Nearshore Structures

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Definition

“Nearshore structures” in the context of this entry encompass architecture suited to nearshore environments, with an emphasis on engineering geology aspects of nearshore environments. The description of structures as nearshore engineering solutions does not necessarily preclude the technology deployed beyond the nearshore, although in cases limitations apply.

Types and Functions of Nearshore Structures

A variety of nearshore structures facilitate offshore energy development worldwide. For over 50 years, projects have exploited fossil fuels – oil and gas – and more recently an offshore renewable energy industry has emerged – predominantly wind, but also tidal and to a lesser extent wave energy. Examples of nearshore structures for oil and gas and renewable energies are illustrated schematically in Fig. 1.

Structures may be “fixed” or “floating,” in the latter case enabling limited movement in response to the environmental actions acting on the structure from wind, waves, currents, tides and in places sea ice. Fixed structures may be “subsea” or “surface piercing.” Subsea structures rise from the seafloor to some height within the water column and surface-piercing structures extend above the water line. Floating structures comprise a buoyant facility and mooring system.

Nearshore structures for oil and gas production are typically fixed structures rather than floating since a minimum depth, approximately 200 m, is required to provide sufficient flexibility in the riser casings that transport hydrocarbons from the seafloor to the platform, in order to tolerate the lateral movement of a floating system (Randolph and Gourvenec 2011).

Nearshore structures for renewable energy can be fixed or floating – and in the case of wave energy buoys, buoyancy provides the mechanism of power generation. Floating concepts for wind and tidal energy structures have evolved from established deep water oil and gas technologies but due to the absence of risers they can be deployed in any water depth. Wind turbines are fixed to the seabed via a range of substructures but beyond about 50 m water depth a floating wind turbine solution becomes competitive, and the first floating wind farm commenced production in late 2017. For tidal energy facilities and wave buoys, the foundation or anchoring system, is required to hold the device at the required height in the water column.

Export pipelines and cables bringing offshore energy to shore require structures at their termination and junction points, and are sometimes also provided with stabilization structures such as gravity or embedment anchors and concrete mattresses.

Scale of Nearshore Structures

Fixed platforms for oil and gas structures typically range from a few tens of meters to a few hundreds of meters in height and are limited practically by water depth as the footprint becomes too large and the structure too heavy to build and float out. The largest gravity base platform in the world, the Troll A condeep platform, has a total height of 472 m including the topside, and is located in the Norwegian North Sea in 305 m depth of water. The concrete substructure is 370 m tall with a foundation base 160 m in diameter (Andenaes et al. 1996). The largest jacket platform in the world, Bullwinkle, is located in the Gulf of Mexico in 412 m of water and stands 529 m tall. At distances from shore of 80 km and 260 km for the Troll A
and **Bullwinkle** platforms, respectively, in conjunction with the water depths in which they are sited, these are arguably not “nearshore” structures, but merely conform to a nearshore architecture. That these structures were installed 20 years ago and are still record holders speaks to the evolution of oil and gas architecture towards floating and subsea solutions.

Subsea structures perform a variety of functions that dictate their scale and may range from a meter or so edge length to tens of meters.

Offshore wind turbines have evolved from structures with hub height and rotor diameter of less than 20 m to over 100 m to facilitate the increase in yield from tens of kWs to several MWs (World Energy Council 2016). At the time of writing, the largest wind turbines had a maximum capacity of 9 MW and rotor diameters up to 180 m (Wind Europe 2017). With improvements in blade technology and controllability of offshore wind turbines, the continued increase in wind turbine size to facilitate increase in power output is not inevitable.

Fixed offshore wind turbines have been deployed in water depths of 50 m and located as far as 100 km from shore. Fixed offshore wind structures are practically limited to water depths less than 50 m because of allowable bending deflection of the structure up to the transition piece. Tripod and jacket founded turbines can overcome this limitation to some extent but are not commonly adopted technologies. The world’s first and only floating windfarm (Hywind) is installed in 100 m water depth, 25 km from shore, using technology that has the potential for deployment in any water depth, with an appropriate mooring, at any distance from shore.

Tidal turbines and wave energy buoys are more limited in number to quote typical dimensions but those in existence or development have a rotor or buoy diameter up to 20 m and are sited nearshore in relatively shallow water.

Irrespective of size and function, all offshore structures require fixing in place on the seabed with a system that is

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**Nearshore Structures, Fig. 1** Nearshore energy structures
sufficiently robust to resist the design loading of the structure and ensure the function of the structure over the design life.

**Foundations and Anchors for Nearshore Structures**

Foundations support fixed structures whereas the term anchor is used to describe a foundation for a floating facility. The foundation elements used to support a fixed or floating structure can be essentially identical with the different label simply defining a different application (for example, pile and anchor pile). A range of foundation and anchor solutions for offshore energy structures is shown in Fig. 2.

Gravity foundations or anchors, irrespective of what structure is being supported or tethered, rely on their submerged self-weight to maintain stability on the seabed and resist the loads transmitted by the structure to the foundation or anchor. If self-weight and gravity are insufficient to provide the required resistance, an embedded foundation or anchoring system is required. An embedded system mobilizes the resistance of the seabed to enhance the capacity of a foundation or anchor. All foundations and anchors, whether surface gravity systems or embedded systems, derive capacity from bearing and shear resistance of the seabed that they are installed on or in. The magnitude of the available bearing and shear resistance for design is intrinsically linked to the engineering properties of the seabed.

Embedment of foundations and anchors for offshore structures can be achieved by driving, drilling and grouting, jacking or dragging, or using suction or torque, or by dynamic free-fall. The ease or practicality of installation of different foundation or anchor types is intrinsically dependent on the engineering properties of the seabed.

*Nearshore Structures, Fig. 2. Foundations and anchoring systems for nearshore structures*
Seabed conditions, and the influence in respect of installation and in-service performance, are thus a key driver in selection of a foundation or anchor type for an offshore structure.

Nearshore Seabed Conditions

Nearshore seabeds may comprise almost any geomaterial, including gravel, sand, silt and clay. These may range from competent granular materials to crushable carbonate sand, or clay and muds that may have strengths varying over several orders of magnitude depending on depositional history. Nearshore seabeds can also present extremely complex features and processes, including relics of historic buried shorelines or glaciation, geohazards, and scour. The range of offshore geomaterials in an engineering context is shown in Fig. 3. Different types of geomaterial are organized by grain size along the abscissa, small to large plotted left to right, and the strength of the deposit, expressed as a penetration resistance or capacity in stress units, is plotted on the ordinate. In an engineering geology context, clay is defined by a particle size below 0.002 mm; silt 0.002–0.063 mm, sand 0.063–2.0 mm, and gravel 2.0–63 mm (ISO 2016). The labels to the right show indicative values of stress required to install or support different foundation types. The stress exerted by an “average” person is also shown to give context to the scale, noting that a person standing on a soft normally consolidated seabed of a drained ocean would sink – until the increase of the strength of the soil with depth became sufficient to support their weight. Similarly, pile driving may not be needed in clay soils, since the tip load generated by the submerged self-weight of the pile may be sufficient to push the pile down through the clay.

The strength of each seabed material can vary by orders of magnitude within each soil type depending on state in terms of grain mineralogy and microstructure, depositional history, and postdepositional physio-chemical changes and grain packing. For example, for sand of similar particle size, silica-based granular materials are hard due to the quartz mineral and are generally a competent foundation material with a reliable geotechnical response; in contrast, carbonate deposits, which are in the most part comprised of the skeletal remains of marine plant and animal life, are constituted of soft and fragile calcium carbonate. The fragility of the calcium carbonate coupled with the highly variable grain shapes and sizes can lead to apparently high but easily degraded frictional strength and high compressibility. These characteristics can adversely affect, for example, driven pile capacity or shaft capacity of dynamically embedded anchors. They may also lead to large, potentially differential, settlements under shallow foundations, and significant strength degradation under cyclic loading. Calcium carbonate is also prone to postdepositional biochemical processes that can lead to cementation, causing spatially variable cemented lenses of material that can lead to pile toe buckling or pile refusal.

Figure 4 shows images from scanning electron microscopy that illustrate the differences in the microstructure of a silica and carbonate sand and the variability of grain shape and size in the carbonate sand.

Nearshore seabeds, with water depth less than ~150 m, were subaerial land surfaces during previous sea-level lowstands, meaning they were exposed and potentially subjected to glaciation in many parts of the northern hemisphere. A relic of the unloading from past glaciation is relatively homogenous, highly over consolidated stiff and strong clay that presents a reasonably desirable foundation material for offshore development. However, postglacial till deposits are unsorted sediments derived from the erosion, entrainment and deposition of material by a moving ice mass. The high lateral and vertical variability of the nature and strength of tills, and related submerged landforms, is a key engineering challenge. Seabed conditions can vary significantly with depth and two locations a kilometer apart may have completely different stratigraphy presenting clear challenges for site characterization and design. Historical shorelines resulting from sea level changes have particularly high variability over short distances, for example, with competent rock and soft normally consolidated clay nearby. Seabed variability is particularly challenging to renewable energy developments as these typically cover tens of square kilometers of seabed with multiple structures that are required to be placed in a fixed array. Effective and efficient methods of site characterization over large areas are required to ensure a sufficiently detailed picture of a site can be practically constructed from site investigation data.

Ongoing seabed processes also pose a challenge to offshore engineering. For example, seabed scour that causes the net removal of material from adjacent to a seabed structure occurs due to the presence of the structure disturbing the flow, causing preferential transport of sediment close to the structure. The extent of scour is dependent on a number of factors, including the near bed flow conditions (the existence of currents, waves, or both), the local seabed sediment properties, and the shape of the structure. For deeply embedded structures, scour will usually reach some maximum (or equilibrium) erosion depth around the structure in a given flow condition. For shallowly embedded structures (including shallow foundations and pipelines), scour can cause undermining of the structure leading to tilt and settlement. Scour potential needs assessment as part of offshore foundation design and scour protection around the foundation may be needed, particularly nearshore, in shallow to medium water depths, where hydrodynamic energy tends to be high.
Future Challenges for Nearshore Structures

Globally, offshore infrastructure amounts to thousands of platforms, a range of seabed structures, many thousands of kilometers of pipeline and tens of thousands of wells, much of it located nearshore. Offshore oil and gas construction booms in the 1960–1980s have resulted in a significant asset base approaching or reaching the end of their production life and present a significant decommissioning challenge. Offshore wind turbines, although less mature, are already being decommissioned having reached the end of a shorter design life and to make way for larger, more powerful turbines.

Considering the potential scale of the challenge, the Gulf of Mexico hosts almost 3500 facilities; in excess of 1700 offshore installations are sited in South East Asia, nearly half of which are older than 20 years and due to be retired;
over 600 fields are expected to cease production in the Asia-Pacific in the next 10 years; in Australia, there are 110 offshore oil and gas platforms and subsea structures many approaching the end of production life and only a small number of early projects have already been decommissioned; more than 550 platforms and subsea structures and more than 2500 wind turbines are currently installed in the North Sea (Gourvenec and White 2017).

Offshore decommissioning costs of just the oil and gas infrastructure in the North Sea are forecast to £47 bn GBP (US$66 bn) to 2050 – with an uncertainty of ±40% (Oil and Gas Authority 2016) and total global offshore decommissioning expenditure expected to amount to US$210 bn over the period 2010–2040 (Foxwell 2016). In the North Sea, only 12% of the infrastructure has been decommissioned to date, and 100 platforms are expected to be decommissioned on the UK and Norwegian continental shelves over next 10 years – along with 1800 wells and 7500 km of pipeline (Oil and Gas UK 2016).

The scale of the offshore decommissioning challenge is increasingly well understood – what is less well understood is the life cycle effect of decommissioning alternatives – and the evidence base and decision tools to determine which alternative realizes the optimal outcome.

A range of potential decommissioning alternatives for offshore infrastructure are illustrated schematically in Fig. 5. These span the ubiquitous base case of complete removal; removal and relocation – best known through the US rigs to reef program; and in situ decommissioning, potentially with augmentation of purpose built artificial reef modules to stabilize structures left in situ and maximize the benefit to marine ecology or fisheries.

Determination of the most appropriate outcome on a project-by-project basis requires a multicriteria, multisector, transdisciplinary decision framework to inform across all decommissioning outcomes and for all infrastructure types. The engine of the framework requires a bank of weighted evidence to assess whether infrastructure can be removed, relocated, or left in situ and determine the impact of the spectrum of options, reflecting multiple disciplines and a diversity of opinions (Gourvenec 2017).

An opportunity exists, with the right evidence base, to transform decommissioning of offshore infrastructure from the current base case of complete removal, borne out of guidelines to prevent sea dumping, to a broader portfolio of options including in situ decommissioning to ensure the minimum environmental impact of the decommissioning challenge ahead and the maximum positive outcome for other ocean users.

Summary

This chapter has presented a selection of types and functions of nearshore structures that facilitate offshore energy development worldwide. Structures for harnessing fossil fuels and renewable energies are presented in the context of design drivers and constraints, highlighting technology transfer from the established offshore fossil fuel industry to the emerging offshore renewables industry. The interaction of the
structures with the seabed, through the foundation and anchoring systems that keep the structures in position, and meeting the basis of design is discussed. The extreme variability of seabeds (at all scales) as a result of origin and postdepositional processes and the challenges these pose to offshore engineering are highlighted.

Cross-References

- Engineering Geology
- Foundations
- Geology
- Geotechnical Engineering
- Infrastructure
- Marine Environments
- Sediments
- Site Investigation
- Soil Mechanics

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References

Oil & Gas UK (2016) Decommissioning insight 2016 http://oilandgasuk.co.uk/decommissioninginsight.cfm