# Fabrication of Concrete Gravity Foundations as Support Structures for Offshore Wind Turbine Facilities

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**Abstract.** Offshore wind turbines in shallow waters are most often supported by monopiles driven into the ground. As a means to reduce the installation costs, alternative concepts should be investigated, as for example tower structures with gravity foundation that potentially could bring the tower, the nacelle and the blades to the offshore location for easy installation. In this paper it is suggested that concrete gravity foundations be considered for support of wind turbines offshore Vietnam. As an additional effect, the structures can be prepared in a dry dock using only local goods and services and towed to site by smaller tugs available in the country. The fabrication site should be sufficiently large to ensure an assembly line for fabrication of a series of same design wind turbines. The most optimal site for a construction yard is identified with sufficient water depth to tow fully commissioned wind turbines to the actual offshore locations.

**Keywords:** Wind power potential · Selection of foundation concept · Concrete gravity support structures · Fabrication site considerations · Installation

## 1 Background

### 1.1 The Scope of the Study

The offshore wind power potential in water depths up to 30 m is large in some of the Vietnamese provinces, Fig. 1, [1]. The technical potential is approximately 100 GW in up to 30 m depth, 160 GW in 30–60 m, and for floating wind the potential is 210 GW, in total 470 GW [2]. The most promising region is the coastal area of the Binh Thuan and Ca Mau provinces with a power capacity density of nearly 1000 W/m$^2$ [3, 4].

Support structures for offshore wind turbine facilities in shallow water (in the range of up to 30 m) are most often large mono-columns driven into the ground by pile hammers. In this case, competent sand is needed to support the foundation in order to provide a stable foundation and avoid large vibrations. For water depths exceeding 30 m, the most common support structures are jacket type piled structures. In even deeper waters, there is a range of depths where jackets and floating support structures are competing, however; for depths of more than, say 120 m, floating support structures take over.


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The installation process requires use of heavy equipment like jackups with crane arrangements or large floating lift barges. This equipment is sensitive to the wave environment and even low height swell conditions with long periodic waves could lead to resonant motions whereby the installation work has to be set on hold, waiting for suitable weather conditions [5].

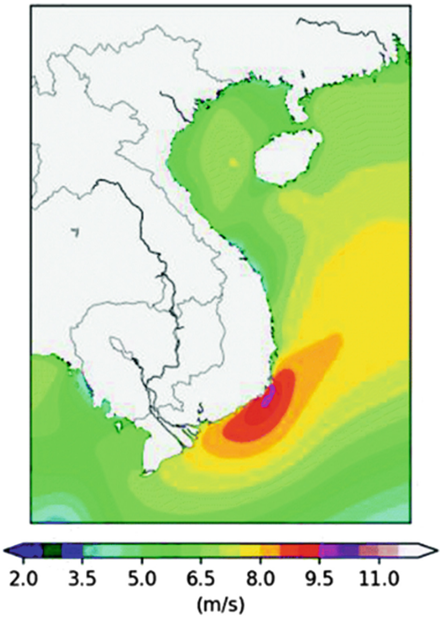


**Fig. 1.** Wind Energy resources offshore Vietnam, wind average velocity measured at 100 m height [1].

A more elegant foundation solution is to use concrete gravity foundations with large base areas. These have been employed in European waters, Fig. 2, in case of large loading (ice loading in the Baltic or breaking waves on shoals). The turbines fabricated for Thornton Bank (Fig. 3) were installed with use of crane vessels, however, in case of deeper tow out channels from the construction site, these structures should be in position to carry the nacelle and the rotor/the blades to the offshore site during a tow operation, see discussion below.

The requirements to site condition are important as a concrete gravity foundation structure has to be placed on sandy soils or hard clay [6]. The foundation plate is to be outfitted with a steel ring (a "skirt") that will penetrate into the soil to avoid erosion. The length of the steel "skirt" will be determined by the erosion potential and the depth to competent soils that can withstand the vertical weight and the moments due to the wave actions. The bottom should be plain without stones, however, to adjust for unevenness, grout could be injected under the foundation plate. Checking of these requirements will demonstrate which sites in Vietnam are suitable for that type of foundation.

**Fig. 2.** Assembly line for fabrication of offshore wind turbine foundations for Thornton Bank, Belgium [7].

**Fig. 3.** Installation of wind turbines on Thornton Bank, Belgium [7].

## 1.2 The Experience with Offshore Concrete Gravity Structures

The main region for the application of platforms with concrete gravity foundations has been the North Sea. The search for oil and gas reached the North Sea area in the late 1960's. Almost at the same time the increasing price of hydrocarbons substantiated economic development of the findings in this area. As a result, a rapid development of structures fit for the North Sea was seen. It should be kept in mind that the average weather conditions of the North Sea are considerably more hostile than in the Gulf of Mexico, on which early North Sea developments were modelled. Technology developed for the Gulf of Mexico failed in the North Sea, in particular due to larger fatigue loading.

In the late 1960's and the early 1970's platforms with concrete gravity foundations were selected in preference to steel jackets by several oil companies for production platforms in water depths from 70 m to 150 m. The lack of deep "fjords" in the UK, where deck transfer can take place, was, however, a drawback for the selection of concrete gravity foundations in the UK. In Norwegian waters, where deep water sites are available and where deep tow out channels are present with water depths up to 241 m, concrete gravity foundations were chosen for several major offshore developments up to the mid 1990's. The availability of suitable local locations for construction of concrete gravity foundations was important. Since the 1990's, design fabrication and installation techniques of both steel and concrete platforms improved. Concrete gravity foundations as support structures for the drilling and process equipment were still selected for several offshore field developments offshore Sakhalin (Russian Federation) and Newfoundland (Canada).

### 1.3 Wind Turbine Concepts Made of Concrete

As was discussed above, wind turbine foundations made of concrete have been installed on the Thornton Banks. Furthermore, such foundations have been installed in the Baltic due to their resistance against potential ice drift. The idea of using a self-installing concrete mono-tower was also presented by Bouygues Offshore in 2002 [8].

The process of designing an efficient wind tower foundation fabricated in concrete must include the following aspects:

- Size the foundation structure to bring the tower, the nacelle and the rotor (the turbine blades) to the offshore location.
- The foundation slab will be dimensioned to resist the wave and wind loads using the actual physical environmental data and the soil conditions at the offshore location [9].
- Sufficient initial stability during the tow to the offshore location must be secured by ensuring deep draft along the tow route, adequate amount of ballast and a sufficient water plane.
- By designing the *tower* as a telescope [10], the nacelle and the blades could be lowered into the gravity foundation to lower the center of gravity during the tow. Furthermore, the design of the concrete tower must ensure a *water plane area* sufficient to secure stability when the structure is lowered to the seafloor at the offshore location.

  - Should there, in the case a telescopic tower is selected, be any conflict between the blades and the required height above surface during the tow, it is proposed that the tower of a two-bladed wind turbine can be lowered down closer to the sea surface as compared to a three bladed rotor.

## 2 Identification of Site for Fabrication

### 2.1 Potential Fabrication Site in Vietnam

During visits to Vietnam in the early 1990's, Vietnamese authorities associated with Petro Vietnam drew our attention to a site north of Nha Trang that would be a strong candidate for fabrication of concrete support structures for offshore oil and gas production platforms [11], see Figs. 4 and 5.

In the "fjord" system north of Nha Trang, in Dam Mon Bay, a dry dock with a depth of 14 m can be established for fabrication of large offshore concrete structures. Tow out drafts of 25 m (or possibly near to 30 m, with some dredging) can be achieved and the towing route is straight into the open ocean. Therefore, concrete foundation structures


**Fig. 4.** Location of possible fabrication site

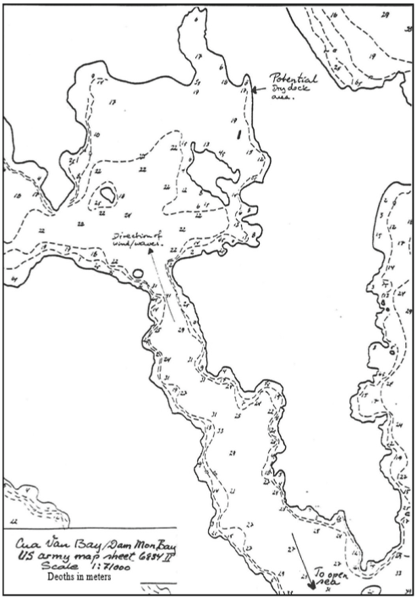


**Fig. 5.** Water depth in the area where a fabrication site could be established

fabricated in a dry dock established here, can be considered for offshore wind turbines. This site would also represent an excellent site for construction of floating wind turbines for deeper waters.

## 2.2 Fabrication Dock Requirements

A dry dock where wind turbine foundation fabrication is necessary. The size of the dock depends on how many structures should be fabricated simultaneously in an assembly line production scenario. In addition, there needs to be an area for rigging, storage, prefabrication, workshops and offices. The size of this area depends on the amount of work which is expected to be performed in the yard. It is further assumed that all structural steel and pipework prefabrication is performed at a different location. For the suitable concrete platform yard, it is necessary to have sufficient deep water for tow out of the completed structure. Furthermore, dry dock excavation can be expensive so it is important to find an area which offers minimum rock blasting. The dock must be stable and not leak. Also, the dock floor has to support the completed structures Construction of concrete platforms is labor intensive and it is important that there is an adequate supply of skilled as well as unskilled labor in the vicinity of the yard. The main utilities required for concrete platform construction is water and electrical power. The consumption of water and the electricity demand depend on the activity in the dock.

A 14 m deep dry dock (below mean sea level) have large potentials. This depth, however, means that water ingress and dock foundation stability must be considered carefully. For dry dock general arrangement, see [11]. Dry dock development based on experience from Norway requires steel sheet pile walls supported by granular fill materials. Steel sheet piles, piled to rock, will give a water tight dock. Further soil investigations and review of available resources may, however, result in other methods being more cost effective. A dock gate that can be opened when the concrete foundations are ready must be installed. It is also assumed that a quay is required to offload equipment and material transported by sea. The size of this quay will depend on the expected marine traffic. It is anticipated that bulk materials such as sand, cement aggregates and reinforcing steel to be transported by ship. The dock floor may need a concrete foundation slab in order to support the heavy structures. The size and type of foundation in the dry dock will depend on the distance to rock below the dock floor.

Out of the dock, the concrete structure will be lowered to tow draft and the equipment that could not be installed in the dock, for example the nacelle and the rotor, will be lifted in place in the Bay prior to tow to offshore location.

## 3 Materials and Concrete Quality

The concrete structure should be designed in accordance with the International Standardization Organization's Fixed Concrete Offshore Structures Standard [12]. Highlights are that:

- Durable offshore concrete should have high strength, be dense and have at least 40 mm cover over the reinforcing bars to avoid rebar corrosion and spalling.
- To obtain a concrete quality of C55 or better, it is important to have the right mixture of cement, aggregates, and water, as well as additives to control the concrete hardening and to obtain good workability.
- The cement normally used for offshore concrete is Portland cement with $C_3A$ content less than 8% and with no CaC1. Test certificates from the cement manufacturer should be required for every cement delivery. Special cement with smaller particle size, like Portland P30 Rapid cement, will harden faster than normal cement but will have about the same quality after 28 days. Special care must be taken to avoid excessive heat development during curing.
- The aggregates consisting of natural or manufactured hard sand and gravel are an important part of the concrete mix. The gravel usually is up to 32 mm. A good aggregate mix has a certain sieve grade distribution. The minerals that react with alkalis in the cement must be limited so that no deterioration will occur. Only a small amount of organic impurities is allowed. In many cases, the impurities will be removed by washing the sand and gravel with fresh water.
- The water should be fresh, clean, and free of injurious amounts of oil, acids, alcohols, salts, or organic materials. Seawater should not be used.
- The concrete quality and strength depend on the water/cement ratio ($<0.45$), cement content ($>400$ kg/m$^3$), sieve grade of aggregates and cement quality. Furthermore, compacting of the concrete with a vibrator is necessary. During concrete curing, the temperature should not exceed 70 °C and the temperature gradient should not be higher than 30 °C/300 mm.

There are several types of additives: retarders to slow the hardening process if necessary, accelerators for casting by slip forming, and water-reducing additives to obtain good workability of the concrete mix when the water/cement ratio is low. Silica fume may be used when high-strength concrete is required. The silica also improves fresh concrete properties like workability, stability and pumpability.

- Reinforcing steels normally are classified on the basis of their size (bar diameter); characteristic yield stress, good bond properties and weldability. The most common nominal diameters for bars in offshore structures are 16, 20, 25 and 32 mm; 12 mm bars are used for stirrups.
- Characteristic yield stresses of 400 MPa (Grade 400) and 50 MPa (Grade 500) are used. The value of yield corresponds to 0.2% permanent elongation. The bond properties depend on rib size and form. Bars that do not satisfy the requirements should be treated as plain bars with respect to bond. Carbon, Silicon, Mangan, phosphor, sulphur and nitrogen content in the steel is limited.
- The prestressing steels usually are classified on the basis of their characteristic tensile strength, $f_{pt}$. The prestressing steel should withstand without failure $2 \times 10^6$ cycles at 200-MPa stress, with a maximum stress of 0.8 $f_{pt}$.

## 4 Discussion of Potential Benefits

The potential benefits of fabricating wind turbine foundations in concrete are considerable:

- The fabrication can be undertaken with a limited workforce of skilled laborers and materials (cement and aggregate) produced in the country can be utilized to a maximum degree.
- The fabrication of concrete gravity foundations will enhance the competence of those who are involved in the work at the fabrication site and in the engineering related tasks.
- The completed turbines can be assembled and be fully commissioned in a dry dock/in a Bay and sailed to the offshore location with the use of easily accessible harbor tugs, thereby saving the cost of hiring expensive international installation vessels.
- A suitable location for dock facilities in Vietnam is identified and export to other countries where potential deep-water fabrication sites do not exist seems possible.
- Furthermore, dense concrete has demonstrated its use in harsh North Sea conditions over 50 years of utilization and requires less maintenance as compared to steel structures.

The author will suggest that a thorough detailed study of the benefits and the cost savings be undertaken to the benefit of Vietnamese industry and for the provision of electric energy at affordable costs.

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