and washers in the tower grillage, should be considered in the tower seafastening and enough to cover all seafastening nuts and washers. Below picture is an example of a typical arrangement.

Figure 4-11 - Storage solution for nut and washers in the tower grillage example

4.8. Corrosion protection system

The interface surface towards the tower bottom flange shall be coated with thermal spray metallization with class C3. The coating system is to ensure a clean interface towards the WTG component. It is recommended that the coating thickness of the thermal spray metallization shall be in the range of 100-160 µm, According to EN ISO 2064:2000

4.9. Power supply

The tower sea fastening must be supplied with power, light, and outlet sockets inside the tower grillage. See figure 4-12 for example power supply arrangement and Annex [A2] Power Supply for detailed requirements to be complied with.

Figure 4-12 – Tower seafastening light and power outlets example

5. Design criteria for nacelles

Transport of the nacelles can be by either an OEM transport frame or grillage designed by the seafastening designer. In the case of a grillage it shall follow the general requirements tower grillage design described in Section 4.4 and in Annex [A1] Scope and Responsibility Matrix Section 4.2

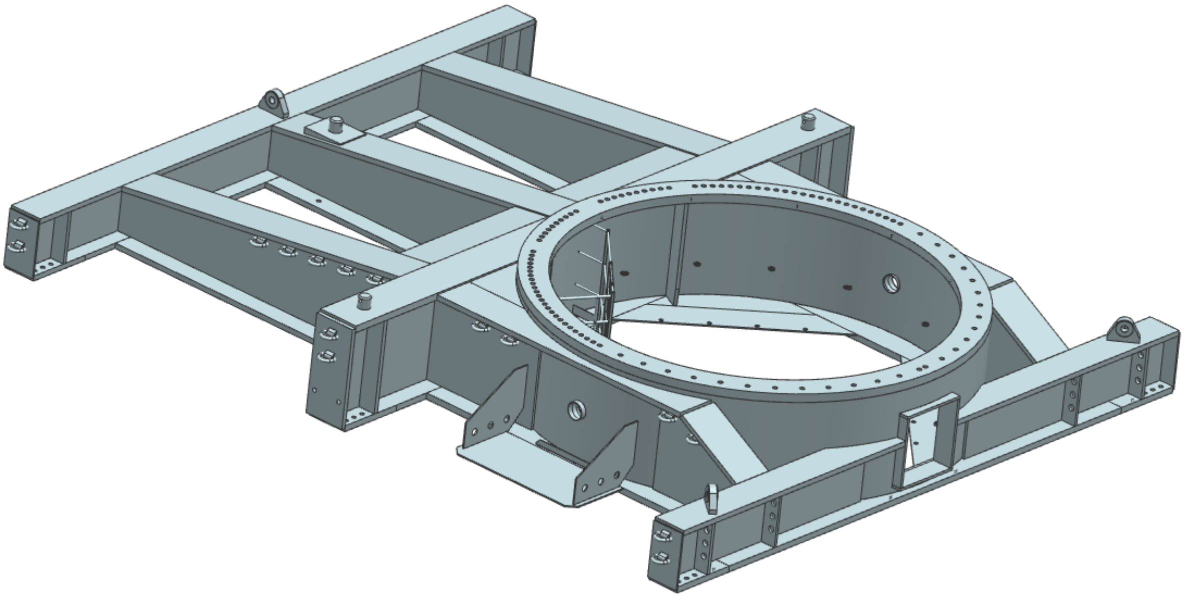

Figure 5-1 - Nacelle transport frame example

5.1. Acceleration

The strength of the nacelle and transport frames have been verified. The limiting accelerations (characteristic values, 10^{-4}) are shown in the Table 5-1.
The accelerations from the vessel motion study should not exceed the values listed below.

Table 5-1 – Transportation limits for Nacelle – characteristic values (10^{-4})

Accelerations at CoG	a_x m/s²	a_y m/s²	a_z m/s²
Assembled nacelle on transport frame/grillage	1.04	3.65	4.0

Note that accelerations are defined in vessel coordinate system shown in Figure 5-2.

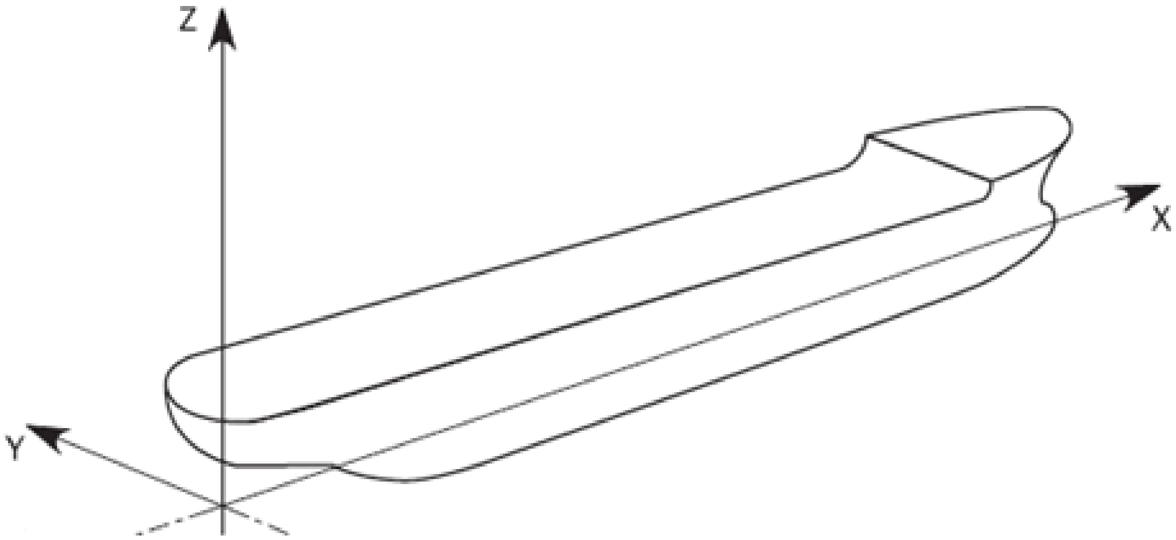

Figure 5-2 - Vessel coordinate system

The nacelle can be orientated both longitudinally and transversely. If actual vessel accelerations are expected to exceed the above limits, OEM must be informed, and further evaluation is required.

When evaluating acceleration and strength limit of nacelle and its transport frame, the combination of accelerations and resultant loads must be taken into account.

In case transport frame are used,

- Frames can be fixed with stoppers (around the outer parameters of the frame) or lashings.
- Vessel operator is responsible to validate the stability of nacelle to verify if lashing is required.

5.2. Seafastening and Interface

In general, the following items are included in the seafastening of nacelles:

- Corner stoppers
- Clamps (If uplift is present)
- Supports for the nacelle transport frame
- Turn buckles for lashing (if necessary, depending on if uplift is present)
- Access up to frame if elevated from deck

The nacelle with generator and the hub is supported by a transport frame, which is assembled with the nacelle flange. The transport frame is the interface for the nacelle seafastening.

Basically, the nacelle and transport frame need to be supported in all directions. Regardless of the seafastening concept, corner stoppers must be used. It is recommended to use adjustable corner stopper, also turn buckles can be used in the occurrence of uplift as shown on figure 5-3.

For easier landing of the nacelle the corner stoppers must be 200 mm higher on one end depending on the vessel crane hook movement.

Figure 5-3 – Corner stoppers and lashing options on nacelle transport frame example

If subjected to uplift the nacelle and transport frame also need to be lashed.

Two different seafastening concepts are recommended:

1. The Transport frame must be fully supported. This support method requires that the vessel deck must be in level, if the transport frame is placed directly on the deck. Alternatively, beams can be welded onto the vessel deck, see Figure 5-5. The contractor is responsible for verifying all aspects of the seafastening, including beams, support plates, weldments, corner stoppers, lashing points etc.

2. If a full support of the transport frame is not possible, the transport frame must as minimum be supported at three points along each of the side beams and in the centre beam where it meets with the barrel (so that supports are located below strong points in the frame), see Figure 5-7. The contractor is responsible for verifying all aspects of the seafastening, including support plates, weldments, corner stoppers, lashing points etc.

Figure 5-4 - Deck plate reinforcement example

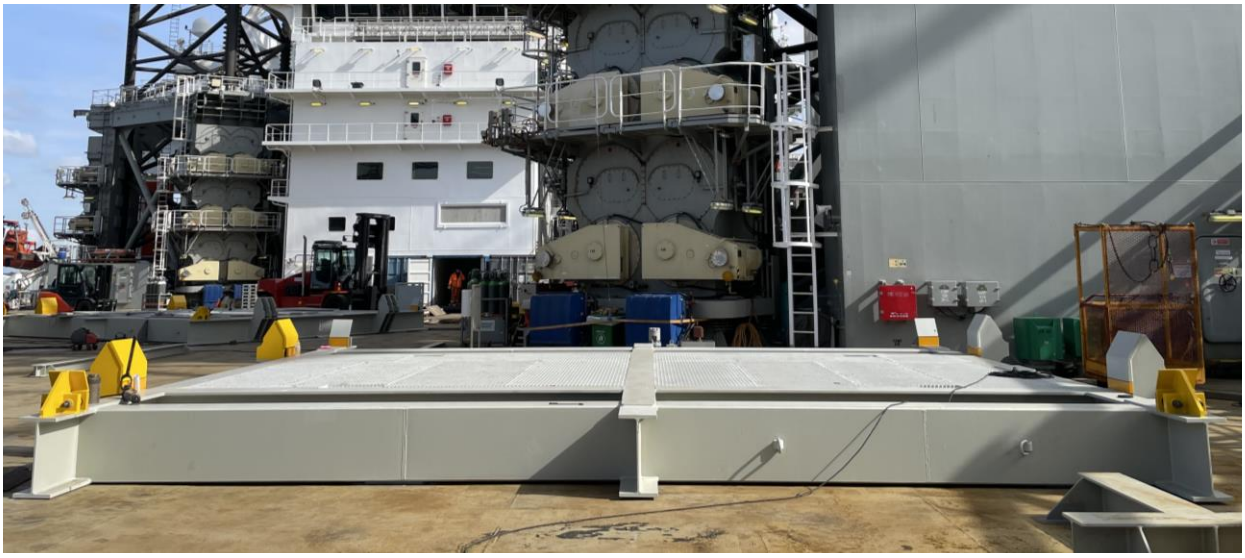

Figure 5-5 - Deck beam reinforcement example

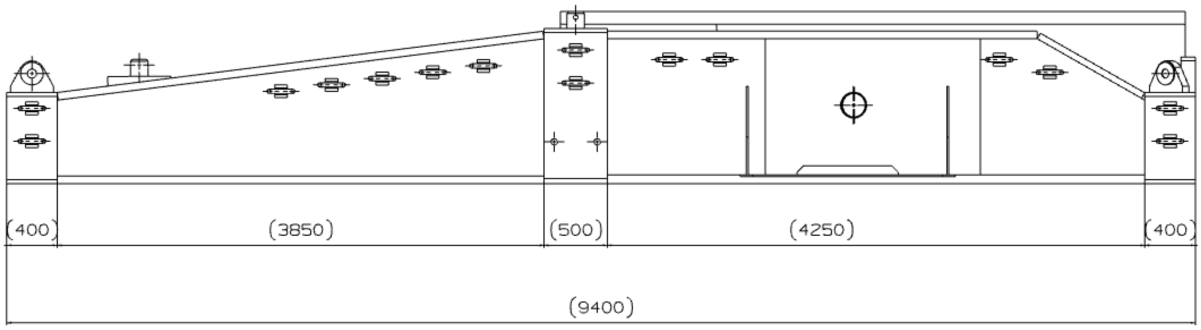

Figure 5-6 - Overall dimensions of an example nacelle frame

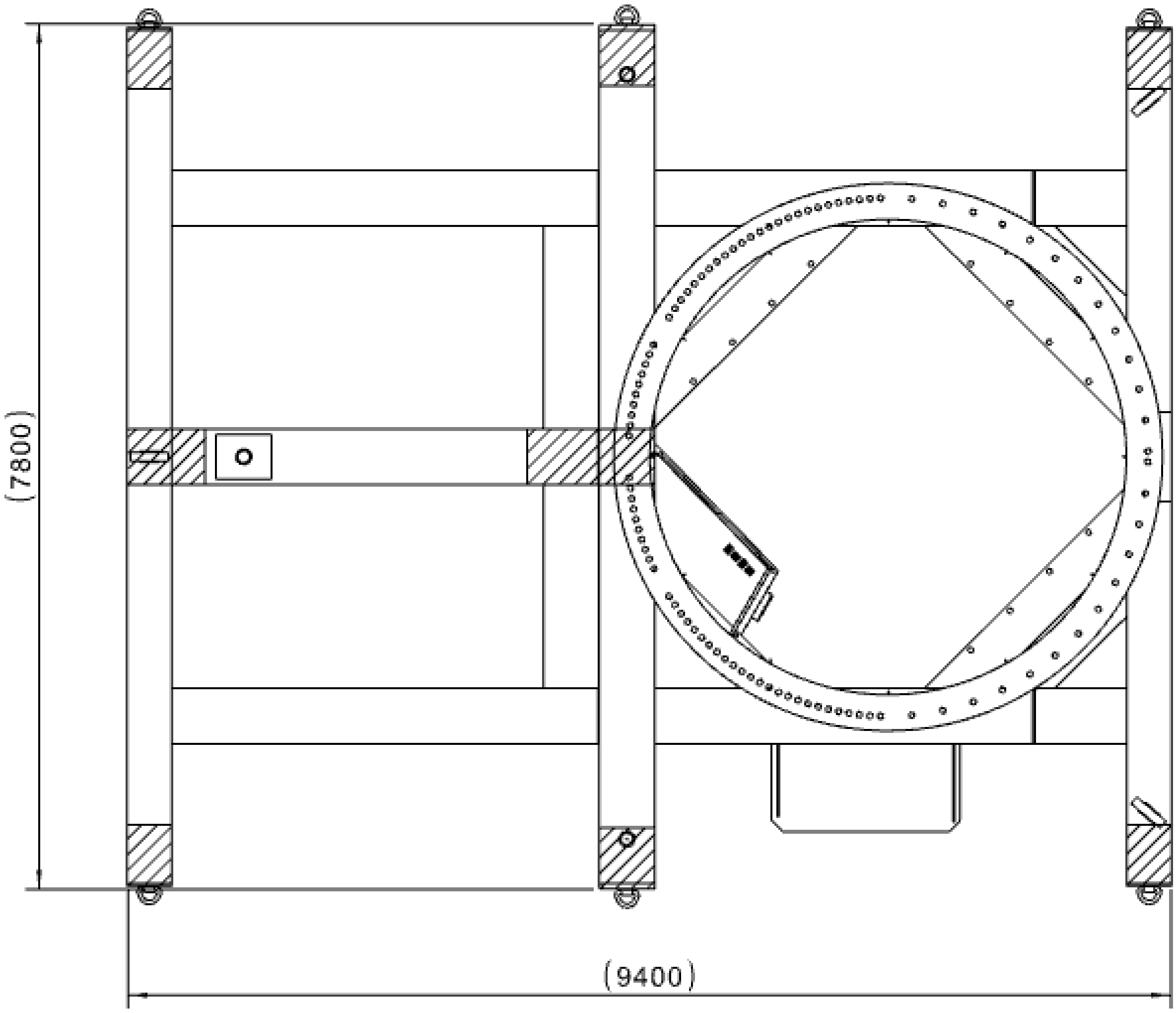

Figure 5-7 – Overall dimensions – strong points on example nacelle frame

If positions of the supports are expected to deviate from the above shown, the nacelle frame must be checked as well, and the OEM must be informed to confirm the position of the supports. In cases when the nacelle frame is elevated or there is a grillage designed for Nacelle, a proper lashing points for the HPU needs to be in place see Figure 5-8 as an example.

Figure 5-8 – HPU for nacelle testing example

5.3. Power Supply

During sea transport the nacelle must be supplied with power, see Annex [A2] Power Supply.

Figure 5-9 - Nacelle frame seafastening power supply example

6. Design criteria for blades

For single blade installations the blades are stacked in a blade rack system. The blade rack is designed in a modular way which makes it possible to have different arrangements and no. of layers. See figure 6-2 and Figure 6-3 as examples. For further information Annex [A4] Blade Rack Design Load Manual should be referred to. This section is applicable for is B108 for SG 14-222 DD WTG and B115 for SG 14-236 DD WTG and 115.5 meter blade for V236 platform.

6.1. Acceleration

The blade rack has been structurally verified using the characteristic accelerations (10^{-4}) given Table 6-1 below. Coordinates added for reference as used to define the characteristic accelerations.

The accelerations from the vessel motion study should not exceed the values listed below.

If accelerations are expected to exceed the accelerations shown below, OEM shall be informed. Note that blade rack is designed to have blade located in vessel transverse direction.

Table 6-1 – Characteristic accelerations for modular blade rack (note values are preliminary)

	Surge m/s^2	Sway m/s^2	Heave m/s^2	Roll deg/s^2	Pitch deg/s^2	Yaw deg/s^2	
LC1	2.0	2.7	4.4	0.5	2.0	1.1	Blade 4th layer
LC2	0.7	4.1	3.5	2.8	1.6	1.1	Blade 4th layer

	X [m]	Y [m]	Z [m]
CoG Blade 4th layer	-20	2.5	41.15

Note: blade COG position provided in vessel coordinate system (coordinate for reference only, the location of blade rack is project specific and will vary for each vessel)

6.2. Wind Loads

The blades are designed to produce the highest possible torque when installed on the WTG. This also means that the blade will generate significant wind load reactions during transport on WTIV.
The presented loads comprise of loads due to accelerations and wind speed 32.5 m/s (@10m @10min).

Please note that the following tables are given for a summary of wind loads for reference only. Project-specific loads to be determined by seafastening designer using Annex [A4] Blade Rack Design Load Manual.

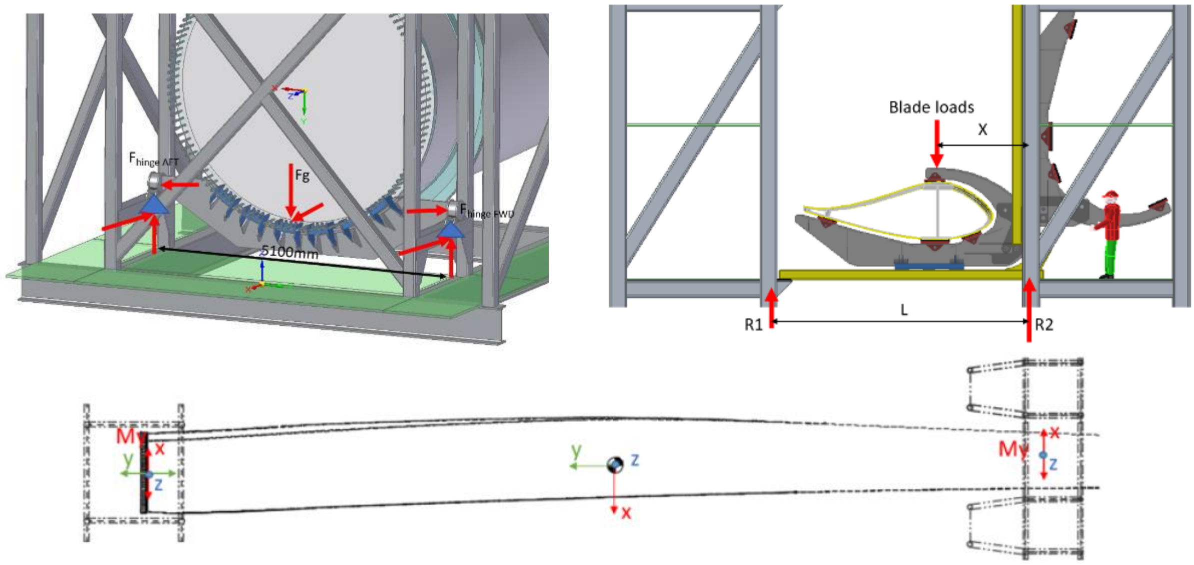

Figure 6-1 - Load points for root end (top left) and tip end (top right) blade supports, blade coordinate system aligned with vessel coordinate system (bottom)

Table 6-2 Reaction forces on blade rack root end calculated for one blade example

		B108		B115		V236	
		LC1	LC2	LC1	LC2	LC1	LC2
Aft Pin	Load in X	103	61	108	64	76	29
	Load in Y	71	104	66	97	115	174
	Load in Z	174	174	176	184	305	283
Fwd Pin	Load in X	103	61	108	64	76	29
	Load in Y	113	166	123	180	88	133
	Load in Z	320	307	369	356	235	217

Table 6-3 Reaction forces on blade tip root end calculated for one blade example

		B108		B115		V236	
		LC1	LC2	LC1	LC2	LC1	LC2
Aft Pin	Load in X	0	0	0	0	0	0
	Load in Y	34	48	31	48	34	47
	Load in Z	235	234	226	226	247	232
Fwd Pin	Load in X	89	50	88	50	83	31
	Load in Y	48	69	44	69	43	62
	Load in Z	342	341	329	329	327	308

Note: By design the aft pin (R1 on the image) of the Tip End does not take load in x direction and therefore this load in all case is 0. Moreover, the y load is only due to friction as all the dynamic load in this component is taken by the Root End. Load in Z indicates max compression.
LC1: Head seas
LC2: Beam seas

6.3. Seafastening

The blade rack is common for both OEMs in some features.

Amongst the others, tip and root rack structure, access stairways, distancing between center to center of two neighbouring blades in X axes (w.r.t. vessel standard coordinate system), and footprint on deck/substructure are common features.

Other features which are not common, but OEM specific are interface to tip support, root end support interface see, spacing between tip rack and root rack Table 6-4.

The substructure shall allow access to lower blade rack level for seafastening and access to higher blade rack layers for operations made possible via stairways incorporated into the blade rack design.

For loading and design considerations and requirements of substructure please refer to Annex [A4] Blade Rack Design Load Manual.

The blades are supported at the root and the tip end in each rack. The blades are being transported in horizontal orientation with the blade tip end pointing upwards.

6.3.1. General overview of the blade rack

The blade rack consists of column modules that are 3 layers tall, but an additional module can be added to increase the intake to four.

Safe access and platforms, lights and sockets are included in the blade rack design. Safe walkways are on all levels and where possible staircases are included so technicians can work without harnesses. Rescue points, emergency exits, and the substructure design need to align with the evacuation routes.

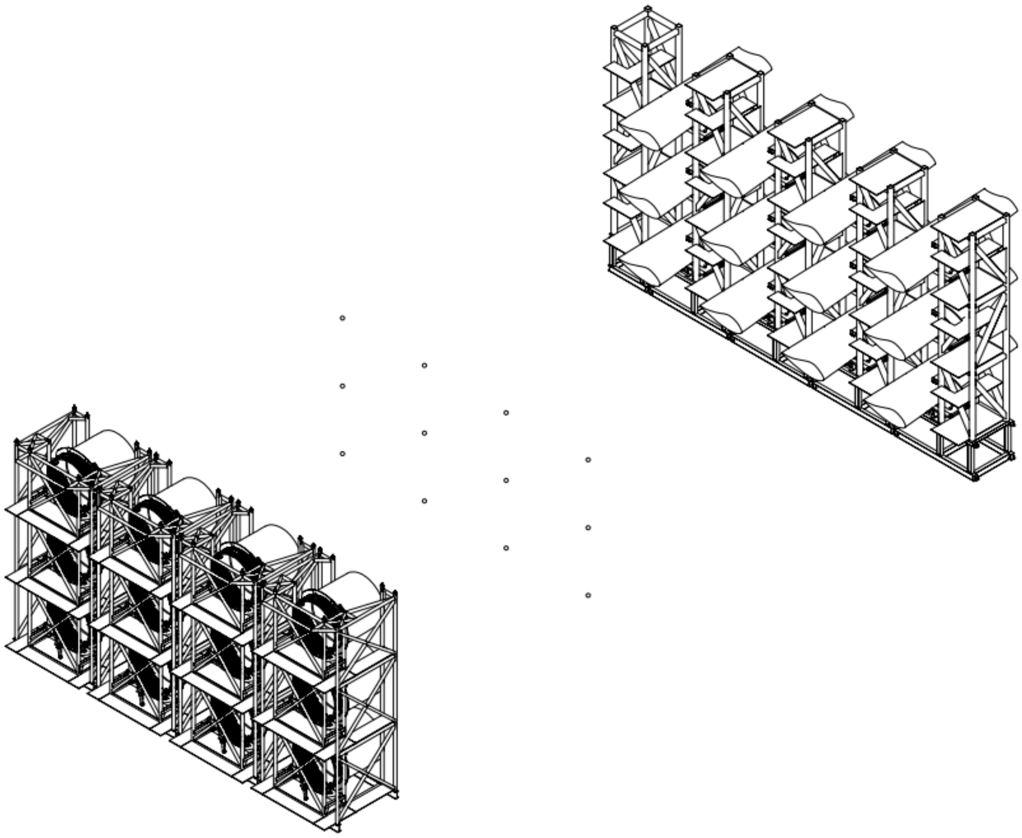

Figure 6-2 – Example of blade seafastening

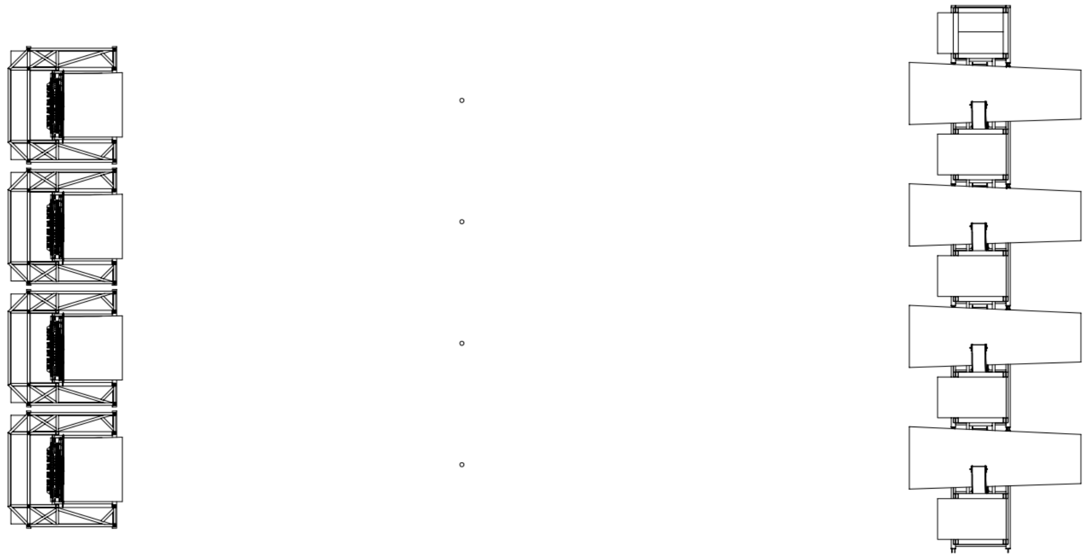

Figure 6-3 – Example of blade seafastening, top view (4 root modules and 5 tip modules shown)

The preferred blade COG positioning is so that the crane boom will be at 90 degree angle relative to the blade longitudinal axis when picking up the blades, alternative angles subject to OEM approval of the deck layout. Regardless of the actual positioning, it is essential to perform a clash check between the traverse taglines and the blades during lifting.

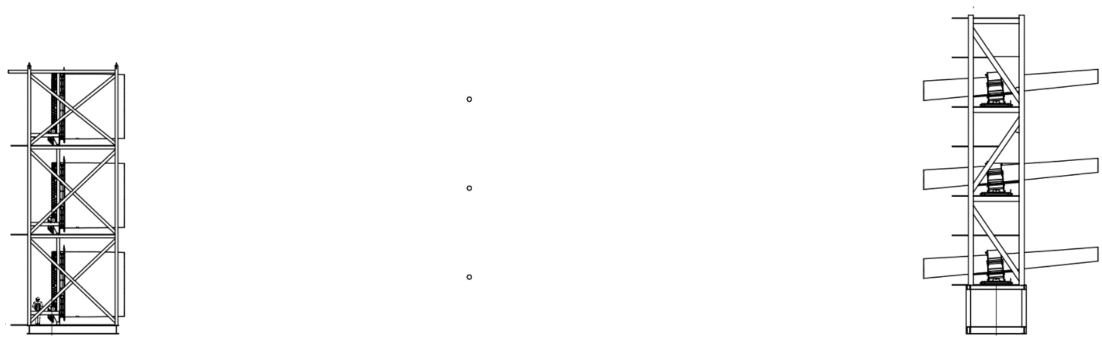

Figure 6-4 – Example of blade seafastening, side view

The distance to the tip supporting point as well as spacing between the blades shall enable free access for blade lifting yoke so that blades can be lifted safely and directly into the installation position.

In order to see how blades are fixed and seafastened in the blade rack, see Annex [A4] Blade Rack Design Load Manual. Examples are shown in Figure 6-7 to Figure 6-9.

At the root end the blades are supported, allowing the blade to rotate around the vertical axis and at the tip end each blade is supported by a tip clamp at a fixed position on the blade which can slide in Y direction. The tip end support point to the blade is to be placed in accordance with the values in Table 6-4.

The horizontal "center to center" distance between two blades is 8.5m, see Figure 6-6. The vertical distances vary based on OEM setups. For further information please refer to Annex [A4] Blade Rack Design Load Manual.

For landing and lifting fenders and guides will be included in the blade rack substructure design. As supporting control, the traverse system and eventual deck capstan will increase the control when picking up the blades.

The modular blade rack is designed to provide sufficient spacing between layers to mount blade yoke. For the blade lifting yoke to access the lowest blade (1st layer) properly, the space between lowest blade and blade rack base surface must stay clear.

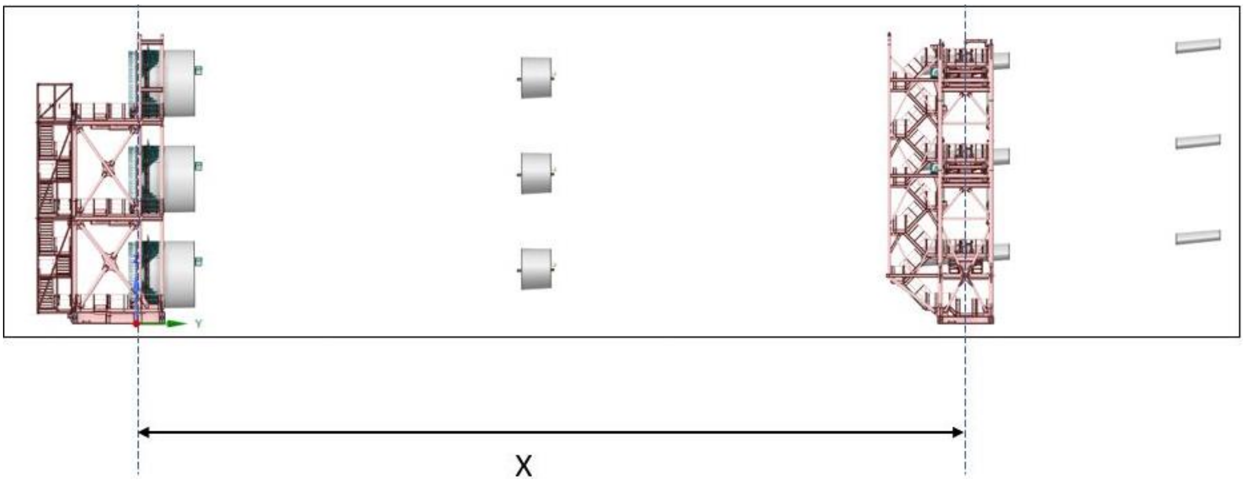

Figure 6-5 - Spacing between root and tip support points

Table 6-4 - Requirements for spacing between root end and tip support

Blade type	Support span X (m)
V236 115.5m blade	57.5
B108 (SG222)	57.0
B115 (SG236)	65.0

Please note the X spacing of the racks on the support structure for B108 and V236 is identical. The 50 cm difference will be adjusted by supporting method for each individual blade in the root end.

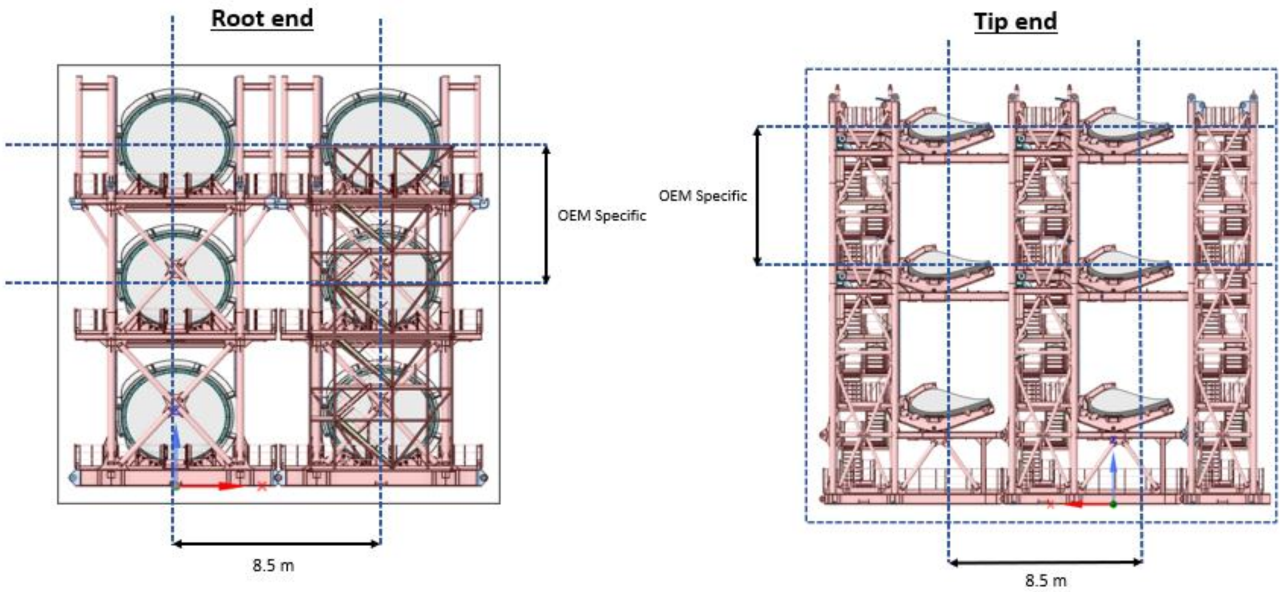

Figure 6-6 – Blade "Centre-to-Center" distance (common for B108, B115, and V236 115.5m)

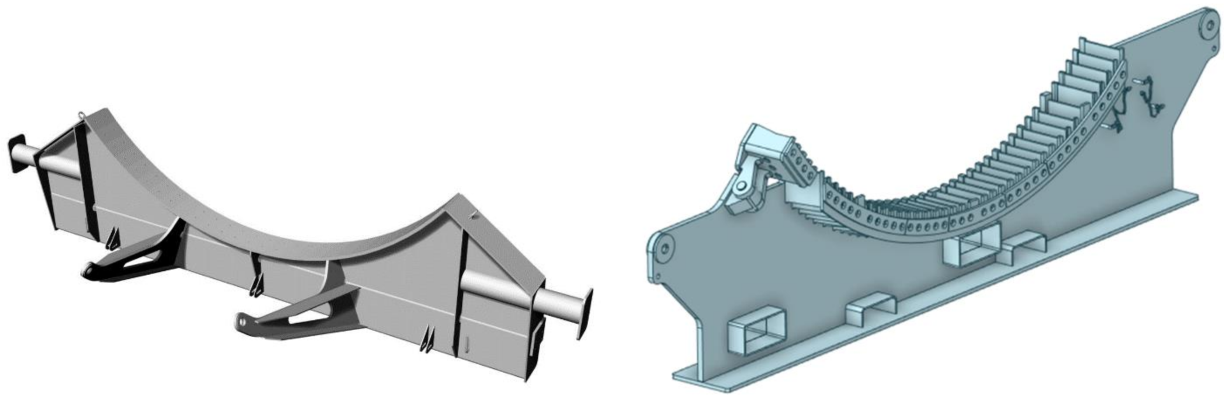

Figure 6-7 – OEM-specific root end blade foot interface examples

Figure 6-8 - Blade foot mounting interface on the blade rack (for root end) example

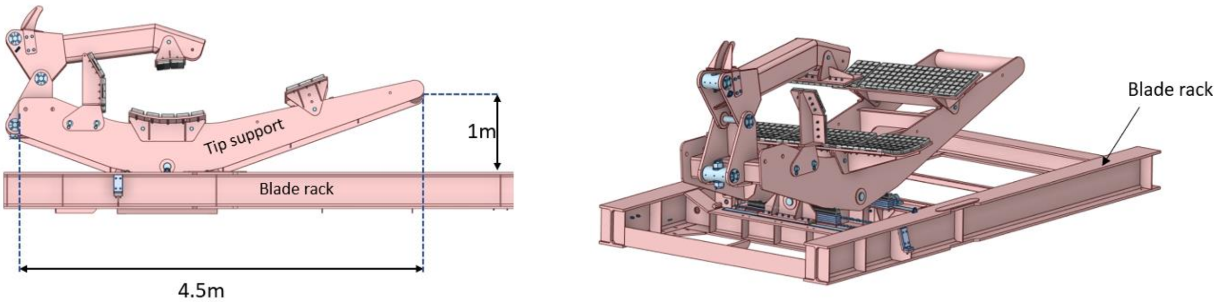

Figure 6-9 - Blade tip support interface on blade rack example

The substructures are the structures between the deck and the blade rack structure described in Section 6.3.2. The substructure must be designed to be able to withstand the loads from the blade rack Including blades and to have sufficient strength to maintain integrity of the blade rack itself.

If the substructure is to protrude above the base of the blade rack (see Figure 6-10), OEM is to be notified for acceptance. Further the blade yoke needs to operate in all positions on the blade rack with free space around the structures. When available, a simplified model of the Lifting Yoke may be provided by OEM upon agreements.

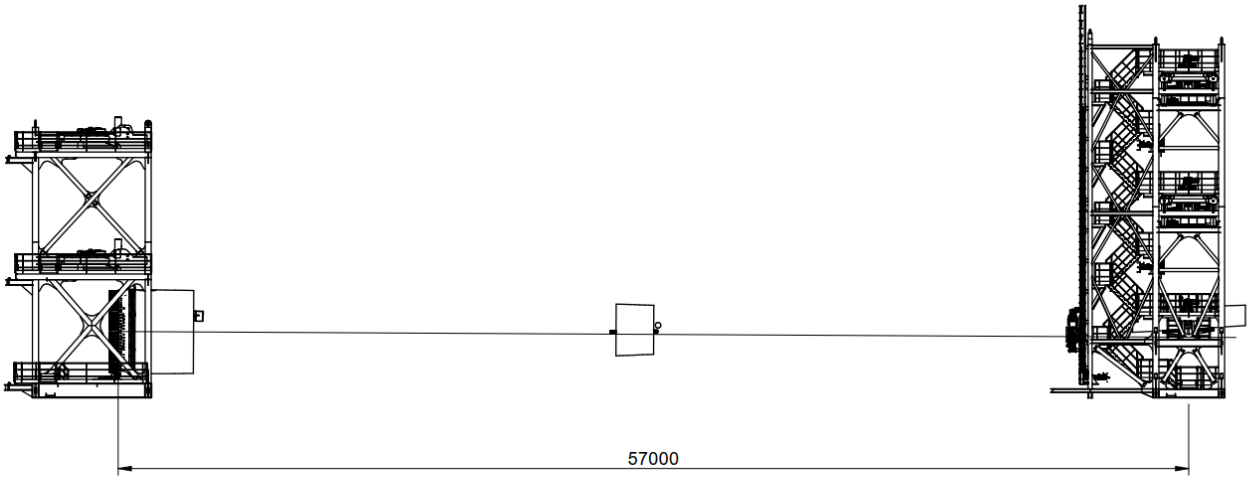

Figure 6-10 – Blade rack side view example

The substructure for the modular blade rack shall be designed to support the blade racks according to the procedure described in Annex R4.

Note that the modular blade rack is designed to be assembled at quayside and lifted onto the substructure as one assembly. Guiding bumpers shall be provided by seafastening designer to aid installation of blade rack onto the substructure. It is currently deemed not possible to assemble the modules individually on the substructure.

If there are any split between OEM and vessel provider regarding loading or installation onto substructure this shall be specified in Annex R1 Scope and Responsibility Matrix Seafastening.

The horizontal relative alignment of root and tip end of the blade rack is shown in Figure 6-11 for a four-column rack. The picture is for reference only, please refer to Annex [A4] Blade Rack Design Load Manual for further information.

To detail the load on the bladerack and bladerack substructures, wind loads acting on the blades are to be provided by the OEM. Refer to Annex [A4] Blade Rack Design Load Manual and [O3] Installation & transportation tools and solutions for further information on pitch angles.

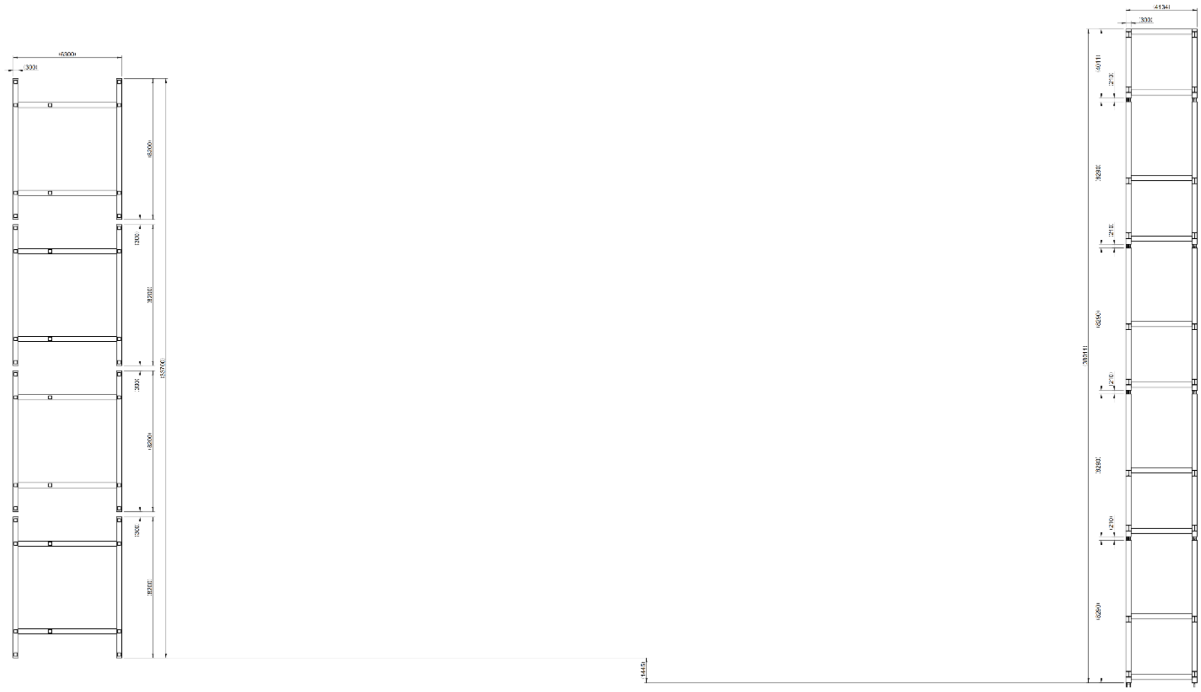

Figure 6-11 – Substructure interface for blade rack (Annex R4 may be referred for more details) example

The footprint of a module is depicted in the below picture. Note that the position of the uplift preventers and seafastening brackets of the Tip end of Vestas bladerack and a SGRE bladerack are slightly different from each other. Check the details on the GA drawings; refer to Annex [A4] Blade Rack Design Load Manual for further information.

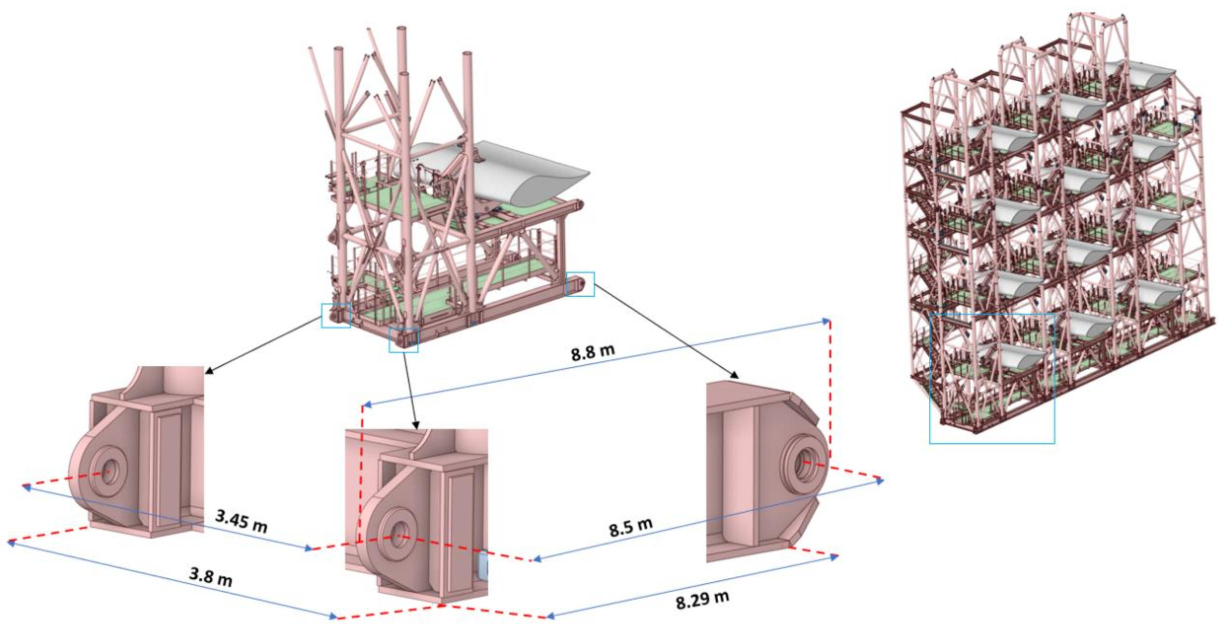

Figure 6-12 - Modular connection between modules of the tip end blade rack example

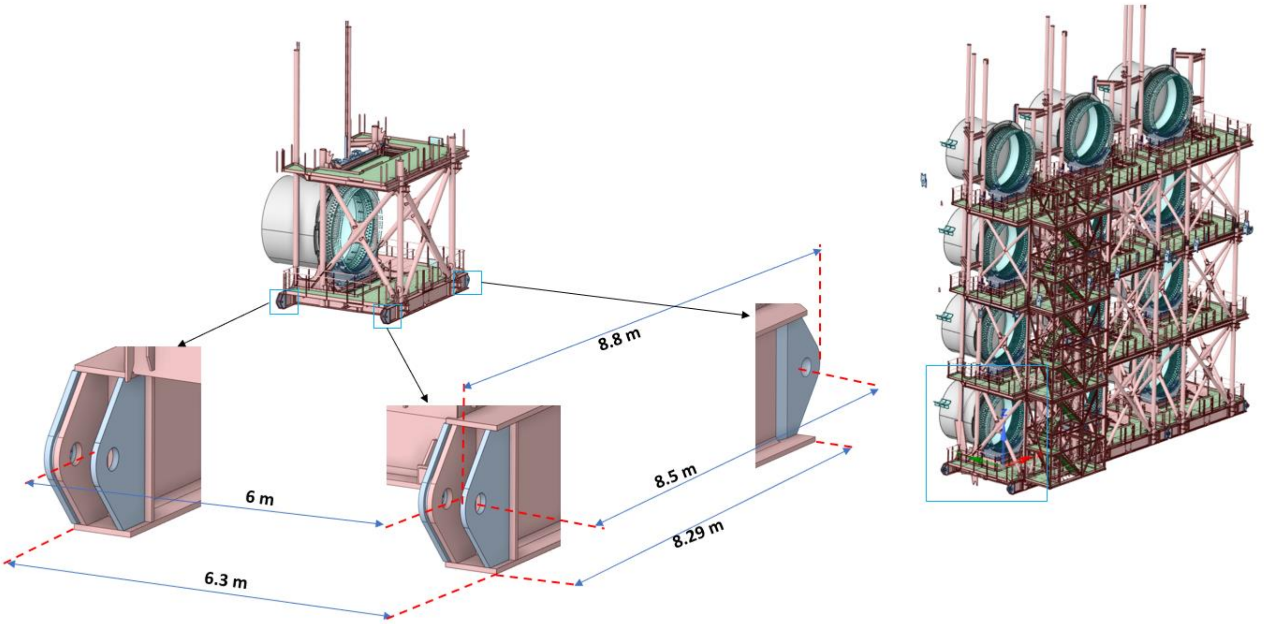

Figure 6-13 – Modular connection between modules of the root end blade rack example

6.3.3. Minimum height of the first blade

The minimum height is to be calculated by sea fastening designer taking into account the motion analysis and geometry of the blade.

The blade tip deflection when loaded by accelerations of Table 6-1 and wind speed 32.5 m/s (@10m @10min) is presented in Table 6-5. Please note the values are characteristic, meaning that load factor is considered 1.0 for deflection evaluation. Figure 6-14 shows the baseline and direction.

The substructure shall be designed with enough height to secure that the blade tips do have sufficient clearance to wave tops during all sailing conditions. It is recommended to keep 1.0 m clearance between blade tip and wave tip crest.

Table 6-5 – Blade tip deflection

Blade type	Characteristic Tip deflection (m)
V236 115.5m blade	3.5
B108 (SG222) & B115 (SG236)	

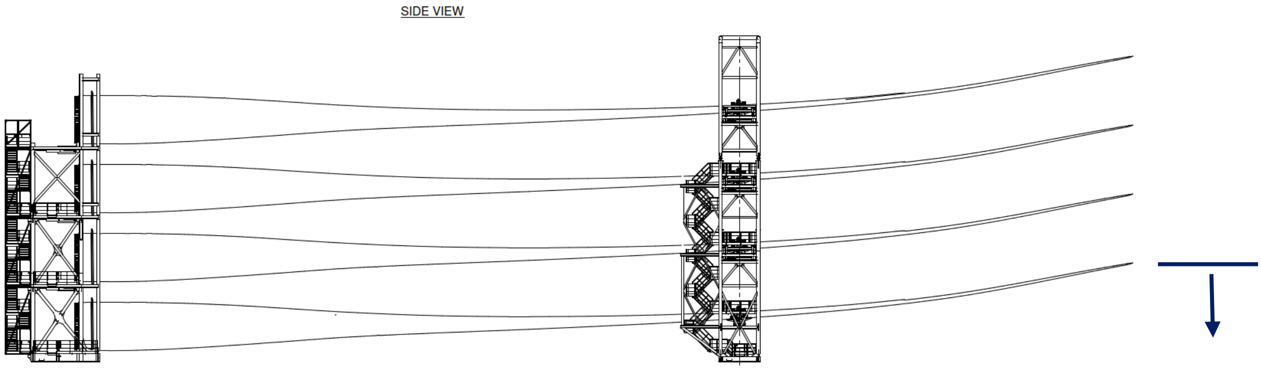

Figure 6-14 – Direction of blade tip deflection for an example blade rack arrangement

Staircases should be constructed in such a way that the climb angle is between 35-45deg, preferred 40deg. Staircases, walkways and platforms should be constructed according to EN 14122 and in such a way that evacuation is possible e.g. with spine board. Required height is minimum 2.1m; width of staircases, walkways and platforms in areas of evacuation is minimum 900mm.

Evacuation of a casualty must be aligned with the blade rack design so the casualty can be carried or lifted down to deck level.

6.4. Power requirement

Sufficient lighting is to be provided on blade rack substructure access ways, stairways, and communication routes leading to the blade rack.
The OEM recommended lights are 20 lux. Electric cabling must be IP67. The lights must be usable in an emergency situation with battery pack included on the main access route.

More details regarding power requirements can be found in Annex [A2] Power Supply

Figure 6-15 - Power Supply on blade rack example

7. Design criteria for lifting equipment

7.1. Tower lifting yoke

OEM will provide the seafastening feet along with the tower gripper. The sea-transport feet are welded to the deck. The Tower Gripper is delivered with seafastening feet which must be level. The feet must be welded onto the vessel deck corresponding to the Tower Gripper footprint. The Tower Gripper is then lowered into the feet and secured by turnbuckles. Feet and turnbuckles are provided by OEM. See Annex [A1] Scope and Responsibility Matrix for scope of supply responsibility details.

Figure 7-1 - Tower gripper support example

7.2. Nacelle lifting yoke

OEM will provide the seafastening feet and turnbuckle along with the nacelle yoke.

The sea-transport feet need to be welded to the deck.

Figure 7-2 - Nacelle yoke support example

7.3. Blade lifting yoke

In general, the following items are included in the seafastening for the blade yoke:

- Supports for footprint
- A solution for taking shear forces and tie-down for uplift

Figure 7-3 - Blade yoke support example

8. Storage of minor handling components

8.1. Containers

All containers require elevation (e.g. 125mm) due to risk of water on deck. Containers also require grounded connections. Corner castings and/or dove tails must be welded onto the vessel deck, see Figure 8-1 and Figure 8-2. For containers having power outlets in the side, there should be a minimum of 250mm spacing between the containers.

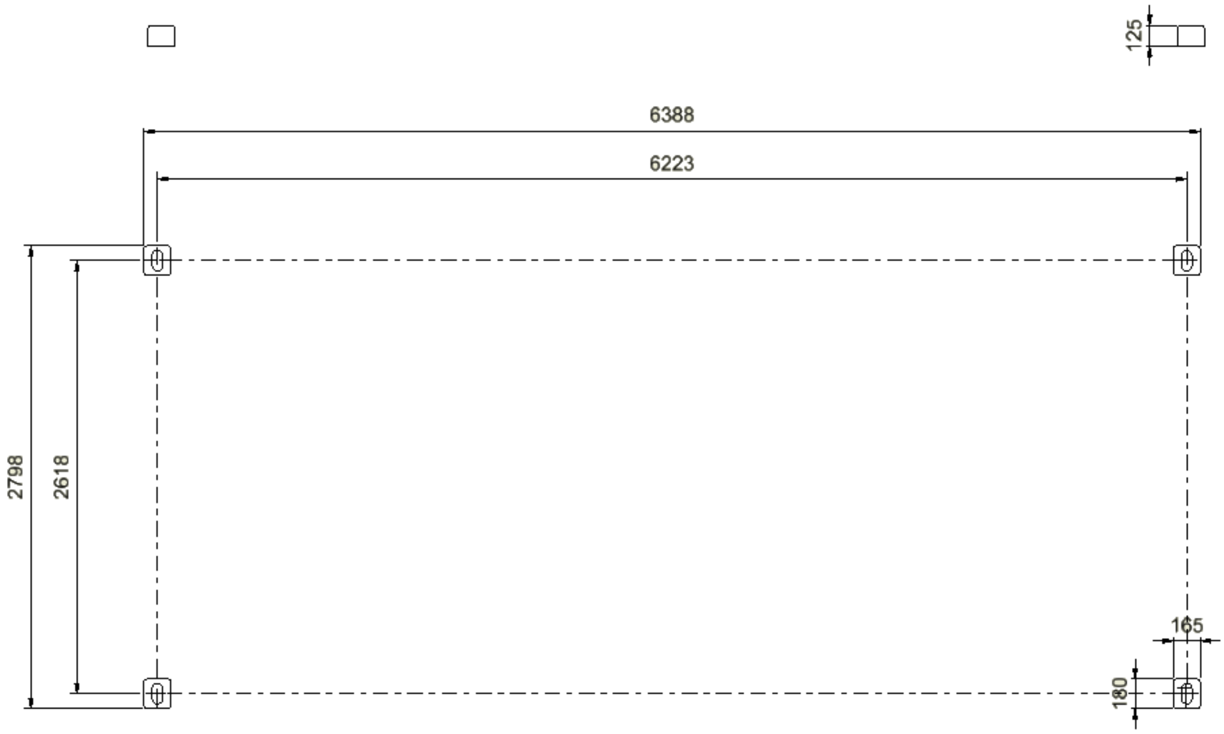

Figure 8-1 – Schematics of 20ft container corner casting footprint.

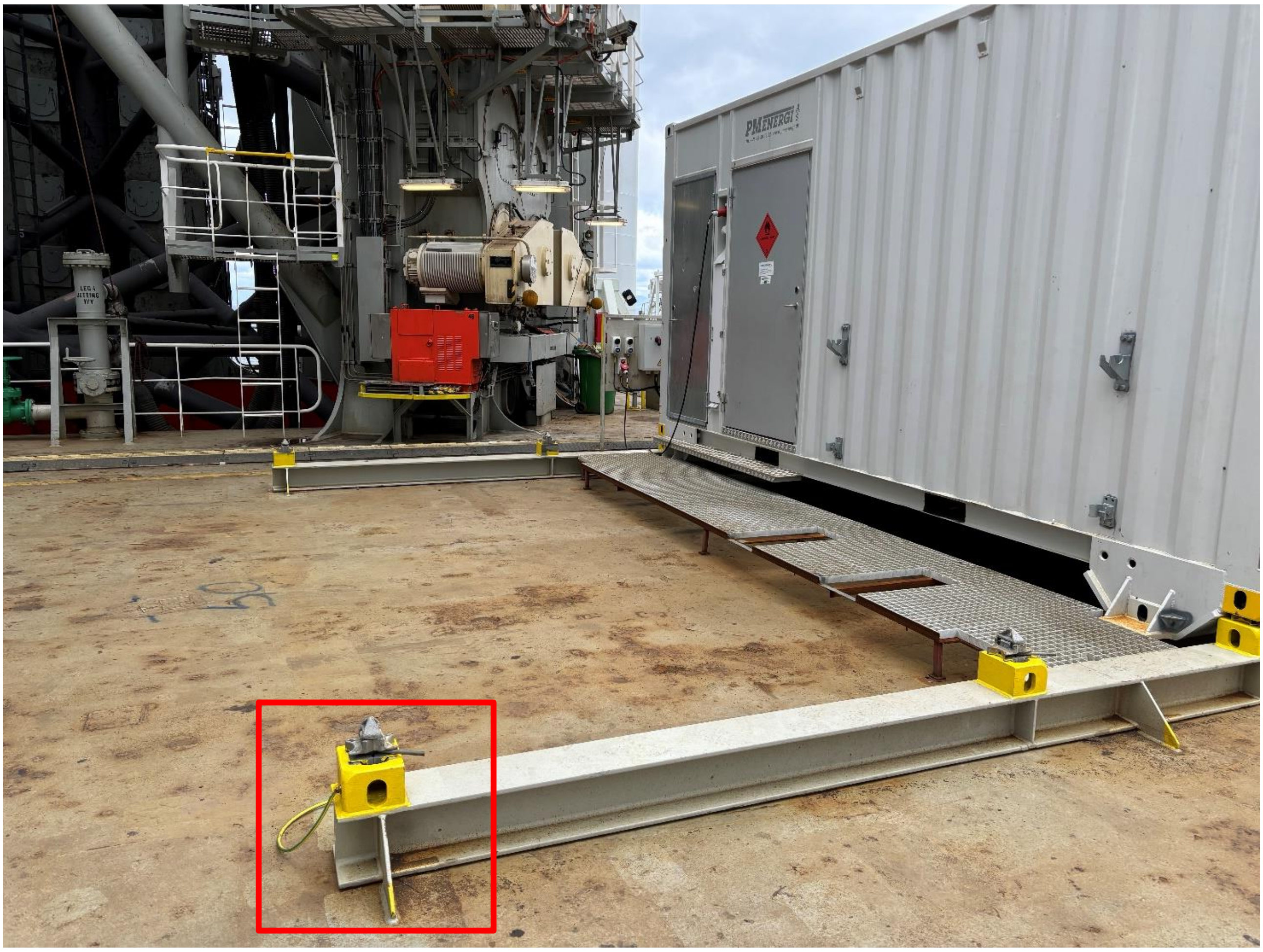

Figure 8-2 – Grounded connections of 20ft container

A stand needs to be created to place the rigging equipment/ lifting frame of the containers, this stand should be part of the deck layout and verified by OEM. (see Figure 8-3 as an example)

Figure 8-3 – Seafastening of the lifting frame example