Construction Port Requirements for Floating Offshore Wind Turbines

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Abstract**—**As the floating offshore wind turbine industry continues to develop and grow, the capabilities of established port facilities need to be assessed as to their ability to support the expanding construction and installation requirements. This paper assesses current infrastructure requirements and projected changes to port facilities that may be required to support the floating offshore wind industry. Understanding the infrastructure needs of the floating offshore renewable industry will help to identify the port-related requirements. Floating offshore wind turbines can be installed further out to sea and in deeper waters than traditional fixed offshore wind arrays, meaning it can take advantage of stronger winds. Separate ports are required for substructure construction, fit-out of the turbines, moorings, subsea cables and maintenance. Large areas are required for the laydown of mooring equipment, inter array cables, turbine blades and nacelles. The capabilities of established port facilities to support floating wind farms are assessed by evaluation of size of substructures, height of wind turbine with regards to the cranes for fitting of blades, distance to offshore site and offshore installation vessel characteristics. The paper will discuss the advantages and disadvantages of using large land based cranes, inshore floating crane vessels or offshore crane vessels at the fit-out port for the installation of the turbine. Water depths requirements for import of materials and export of the completed structures will be considered. There are additional costs associated with any emerging technology. However, part of the popularity of Floating Offshore Wind Turbines stems from the cost savings against permanent structures like fixed wind turbines. Floating Offshore Wind Turbine developers can benefit from lighter, more cost effective equipment which can be assembled in port and towed to site rather than relying on large, expensive installation vessels to transport and erect fixed bottom turbines. The ability to assemble Floating Offshore Wind Turbines equipment on shore means minimising highly weather dependent operations like offshore heavy lifts and assembly, saving time and costs and reducing safety risks for offshore workers. Maintenance might take place in safer onshore conditions for barges and semi submersibles. Offshore renewables, such as floating wind, can take advantage of this wealth of experience, while oil and gas operators can deploy this experience at the same time as entering the renewables space. The floating offshore wind industry is in the early stages of development and port facilities are required for substructure fabrication, turbine manufacture, turbine construction and maintenance support. The paper discusses the potential floating wind substructures as this provides a snapshot of the requirements at the present time, and potential technological developments required for commercial development. Scaling effects of demonstration-scale projects will be addressed; however the primary focus will be on commercial-scale (30+ units) device floating wind energy farms.

Keywords**—**Floating offshore wind turbine, port logistics, installation, construction.

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I. Introduction

THE ability to assemble Floating Offshore Wind Turbines (FOWT) structures on or near shore means minimising highly weather dependent operations such as offshore heavy lifts and assembly, saving time and costs and reducing safety risks for offshore workers. Maintenance might take place in safer nearshore conditions for barges and semi submersibles.

The floating offshore wind industry is in the early stages of development and port facilities are required for substructure fabrication, turbine manufacture, turbine construction and maintenance support. The article discusses the potential floating wind substructures. Demonstration and pre commercial units have been installed. With regards to ports the primary focus will be on commercial-scale (30+ units) device floating wind energy farms.

The function of ports for the construction, installation and maintenance of floating wind is varied:

- Supply base for the geotechnical and weather survey of the offshore site. This takes place before the detailed design of the FOWT starts.
- Construction of the substructure, possibly an existing shipyard
- Quayside factory for blade manufacture
- Loadout quay for nacelle and tower
- Laydown area for mooring components
- Laydown area for dynamic array cables
- Fit-out quay for installing turbines
- Support port during offshore installation phase
- Future maintenance support harbour

This paper reviews the port requirements and defines the role of ports for floating wind.

The challenges for floating offshore wind turbine (FOWT) depend on the type of substructure, water depth, prevailing weather conditions, seabed soil and size of the wind turbine. To date the largest turbine on a FOWT is 9.6 MW [17]. Larger powered turbines, up to 15 MW, are being ordered for new bottom fixed wind farms.

The remainder of the article is structured as follows: Section II provides a brief literature review for floating wind construction and installation. Options for reviewing floating wind construction ports are discussed in Section III. The analysis of port requirements is considered in Section IV. Results are shown in Section V. Discussion is in Section VI and conclusions are given in Section VII.

II. Literature Review

The shipyard for substructure construction can be a long distance from the offshore location. But the fit out yard needs to be as close to the offshore site as possible, to minimise tow out times which are weather restricted. Ports are regarded as the pinch points in the deployment of FOWT [1].

The availability of fit out ports, and respective water depth alongside the quay, is a major factor in determining the type of floating wind turbine that is to be used. This is important as the design focus for floating wind platforms is often on the site conditions. Yet, ports are a critical engineering constraint to be able to realise the installation of floating turbines. The achievement of energy production decarbonisation goals requires stepping up the deployment of floating offshore wind.

Upscaling port infrastructure and investments need to be aligned with the long-term use of FOWT [2]. There are several floating wind designs competing for commercial deployment, which will need different infrastructure requirements. The assembly of floating wind systems, as opposed to bottom-fixed turbines, is mostly based onshore. Therefore, ports will need expansion of their land area, quay reinforcement, storage for components, carrying capacity, cranes and other retrofits to host mass production of floaters and other turbine components.

The floating wind industry could partly use the infrastructure of the existing ports, currently used for bottom-fixed offshore wind and offshore oil and gas platforms. Ports, existing or future, need to maximise the whole supply chain efficiency of existing bottom-fixed offshore wind platforms. Space is and will become a bigger issue for ports. To overcome this, ports will require new strategies and regional collaboration.

Port Talbot in South Wales [3] is being promoted as a potential port for construction of substructures and fit out of topsides because it has over 15 m of water at low tide in a sheltered location. Port requirements are discussed in [7] for constructing FOWTs in California.

Additional port facilities are needed to support wind turbine manufacturing, substructure fabrication, fit out, and support for offshore installation, operation and maintenance of wind farms.

Demonstration scale projects (approximately less than five devices) have different port infrastructure requirements than full commercial scale projects (30+ units), as the supply chain logistics and costs of scale will be significantly different [8].

III. Floating Wind Status

A. General

The main parts of a FOWT are shown in Fig. 1. The topsides are the blades, nacelle and tower, which are provided by the turbine manufacturer. The substructure is in part limited by the port used for construction and fit out. The moorings include the mooring lines and the anchor type e.g. drag anchors, suction piles, driven piles or drilled piles.

There are dynamic cables from the substructure to the seabed. The export cable is buried in the seabed. The export cable may go to land-based grid, typically via a substation or to supply electricity to offshore oil and gas platforms.

Different types of FOWT are given in Table I. The minimum water depth for alongside quay construction work is at lowest astronomical tide (LAT) 1 m under keel clearance plus the level trim draft of the FOWT. Ports with a water depth of up to 15 m can accommodate semi-submersible, Barge and Tension Leg Platform (TLP) type platforms, whilst Spar platforms require up to 80 m water depths.

Concrete structures, for the same plan dimensions, have a higher weight that steel substructures and so the concrete structures have a deeper draft. Spars both steel and concrete have very deep drafts and gain their intact stability from adding solid ballast to their base. Barges gain their stability from their width and they have the minimum draft, however they have the largest motions in operation. Semi submersibles gain their stability from the second moment of water plane area and have lower motions than barges, multi turbine FOWT are based on very large semi-submersible hulls.

TABLE I
FOWT Types and Fit out Quay Draft Range Requirements

FOWT type	Fit out quay Draft range	Substructure construction material
Barge	6 m to 8 m	Steel
Barge	10 m to 12 m	Concrete
Semi sub.	10 m to 12 m	Steel
Semi sub.	12 m to 15 m	Concrete
Spar	70 m	Steel
Spar	80 m	Concrete
TLP	10 m to 12 m	Steel
Multi turbine	10 m to 12 m	Steel

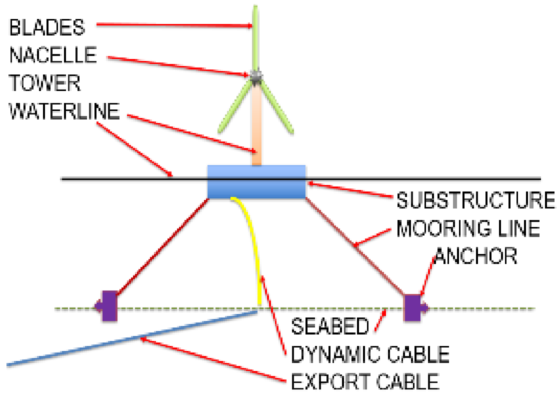

Fig. 1 Main parts of FOWT [7]

The design guidelines for floating wind are provided by classification societies, such as DnV [7].

B. Barges

A barge is a hull made of either steel or concrete, see Fig. 2. It is stabilised in place through its buoyancy (water plane area). The assembly of the structure is performed onshore and towed offshore using tugs. Barge structures have a low draft, making them suitable also for shallow water ports, though they have higher motions in waves than other types of FOWT. Some barges are anchored to the seabed using catenary mooring lines whilst one type uses weather vaning technology. Currently structures weigh around 2,000 tonnes (steel) and 4,000 tonnes (concrete).

Fig. 2 Concrete barge [15]

C. Semi-submersibles

A semi-submersible substructure is a hull with columns which are connected to each other with bracings. The platform uses the buoyancy force to be stabilised when floating. The structure is anchored to the seabed using catenary or taut mooring lines. This substructure is assembled onshore and, despite its heavy weight, it has a relatively low draft of approximately 10 m during transportation. The weight of the structure for a single turbine is around 2,500 tonnes to 5,000 tonnes. The most common steel design uses three columns. Some early designs had the turbine at the centre which has the advantage of minimising active ballast systems but has the issue of requiring much larger onshore crane outreach to fit the nacelle and blades. Most current designs have the turbine either in one corner or one side to maximise use of onshore cranes.

Other semi-submersible substructure concepts have multi turbines in a single platform. These structures are moored using a weather vaning system.

Fig 3 shows a loadout from land onto a heavy transport vessel. The construction of a semisubmersible in a drydock is pictured in Fig. 4.

Fig. 3 Semi sub. loadout from land [12]

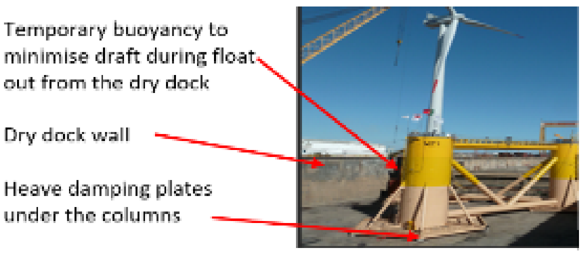

Fig. 4 Semi-submersible in drydock [12]

D. SPARs

A spar-buoy (or spar) is a cylinder structure. It is stabilised by keeping the centre of gravity below the centre of buoyancy, using a ballast made of one or more heavy materials. This is the structure with the largest draft, between 70-90 m once installed, minimising the motions and stabilising the structure. However, this can translate into more complex logistics in the assembly, transportation and installation of the foundation. The structure is anchored to the seabed using catenary or taut mooring lines. The assembly of the steel substructure is performed onshore by building the spar hull horizontally. The steel weight of one structure is around 2,500 tonnes to 5,000 tonnes before ballasted. The substructure is loaded out onto a Heavy Transport Vessel (HTV), taken to deep water in a sheltered location, see Fig. 5. The spar hull is then upended using water ballast. Then solid ballast is added to the base. The turbine is assembled on land and fitted onto the spar hull, in sheltered water using a Semi-Submersible Crane Vessel (SSCV), Fig. 6.

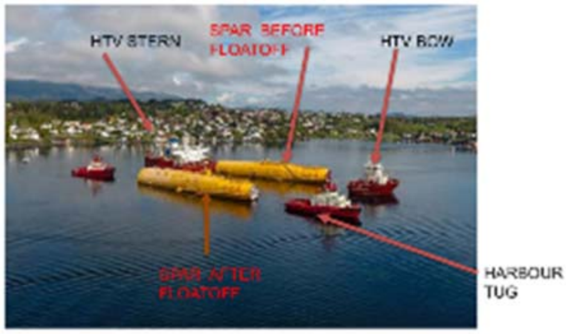

Fig. 5 Spar float off before upending [14]

Fig. 6 Spar topsides lift off quay

The concrete spar starts off by being slip formed vertically in a dry dock. The completion of the substructure continues in deep water using slip forming. Solid ballast is added to the base.

Both steel and concrete types of spar require temporary moorings to be set up in sheltered water and also work barges to be alongside.

E. TLPs

A TLP has a high buoyancy force which requires the anchoring mooring lines to be fully tensioned to provide in place stability. However, during the fit out and tow out the TLP has low or negative intact stability and thus unique methods of installation are required.

Options for TLP installation include:

- add temporary buoyancy to the hull
- construct offshore using a crane vessel with active heave compensation
- use a variable draft i.e. large water plane area for float out and after mooring tensioning go to a draft with low water plane area

Each of these options will require different port facilities. The advantage of the TLP floater is that it has a lower footprint on the seabed below the structure compared to a catenary moored FOWTs and has lower in place motions. There are three TLPs are under construction, in the South of France, [17]. TLP vertical tension mooring technology leads to complex installation. The weight of this platform can be lower than the semi-submersible types.

F. Offshore Turbines

Turbine blade lengths and nacelle diameters are typical manufacturer's information. Table II gives offshore turbine dimensions and weights of the nacelle.

TABLE II
TURBINE DIMENSIONS AND WEIGHTS

Power	Blade Length	Hub Height	Total Height	Nacelle Weight
MW	m	m	m	t
8	84	116	202	443
10	94	126	222	579
12	103	135	241	675
14	111	145	260	868
16	118	154	278	1019

The hub height at which the nacelle has to be installed is a limiting factor for available onshore cranes and for existing floating crane vessels.

It is assumed that there is an air gap of 30 m between a blade at its lowest point of rotation and the still water surface at low tide.

IV. METHODS OF REVIEWING PORTS

This section gives an overview to the construction and installation phases that need to be accommodated by the port. It is separated into categories as follows:

A. Substructure

The substructure can be built as follows:

- In a drydock: This is applicable to barge types and medium sized semi submersibles. Temporary buoyancy may be required to minimise draft and keep trim and heel to zero. There are constraints on drydock width and water depth over the sill, and also on availability.
- On land: This is possible for barges, semi submersibles and Spars. A typical yard is a shipbuilding facility or offshore construction site. Loadout is by self-propelled modular transporters (SPMT) onto a submersible barge or HTV. In this case the minimum ground bearing capacity is 10 tonnes/m^2.

FOWT substructure fabrication will generally require buying pre-rolled and weld prepared steel tubulars which require assembly into larger units [12], which in turn needs;

- large storage space
- complex high strength steel welding. FOWT substructure fabrication is labour-intensive, with many hours of manual welding required.
- cranes for up-righting and gradual assembly.
- large spaces for FOWT manufacture

FOWTs are difficult to fabricate as a serial process because of the large space required for each substructure. Manufacturing facilities may be co-located or spread over a number of highly specialised locations, with additional steps required for transit of goods (i.e., via SPMTs around site and submersibles barges between sites).

There are further practical constraints, such as gaps between orders, meaning that employers are not able to retain all the skilled labour hired for a job. Each new job must therefore carry some cost of hiring and allow time for a certain amount of learning on the first units produced, causing process inefficiencies something which is minimised where the same teams are working continuously from one project to the next.

Installation vessels are continuing to increase in size, which is further increasing the available water depth limits for quayside load-outs. Some sites have short windows during high tide to complete load-outs, increasing the loadout time and cost.

B. Blade Manufacture

Because of the length of the turbine blades, (see Table II) they need to be manufactured close to a loadout quay as they are too long to be transported on public roads. They may be loaded by crane, either individually as shown in Fig. 7, or in bundles of three onto a transport vessel.

Fig. 6 Blade loadout [16]

Ports will continue to increase the use of roll-on/roll-off (RO-RO) vessels particularly for transporting large components (i.e. nacelle, blades). This reduces time and logistical costs compared with traditional methods for component delivery [4].

C. Loadout Quay for Mooring Equipment

The mooring system needs to be installed prior to the offshore arrival of the completed FOWT. The mooring lines and anchors will be delivered from their respective construction ports to a mobilisation port close to the offshore location. Part of the mooring lines may be synthetic fibres or steel wire ropes and would be stored on reels.

Specialised equipment will need to be stored on land and to be loaded onto installation vessels e.g. work class ROVs, hammers for driven piles, drilling equipment for drilled piles or subsea pumps for suction piles, Fig. 7.

Fig. 7 SSuction pile anchors [14]

The moorings have the following marine activities:

- Anchor loadout by crane onto cargo ship
- Offload anchor by crane from cargo ship onto mooring storage quay
- Mooring line loadout by crane onto cargo ship
- Offload mooring line by crane from cargo ship onto mooring storage quay
- Load onto mooring installation vessel

Mooring and anchor systems can be stored in a separate port and do not need particularly high lifting capability. There is potential to use drums to store synthetic rope, which would require less space. Typical drag anchors and chain are shown in Fig. 8.

Fig. 8 Drag anchors and chain [12]

D. Loadout Quay for Subsea Cables

Subsea cables need to be stored onshore prior to deployment offshore. The cables are usually installed prior to the installation of the FOWT. There are export cables which are buried in the seabed and dynamic array cables which connect the export cables to the FOWT.

The export cables may be built and loaded out a long way from the final location as they require specialising manufacturing facilities. The multiple dynamic array cables can also be built a long way from the offshore location, so a marshalling port may be required for the cables.

A secondary port may be required for concrete protection mat construction and storage. These concrete mats are used to protect the export cable from damage, from dropped objects, trawl boards and ships anchors.

E. Loadout Quay for Nacelle and Towers

For smaller wind turbines the tower and nacelle may be built away from a loadout quay. However, with the expectation that the minimum size of commercial FOWT is 8 MW, with the likelihood that the wind turbines will be at least 10 MW capacity on FOWT the nacelle and tower will be too big to be transported on public roads.

F. Fit out Quay

A fit out port will need access to a large laydown area to store nacelles, blades, towers.

For turbine assembly, a port will need to have cranes capable of lifting the nacelle, the heaviest and highest lifting operation and thus one of the limiting factors. Mobile cranes with sufficient lifting and reach capability are limited in global availability. There are high costs to mobilise as it is transported in sections and needs to be assembled for use. Figs. 9 and 10 show a 9.6 MW being lifted by a large onshore crane. As an alternative, a very large inshore sheer crane might be used for inshore assembly but they are limited in availability, too.

After turbine assembly in port, there is paint touch-up, bolt tensioning checks, electrical circuits and safety system checks to be carried out by technicians.

The fit out port requires a storage area and needs to have a minimum overall load of 15 t/m^2 as a uniform distributed load (UDL).

Areas assigned for heavy lifting crane operations must accommodate a minimum surcharge load of 30-40 t/m^2 (UDL) which increases to a maximum surcharge of 50-80 t/m^2 by operation of the main crawler crane on a single track to the load spreading surface. Fig. 9 shows the lifting of a 675 t nacelle for a 12 MW turbine, [5] wind turbine and blades onto a FOWT [13].

Fig. 9 Nacelle lifting [5]

Fig. 10 Blade lifting [13]

G. Wet Storage

Substructures need to be wet stored prior to fitting the turbine topsides. This requires the laying of temporary moorings. Similarly, after fitting the turbines more wet storage may be required prior to tow offshore, whilst waiting on weather or available installation vessels. In this case, the temporary moorings have to be stronger than prior to fitting the turbine because of the high wind loads on the topsides.

H. Navigation out of Fit out Yard

Navigation and fit out port requirements are summarised in Table III. Regarding the sir draft limit there should be no overhead power cables or bridges between the fit out port and the open sea.

Weather forecasts are suitably accurate for up to 3 days in advance. The fit out yard is to be a maximum of 2.5 days sailing time from the offshore location. This allows 0.5 day to get at least 2 mooring lines connected to the FOWT. If the fit out port is too far from the offshore location then a staging port may need to be designated.

TABLE III
FIT OUT PORT MINIMUM (BASED ON [6])

Primary Criteria	Semi Sub	Barge	Spar
Material	steel	steel	steel
Air draft	No limit	No limit	No limit
FOWT width	90 m	30 m	20 m
Channel width	140 m	110 m	90 m
Quay length	120 m	60 m	80 m *
Water depth	12-14 m	10-12m	90m
Shipyard	6 hectare	4 hectare	5 hectare
Area fit out	6 hectare	6 hectare	6 hectare
Fit out quay	15 t/m^2	15 t/m^2	15 t/m^2

*The Spar quay length is for a carne vessel to come alongside the turbine construction site. In addition, the Spar needs a water depth of at least 90m at the sheltered inshore location.

V. RESULTS

Applying the review criteria for each phase a range of constraints and practical requirements regarding weather restrictions, and required port areas have been established.

A. Weather Restrictions

The weather restrictions are expected to be as follows for the port activities, Table IV.

TABLE IV
PORT WEATHER RESTRICTIONS

Location	Hs [m]	Tp [sec]	Wind [m/s]	Current [m/s]
Loadout	<1.0	<8	<10	<0.5
Drydock	<0.5	<7	<10	<0.5
Floatoff HTV	<0.5	<7	<10	<0.5
Fit out crane	<0.5	<7	<10	<0.5
Wet storage	3.0	10	30	1

B. Port Areas

The approximate port area requirements for the different factors are shown in Table V. Port area directly depends on:

- Type of FOWT
- Size of turbine
- Number of turbines in the wind farm
- The number of turbines to be installed in one summer season

TABLE V
PORT AREA ESTIMATES

Wind farm size	25 MW pre commercial	300 MW commercial
Turbine size	5 MW	10 MW
Number of units	5	30
Tower manufacture	2 hectares	25 hectares
Nacelle manufacture	3 hectares	15 hectares
Blade manufacture	4 hectares	32 hectares
Dynamic cable storage	2 hectares	12 hectares
Export cable storage assume 50 km length	10 hectare	12 hectares
Substructure construction	10 hectares	100 hectares

It can be expected that as larger turbines are developed they will be deployed on FOWT.

C. Ports for Steel and Concrete Substructure

Steel substructures have the following advantages in shipyard construction [9]:

- Experience is transferrable from other industries
- Assembly can be executed relatively fast if components are pre-fabricated
- Lighter substructures are possible (compared with concrete) which minimises water depth requirements at shipyard, dry dock and the fit out port

Concrete substructures have the following advantages in construction ports [10]:

- Concrete supply adaptable to local conditions
- Ensured local content
- No specialized equipment,
- Low costs of concrete as a raw material

Steel substructures, [10], have a long history of being used offshore and steel is much easier to recycle. However, steel is subject to corrosion (so is concrete via internal reinforcements, but to a lesser extent). Floating wind substructures made of steel can be assembled faster as these are not as sensitive to environmental conditions (e.g. frost and heavy rain) and are not exposed to concrete curing time.

D. Visual Impact During Construction

There is high visual impact from floating wind turbine during manufacturing, assembly, repair (near shore or in port) and decommissioning, Fig. 11 and Table II. However, it is expected to encounter low opposition as these are short-period tasks that will bring jobs to the area [11].

Fig. 11 Top height, Hub height

VI. Discussion

The market for floating platforms is still in its infancy. There are many platform types, and only few have been demonstrated pre-commercially. Existing shipyards and fit out quays have been used. Different manufacturing techniques will require different facilities, from large yards to covered premises to dry docks [11]. Floating offshore structures are large and will need storage and/or transfer to assembly facilities. It is likely that wet storage will be used, so ports able to offer sheltered moorings ahead of turbine integration will have an advantage. Storage and assembly may happen at different port locations and could be done at quayside (with onshore cranes) or in sheltered locations using floating assembly bases or floating cranes.

Industrialization of floating wind technology is the key for future cost reductions. Ports form an important element in the commercialisation of floating wind and should actively plan for these requirements.

Port facility requirement criteria will differ for each port classification and substructure technology as the functions and installation vessel requirements are different. Because the industry is at an early stage, and deployment technologies and methodologies are still in development, the requirements presented are intended only as a broad review of likely port facility requirements based on available data and technology.

Key outcomes from the research include the following for semi-submersible FOWT construction, Fig. 12:

- Quayside capacity is up to 20 tonnes/m^2.
- Harbour is protected.
- Floating wind substructures will require deep draft channels.
- For tow-out of an assembled unit there must be no air draft restriction
- Rail and road connections will likely be required for transport of materials

Fig. 12 Steel semi submersible construction

Steel barge requirements are similar, see Fig. 13. Spars are similar but need deep sheltered water close to the shore. TLP requirements are unknown at present.

Fig. 13 Steel (damping) barge construction

VII. Conclusions

Ports are important to facilitate the assembly, installation and operations of FOWT. For commercial projects with multiple turbines, shipyards need to be able to construct several FOWT at one time.

For substructure dry ocean transport there are no limits on shipyard locations. However, the shipyard requires a quay strong enough for SPMTS to have a side loadout onto a HTV. There must also be sufficient water depth for the HTV to stay afloat at low tide with 1 m of under keel clearance.

Table VI summarises port sailing times to the offshore location and functions showing that there up to 15 ports required.

TABLE VI
Port Location

	Function of port	Sailing time to
1	Substructure component fabrication	no limits
2a	Substructure assembly and loadout	no limits
2b	Alternate assemble in a shipyard dry dock short distance to fit out quay	
3	Blade construction on loadout quay	no limits
4	Nacelle on loadout quay	no limits
5	Tower on loadout quay	no limits
6	Fit out topside onto substructure	3 days
7	Anchor loadout port	no limits
8	Chain loadout port	no limits
9	Mooring assembly port	5 days
10	Export cable loadout facility	no limits
11	Dynamic array cable loadout	no limits
12	Export cable concrete protection quay	5 days
13	Support base for seabed surveys	3 days
14	Support for operations and	2 days
15	Support base for offshore installation	2 days

A port looking to take on the final assembly and staging of floating wind projects will need access to a large laydown area to store nacelles, blades, towers, mooring and anchor systems before deployment at site.

Mooring lines and anchors require a large space with nearby access to water but do not need particularly high lifting capability. There is potential to use drums to store synthetic rope, which would require less space.

For turbine assembly, a port will need a lifting capacity of 1,000 tonnes for the nacelle, the heaviest lifting operation. Mobile cranes with sufficient lifting and reach capability are limited in global availability and to mobilise it is transported in sections and needs to be assembled for use.

Different types of substructures have different port requirements. Port capability is likely to influence substructure design choices. Semi submersibles and barges require large quayside areas (up to 80 m x 80 m). Spars require a deep-water sheltered area for turbine mating TLPs with a low water plane area and will probably have low stability during towing, so final assembly may take place offshore instead.

Fig. 14 outlines the port interaction for construction of FOWT.

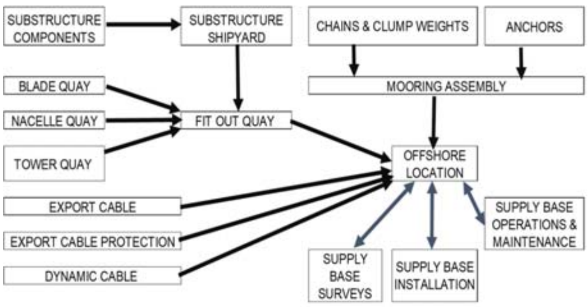

Fig. 14 Port interaction for FOWT

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ABBREVIATION

AHTS	Anchor Handling Tug Supply
Float out	Substructure floated from drydock
GW	Gigawatt
Hect.	Hectare
Loadout	Horizontal movement of structure
M	metre
MW	Megawatt
Sub.	Semi-submersible
T	(metric) tonne
UDL	Uniform distributed load

REFERENCES

[1] Panel discussion at the Floating Offshore Wind Conference 15-16th September 2021, Aberdeen
[2] Report ‘Ports a key enabler for floating offshore wind sector’, Wind Europe, September 2020
[3] Associated British Ports, Future development potential forPort Talbot
[4] A 2030 Vision for European Offshore Wind Ports, Wind Europe, 2021
[5] ‘www.ge.com, 12MW test nacelle, 2019
[6] Infrastructure to support offshore floating wind (focus on California), BOEM, 2016
[7] ‘www.dnv.com, accessed September 2021
[8] Determining the Infrastructure Needs to Support Offshore Floating Wind on the Pacific West Coast and Hawaii, BOEM, 2016
[9] D. Matha, C. Brons-Illiga, A. Mitzlaffa, R. Scheffler, Fabrication and installation constraints for floating wind, Science Direct, 2017
[10] R. Proskovics, Floating Offshore Wind: A Situational Analysis, Ore Catapult, 2018
[11] Scottish offshore wind strategic investment assessment, SOWEC, 2021
[12] UK Strategic Capability Assessment Offshore Wind Foundations, Offshore wind growth partnership, 2020
[13] ‘www.principlepower.com,
[14] Benefits Of Floating Offshore Wind To Wales And The South West, Ore Catapult, 2018
[15] ‘www.equnor.com
[16] ‘www.bwideol.com
[17] ‘www.vestas.com,