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FLOATING WIND WEIGHT ESTIMATING FOR INSTALLATION

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SUMMARY

Weight control of floating offshore wind turbines which is a growing market within the marine renewable energy sector. The floating offshore wind turbines give access to deeper water sites, with minimal visual impact from land, once operational. The paper includes the weight control requirements for Spars, barges, semi submersibles and Tension Leg Platforms (TLPs) as floating wind platforms and in addition for various new arrangements such as turret mooring and suspended ballast keel.

Discussion is included on heavy maintenance the implication for accurate weight control during operations. There are weight control challenges for the various substructure types during the temporary phases of construction and offshore installation. An accurate assessment of the buoyancy of the floating wind turbine for different drafts and trims is required. Allowances need to be included in the weight calculation for temporary buoyancy, sea-fastenings and grillage.

Weight control for installation has an influence on the weather window for the floating substructures during transportation to the offshore site, and for their mooring and electrical connection. The paper will cover weight calculation methods during early design, detailed design, construction, installation, operation and demolition.

The installation process for a floating wind turbine varies with substructure type and this paper will give an overview of the weight control requirements for loadout, ocean transport and mooring connection. The floating offshore wind turbine weight and centre of gravity has a direct bearing on draft, intact stability and motions. As part of the weight control process the centre of gravity and radii of gyration need to be accurately determined for each stage of the installation.

1. Introduction

Floating offshore wind turbines are being developed to produce renewable energy in water depths beyond about 200 and up to 1,000 ft (61 to 305 metres). The options for floating offshore wind turbines are described in section 2. The design requirements for weight control are described in section 3. Weight reports during various the construction phases are described in section 4. Weight measurement during the construction and installation phase is presented in section 5.

2. Structures

2.1 Size and Complexity

The three main types of floating offshore wind turbine are) are shown in figure 1 and are the semi submersible, the Spar and the Tension Leg Platform (TLP) and are certified by classification societies per ref [1], [2], [3] and [4]. Damping barges have similar installation methods to those used for semi submersibles.

Floating Offshore Wind Turbine (FOWT) structures and their associated subsea cables are very capital intensive. The topsides of tower, nacelle-generator and blades are very similar to those used on fixed offshore wind platforms and thus their weight and vertical centre of gravity are readily available. FOWT weight control is carried out in accordance with the international guidelines, ref [16]. The largest turbine on a floating offshore wind turbine at present is 9.6MW, but in the future turbines of up to 15MW are predicted. This means that with limited numbers of floating offshore wind turbines in operation extrapolation of existing weight data is required to provide dimension and weight estimates.

Table 1 gives details of the weight constraints per type of Floating Offshore Wind Turbine, which determines the selection of construction and installation methods. During construction of the floating offshore wind turbine weight control is very important to ensure that draft constraints during fit-out and offshore towing are not exceeded.

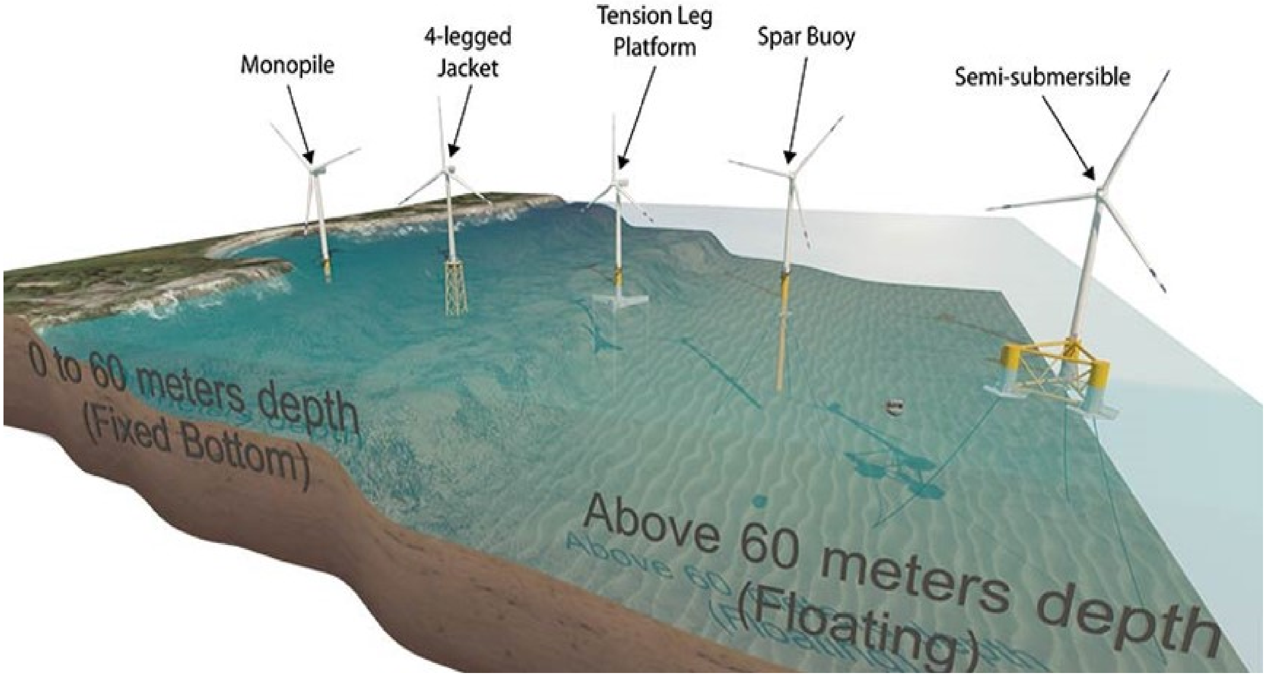

Figure 1 Floating offshore wind turbine types (Ref [5])

Table 1 Weight related constraints for various types of FOWT

TLP	SPAR	BARGE	SEMI SUBMERSIBLE
Very Low intact stability during tow-out, ref [6] and [7] so probably requires temporary buoyancy for tow out of large variation in draft.	Needs solid ballast after upending, ref [8] and [9]. Deep water required for inshore construction	many mooring lines, ref [10]	Heavy construction. Temporary buoyancy in dry dock, ref [11] and [12]

2.2 Floating wind turbine components

Floating offshore wind structures must be moved, floated, and rotated to attitudes differing from those under which they were initially built, thus it is important to have accurate weight data for all the different components. The main components of a floating offshore wind turbine are:

- Substructure is the hull (Spar, TLP, barge or semi-submersible)
- Foundations secure the FOWT to the seabed (driven or drilled or suction pile, drag anchor)
- Mooring lines are chain, wire or synthetic fibre or a combination of these. Note for catenary moorings there is always chain on any section of the mooring line which may touch the seabed.
- The topsides are the tower, nacelle=generator, hub and blades, sometimes referred to as the rotating nacelle assembly and tower (RNA)
- There are inter array cables connecting the FOWT to the subsea export cable

3. Weight control in design

3.1 Inputs

Weight has a direct bearing on draft, intact stability and motions of the floating offshore wind turbine. In addition the centre of gravity and radii of gyration need to be accurately determined.

The input data for the weight report is based on:

- Weight estimates from previous designs
- Material take off from drawings
- Supplier weight quotes
- As the design develops actual weights from suppliers
- Solid ballast in the base

In addition for each weight items the following need to be developed:

- Tolerances on weighed items, e.g. steel plate rolling tolerance of +/- 2%
- Allowances for unknown information
- Contingencies

3.2 Hydrostatics

Hydrostatics of the floating offshore wind turbines are required for different drafts and trims. Due account needs to be taken for variations in water density at the shipyard and fit out quay. The output includes:

- Buoyancy
- Centre of buoyancy
- Metacentric height

3.3 Analysis Steps

- Approve the weight control procedure
- Agree on weight contingencies and reserves
- Agree on weight budget and not-to-exceed weight
- Agree range of CoG, in three directions
- Determine total weight (reported weight + contingencies + loads)
- Confirm that the total weight is less than the not-to-exceed weight

- Confirm that the CoG is within the allowable range
- Issue weight report

3.4 Weight report information

Weight reports are issued on a regular basis, or when there are major changes to the structure. Throughout the project, periodically report

- The status of the overall weight and it's individual components,
- Changes to component weight and CoG from ocurrent report to the previous report,
- Trend of the base weight growth,
- Contingency, allowance reduction,
- CoG location within the CoG envelope,
- Allowable VCG curve
- Radii of gyration
- Buoyancy of the substructure
- Change in weight budget and loads,
- Changes in the weight reserves.
- Flag early warning of any potential over-weight-budget situation

Each weight report, during the design phase, is a snapshot of current knowledge

Weight control will provide continuous reporting of weight and centre of gravity to ensure that:

- Weights and centre of gravity are accurately predicted in detailed engineering
- Lift weights do not exceed the available lift capacity
- Structural design can proceed effectively
- The centre of gravity for each structure does not move outside the envelopes agreed

As the project develops the actual weights are calculated from design drawings and vendor weight data to develop the Net weight. Over the life of the project the net weight replaces the estimated weights. In addition allowances are made from the start of the project, which are gradually reduced as more detailed information becomes available:

- Initial estimated weight and contingencies
- Design development replaces estimated weights with calculated values
- Fabrication may use different materials
- The contingency factors are reduced as the information becomes more accurate
- The nacelle-generator will be weighed before delivery to the fit-out quay
- Weighing the complete substructure before loadout reduces contingency factors.

The radii is calculated as follows:

- The inertia and radii of gyration is initially calculated about the keel of the floating offshore wind turbine
- The vertical centre of gravity is calculated about the keel of the floating offshore wind turbine substructure.
- The radii of gyration is then calculated about the centre of gravity.

4.0 WEIGHT CONDITIONS

4.1 Loadout

Loadout, figure 2, weight and CoG is applicable when the item is to be moved horizontally from the shipyard onto the transport vessel. Installation aids and guides, rigging, or other temporary items are included. This weight is used to check transport vessel intact stability and strength.

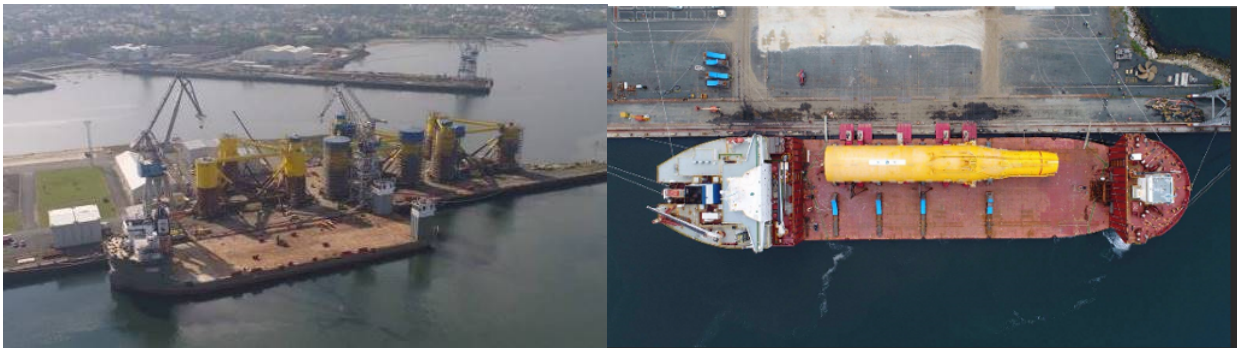

Figure 2 Loadout of semi-submersible, ref [11], and Spar ref [8]

4.2 Floatout

Floatout, figure 3, is the weight applicable when the FOWT is built in a dry dock. Weight, buoyancy and their associated centres are critical elements in floating out of the dry dock.

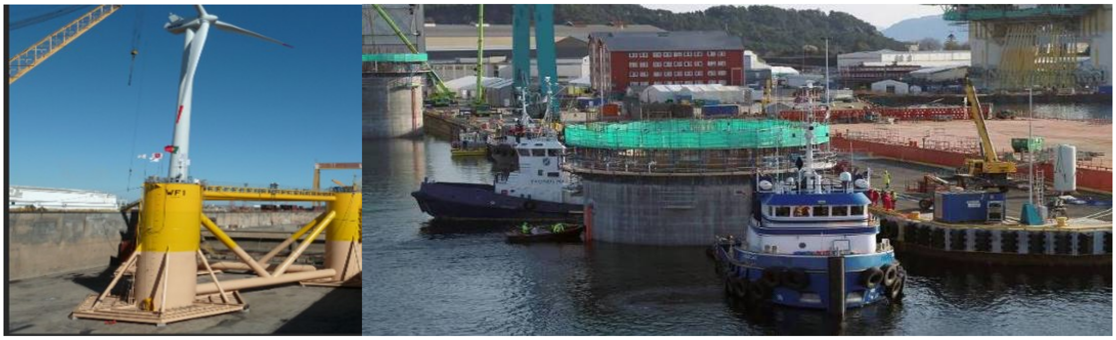

Figure 3 Loadout of steel semi-submersible, ref [11], and concrete Spar ref [8]

4.3 Dry Transport

The transport weight, figure 4, of the substructure during the dry tow phase includes any temporary items such as sea-fastenings and grillage weights are to be included. Weight and vertical centre of gravity is critical for assessing the transport vessel intact stability.

Figure 4 Dry transport of semi-submersible, ref [11] and ref[12]

4.4 Floatoff

Floatoff, figure 5, of the substructure hull after dry tow on a heavy transport vessel (HTV). Note that the heavy transport vessel is ballasted to a deep draft and it is imperative that the draft and hence the weight, buoyancy and their centres of the FOWT substructure are acceptable.

Figure 5 Floatoff of semi-submersible, ref [11], and Spar ref [8]

4.5 Fit out

At the fit-out quay, or sheltered inshore waters, the topsides are added to the substructure, figure 6. Installation aids, guides, or other temporary items such as rigging are included in the weight.

Figure 6 Fit out of semi-submersible, ref [11], and Spar ref [8]

In order to maximise the lift capacity of the onshore cranes during fit out the semi submersible type the turbine is placed over one column, or on the side, not in the centre. This means that the following implications for the 3 column semi submersible:

- Assuming all columns are of the same diameter then water ballast is required in the non turbine supporting columns to provide zero trim and heel during fit out, tow out and operation.
- The supporting column has to be strenthened to support the turbine weight
- If the semi submersible hull is built in a dry dock, because of the extra supporting steel on the turbine column then temporary buoyancy is required to float the substructure hull out of the dry dock
- 2 moorings are required on the turbine supporting colomn and one each on the other 2 columns

Square barges have their turbines on one side, to maximise lifting capcity of onshore cranes during fit out and this has the following effects:

- Ballast on the opposite side to the turbine
- On the corners close to the turbine have 2 moorings each
- On the corners opposite the turbines 1 mooring per each corner

For Spars the topside is lifted onto the substructure using a floating crane or by an onshore crane mounted on a spacer barge. The Spar water plane area is relatively small and so the turbine in mounted in the middle, so thus not effecting crane capacity when lifting the blades and heavy nacelles into place.

4.6 Tow out

Tow-out weight and CoG, figure 7, is important in determining the draft of the structure for the tow to the offshore location phase. It is to include any temporary items.

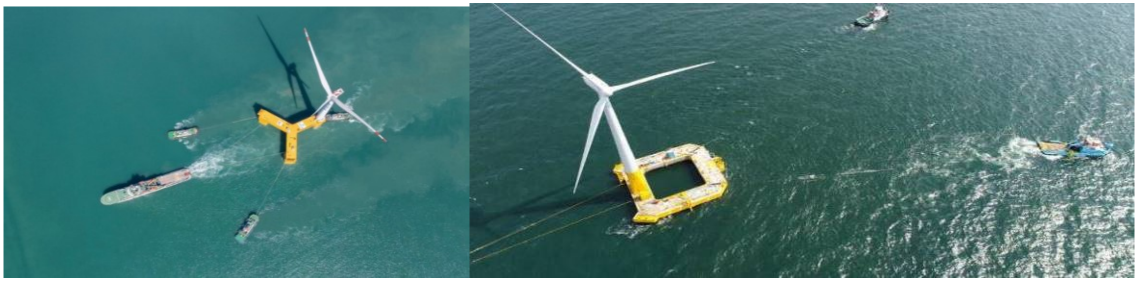

Figure 7 Wet tow of semi-submersible, ref [13] and damping barge ref[10]

4.7 Operating

The Operating weight, figure 8, applies following hook-up and commissioning, when the complete structure operates under normal conditions; i.e. when storage tanks and pipework contain related fluids and consumables, at designed maximum operating levels. The storm weight is assumed to be the same as the operating weight as the floating offshore wind turbines are designed to be unmanned but to remain stable in all operating conditions.

Estimates of mooring equipment are to be calculated but shown as separate items. Estimates of dynamic mooring cables are to be calculated but shown as separate items. Estimated for variables such as marine growth, ice or snow are not included in the weight report however they form part of the naval architecture and structural analyses. One compartment damage is not included in the weight report but forms part of naval architecture analyses.

Figure 8 Semi submersibles operating, Ref [13], Ref [11] and Spar operating Ref [8]

Heavy maintenance of floating offshore wind turbines has implications for weight control as follows:

- For a semi submersible there is a possibility to return the structure to port to for change of nacelle or blades. This return to port becomes very complicated if the dynamic array cables used to export the electrical power are daisy chained from one structure to another on the wind farm. The replacement blades or nacelle may be of different weight from the original.
- For a barge there is a possibility to return the structure to port to for change of nacelle or blades. This return to port becomes very complicated if the dynamic array cables used to export the electrical power are daisy chained from one structure to another on the wind farm. The replacement blades or nacelle may be of different weight from the original.
- The Spar type has a very deep draft and can only return to deep water sheltered locations, complete with temporary moorings. There is further complication if the dynamic array cables used export the electrical power are daisy chained from one structure to another on the wind farm.
- The TLP type has very complicated moorings and very low stability during towing and so it is unlikely that it would be returned to port for heavy maintenance.

Novel ways need to be developed for offshore heavy maintenance of Spars and TLPs and perhaps semis submersibles and barges e.g. using floating crane vessels fitted with crane hooks which have active heave compensation or by using cranes that tower.

Prior to the demolition of the FOWT estimates need to be made of items added or removed during the operation life.

5.0 Weight items

5.1 Radii of gyration

Radius of gyration of a body about an axis of rotation is defined as the radial distance to a point which would have a moment of inertia the same as the body's actual distribution of mass, if the total mass of the body were concentrated. The radius of gyration of a floating body is important input into any motions calculations for the dry tow, wet tow and operations.

5.2 COG

For each construction phase the transverse COG (TCG) and longitudinal COG (LCG) are to be within the range set by naval architecture and structural calculations.

The allowable vertical centre of gravity (VCG) curve is developed by the naval architect. The maximum allowable VCG curve is a combination of the limitations resulting from the intact stability and the damage stability requireements.

5.3 Weight allowances

Weight contingencies are to be developed, example for example in table 2

Table 2.1 Weight contingencies substructure

Item	Source of Margin	First Estimate	End of Detail design	Weighing
		%	%	%
Sub structure, hull	General tolerance error	5	2	2
	Potential design error	4	0	0
	Fabrication – mill tolerance, welding	3	3	0
	TOTAL MARGIN	12	5	2

Table 2.2 Weight contingencies topsides

Item	Source of Margin	First Estimate	End of Detail design	Weighing
		%	%	%
Topsides Tower, nacelle, blades	General tolerance error	8	2	2
	Potential design error	7	0	0
	Fabrication – mill tolerance, welding	3	3	0
	TOTAL MARGIN	18	5	2

6. Weight measurement during construction and installation

6.1 Design input

Theoretical calculations will typically be performed in the engineering office of the shipyard based on approved for construction. A margin or allowance will be carried to account for the missing details until such time as they are defined.

6.2 Weighing the completed substructure

The Fabricator will produce a weight and CoG estimate based on fabrication drawings on a per-component basis. Weight control is a continuing activity, based on a hybrid of design drawings and fabrication drawing take offs. There is a physical weighing of the substructure prior to loadout.

6.3 Draft survey

A draft survey is required just after arrival at the fit-out quay and just before departure for the offshore site. The following are measured:

- Draft mark on each column to an accuracy of better than +/- 1 inch (25mm)
- Sea water density at the surface and 30ft depth
- Fluid in ballast tanks
- Assessment of solid ballast added at the base

From these measurements the following can be determined using the hydrostatics:

- Weight of structure
- Trim
- Heel
- Longitudinal centre of gravity
- Transverse centre of gravity

6.4 Possible inclining experiment

An inclining test, ref. [2] may be used to determine weight, plan CoG and in particular the vertical centre of gravity of the barge or semi submersible FOWT at the fit-out quay.

Where an inclining test is not possible e.g. the suspended keel type,, ref[14] and re[17] and figure 9, accurate weighing of the components is required.

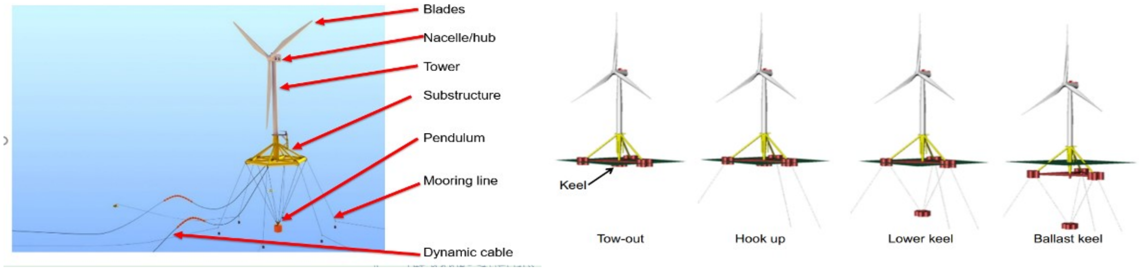

Figure 9 Saipem Hexafloat with submerged pendulum and Stiesdal submerged ballast keel

7. Discussion And Conclusions

7.1 Discussion

The weight and COG of the floating offshore wind turbine is direct input into the draft and intact stability at various stages of construction. The weight, COG and radii of gyration are important inputs into the motions during the dry tow, wet tow and operations. Spars have solid and water ballast. Semi submersibles have water ballast.

7.2 Conclusions

Accurate calculations are required for weight, CoG, radii of gyration and buoyancy at the various stages of construction, installation and operation.

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9. Acknowledgements

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10. **Terminology**

CoG:	Center of gravity
FOWT:	Floating offshore wind turbine
LCG:	Longitudinal center of gravity
RNA:	Rotating nacelle assembly
SPMT:	Self propelled modular transporter
TCG:	Transverse center of gravity
VCG:	Vertical center of gravity