AARSLEFF

Copenhagen Offshore Wind 2005

Installation – Concepts and Risks

Reinforced concrete gravity foundation – A Contractors point of view

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Site Conditions
Geotechnical Conditions

Direct foundation of concrete gravity structures can be feasible if the bearing strata with sufficient strength can be found within a reasonable depth below sea bottom. Otherwise dredging costs, siltation problems and foundation heights and weights can make the solution non competitive.

At the Nysted project the mean dredging depth below sea bottom was around 2 meters. However dredging depths of 6-8m also has proven feasible.

In Nysted the foundation strata consisted of clay till with undrained shear strength of 150 – 300 kPa or more.

To be able to predict foundation level it is necessary, that gotechnical investigations in the form of borings and/or CPT tests are executed in all turbine positions.

Risks: Bearing strata level within the single foundation varies more than can be foreseen.

Action: Surplus dredging to be performed and original bearing strata level shall be created by a surplus compacted stone bed.

Wind Conditions

Primarily the wind conditions should be good for the power production of the turbines. Wind generated waves can create problems for the installation and seabed preparation for the foundation. Sufficient time gaps in the weather windows set up by the demands from the equipment shall be studied carefully and be a part of the installation planning.

Waves and Current

The waves and current are very important parameters for both the determination of loads to the foundation structure as well as for the operating conditions during installation. Also the scour protection is designed based on these parameters. Operational conditions for installation and seabed preparation are very important, as these operations normally takes place with floating equipment.

At Nysted hydraulic model studies at DHI was performed for both the scour protection and operational aspects for the crane barge to place the foundations. For another project we have used hydraulic model studies at DHI to determine the loads from waves and current in form of time series to be combined with the wind loads on the turbine.

Risks: Abnormal conditions through the installation period. Costs can raise and time extension can be necessary. High waves and current can cause siltation in the dredged foundation pit.

Action: Heavier equipment less sensitive to waves.

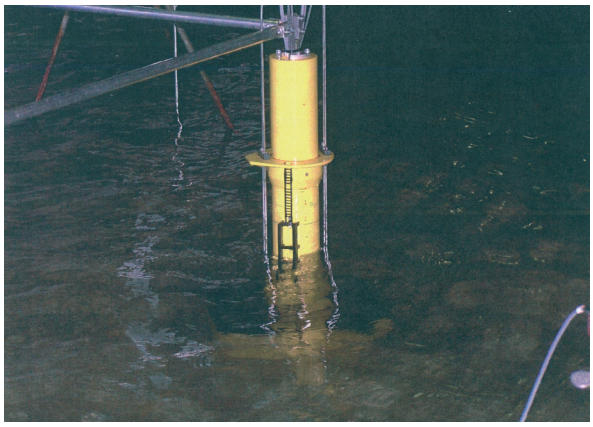
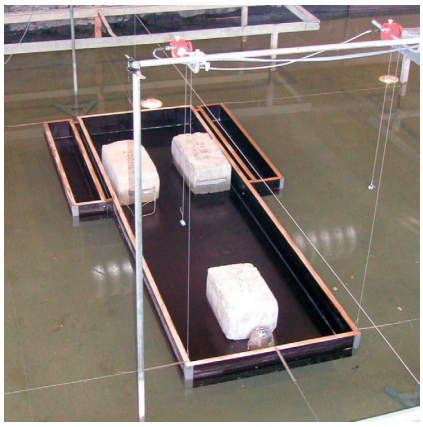


Figure: Model test to measure wave loads



Ships movements of EIDE 5. Model tests at DHI

Tides

High tide variations gives higher and heavier foundations and the seabed preparations are affected. High tide variations combined with high waves leaves the interface between foundation and tower at a very high level resulting in very high foundations. We have recently tendered concrete gravity foundations where the total height was determined as follows:

Sea bed CD	Dredging depth	10 years highest sea level CD	50 years wave crest elevation	Air gap	Total foundation height
-7.5m	6.5m	+9.00m	9.18m	0.82m	33m

However we still kept within our weight limitation on the foundation for the chosen lifting equipment.

Preliminary Design and Layout

Foundation Level

There are two ways to determine the foundation level. Either the level is determined directly as the bearing strata level a certain distance below seabed, or the foundation level can be raised from the bearing strata by constructing a thick compacted stone bed. Which of the two possibilities to chose of course depends on total costs.

We have used the thick stone bed in the following occasions:

- Bearing strata was found deeper than predicted during design. Structure was already fabricated.
- Only one or two positions had deep bearing strata, and it was decided to maximize foundation height for production purposes.

Weight Limitations

Different kinds of crane barge equipment have different limitations and different costs. When the structure is placed by lifting and lowering weight limitation are into force. You may chose heavier equipment or make use of the uplift from the structure. The self-floating caisson type may be chosen.

Lifting Equipment

Lifting of the foundations from the transport barge upon arrival took place with the crane barge EIDE 5. This crane barge was also used for the installation of foundations for Middelgrunden Wind Mill Park. For Nysted it was modified to lift in the ice cone.

Other types of lifting equipment are floating sheer legs and "Svanen".

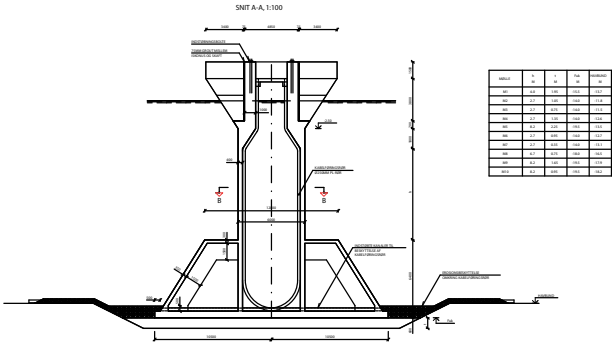
Figure: Eide Barge 5 lifting foundations

Foundation Types

The Nysted foundation is a concrete gravity type to be lifted in place followed by ballasting outer chambers and shaft. With poor soil conditions the same type can be supported by driven piles with grouted connection to the base structure.

Caisson types to be floated into position are another possibility and concrete tripods fastened to driven piles are a third option.

Figure: Model Nysted Foundation



Caisson Type

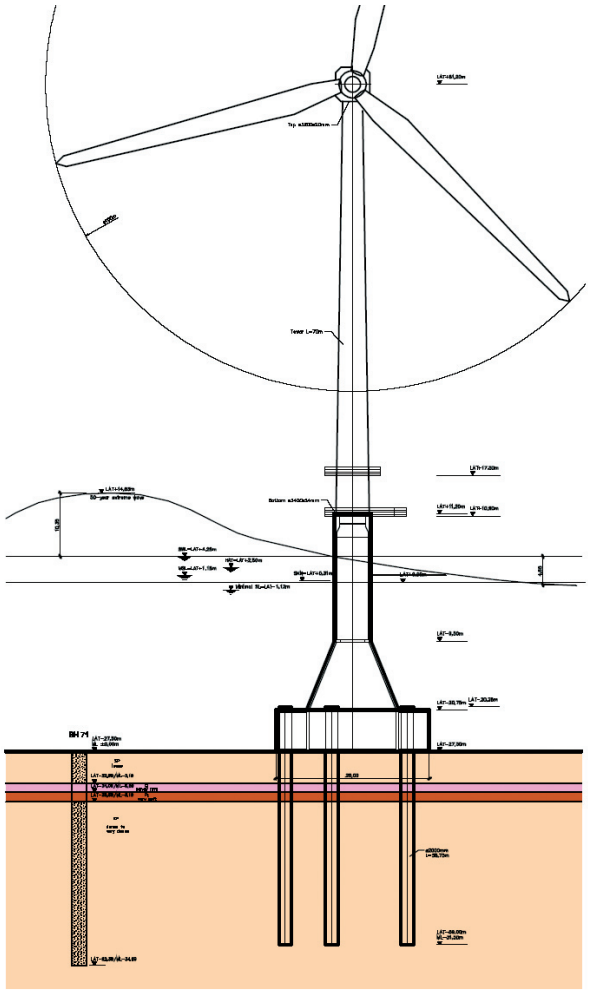
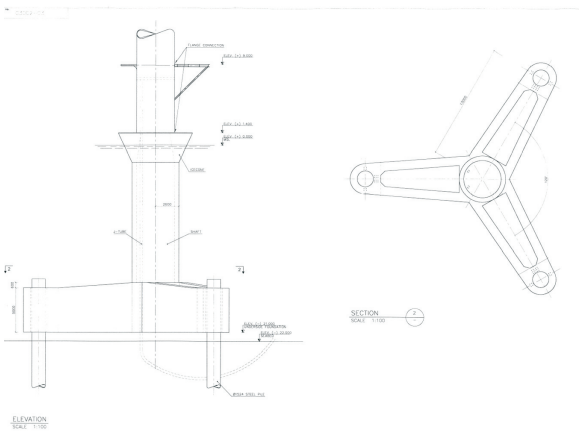


Figure: Model Nysted Foundation



Concrete tripod on piles

Design

Design Basis

Tender Design Works comprise:
- Study Company requirements as set out in Tender documents
- Study factual ground investigation reports and environmental conditions (hydraulic and wind) reports
- Eventually recommendations on supplementary investigations
- Establish tender design basis to include all relevant design aspects and parameters to be applied in the calculations

Design basis shall include:
- Fundamental Codes and Standards
- Employer's functional requirements, incl. corrosion protection requirements
- Loads and load cases:
  - Turbine loads from the selected turbine for ULS, SLS and FLS (as time series), and ALS if not specified in Tender Documents
  - Acceptable natural eigenfrequencies (to be provided by turbine supplier)
  - Hydrodynamic conditions and loads (Design waves and currents, ice loads, water depths and tide). (Verification of wave design parameters for the construction phase and for the permanent situation by model tests may be implemented in the detailed design phase)
  - SN-curves for fatigue calculations
  - Installation requirements
- Design life
- Driving analysis
- Structural design basis
- Geotechnical design basis including variations in all positions including the selection of a typical near "worst case" soil profile for the tender design
- Scour protection and sedimentation design basis (Physical hydraulic model tests shall be a part of detailed design, but not be included in Tender Design)
- Appurtenances (boat landing, working platform and J-tube arrangements)
- Structural, geotechnical and hydraulic design methods to be applied in the detailed design
- Specification of facilities, including software, to be applied in the detailed design

Basic Design

- **Basic Design**
  The purpose of the basic design is to verify the structural design for a typical near "worst case" location to a sufficient level to verify dimensions and to prove the feasibility for the concept .It might be agreed to include more than the near "worst case" location if location conditions varies much.

  The basis for the basic tender design is the Design Basis.
  The Basic Design shall include:
- Summary of design conditions
- Basic Geotechnical Design, including calculations
- Basic Structural Design, including calculations
- Basic Scour Protection Design, including calculations
- Specification of material design properties
- Drawings

Detailed Design

Detailed Design shall include:
- Final Design Basis
  (incl. Physical Hydraulic Model Tests)
- Detailed Foundation Design comprising the differences for each single foundation
- Detailed Appurtenances Design
- Certification from Independent Verification Bureau
- As-built documentation

Production

Concrete, Reinforcement, Form Works, Site

To reach the target production it was necessary to prefabricate as much of the reinforcement as possible before installation in the form. A special template was constructed to prefabricate the reinforcement for the ice cone.

All forms were special designed for the purpose and was reused in the production of all foundations. Foundations heights could vary in steps of 250 mm. The forms were made of steel and were shaped exactly according to requirements in transition from substructure to shaft and from shaft to ice cone.

The production Site was situated in Odraport – Swienoujcie in Poland. We had the most of a harbour basin at our disposal.

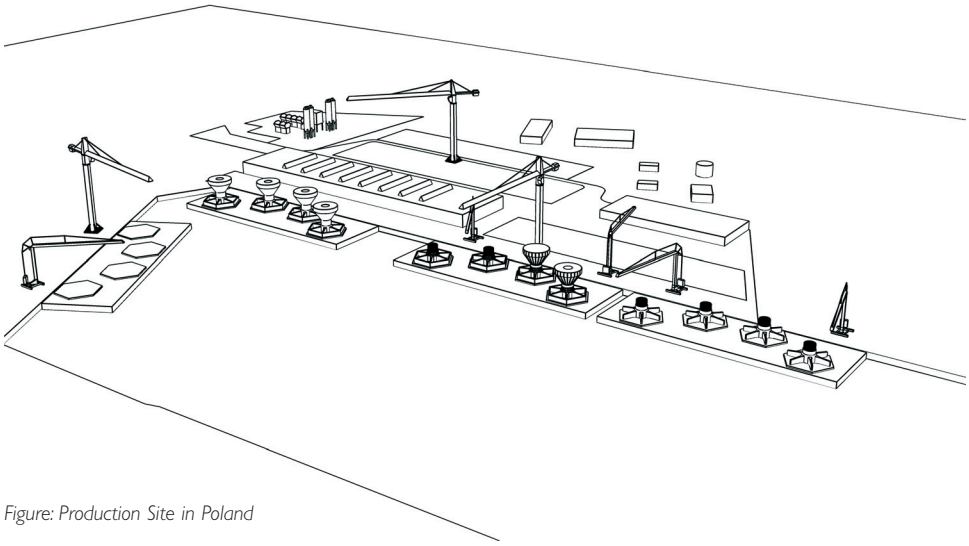
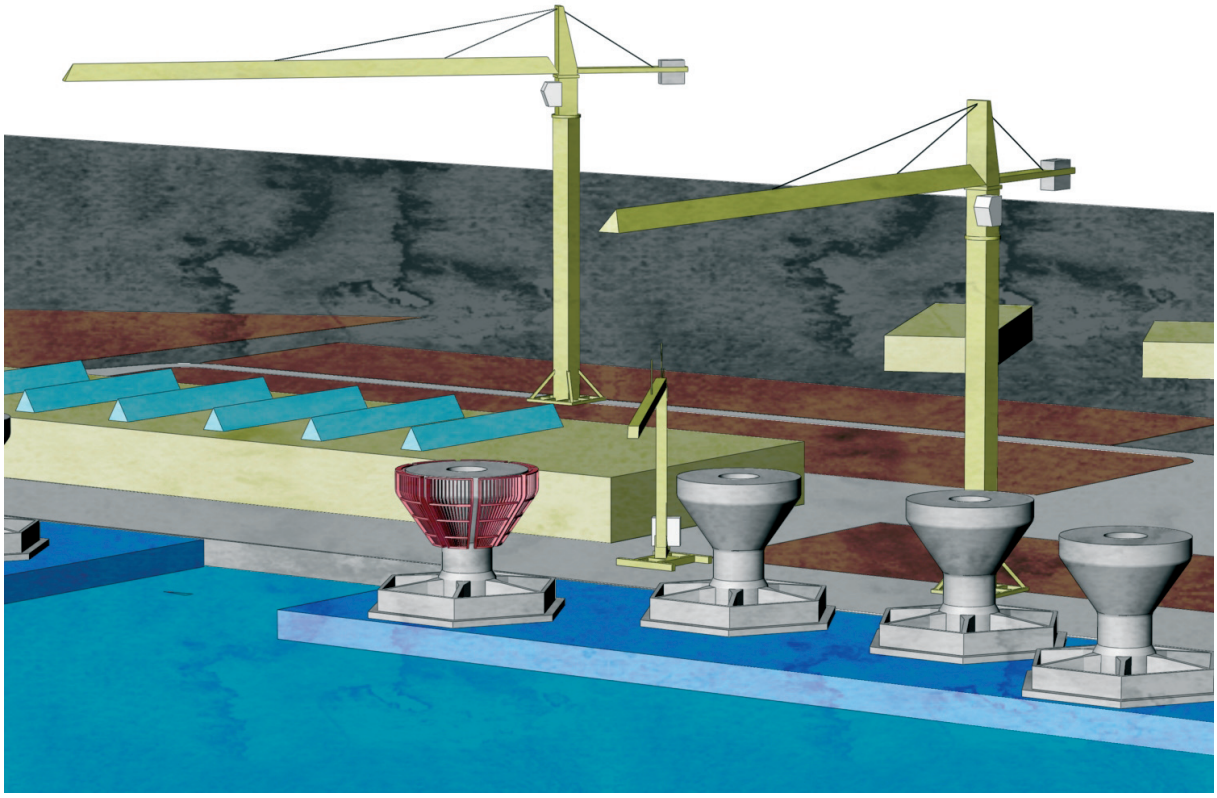


Figure: Production Site in Poland



Major Site Equipment:

- Double Concrete Batch Plant to ensure uninterrupted supply of concrete in case of breakdown of one of the Plants.
- Aggregate storage yard.
- Laboratory for testing and control of the concrete production.
- Cutting and bending station including erection Jigs for pre-fabrication of reinforcement panels. The station was be equipped with Tower Cranes for handling of the raw bars and the completed panels. Internal transport of finished panels was on trucks/low loaders.
- Site offices and rest rooms for the employed personnel.
- Workshops for maintenance of equipment.
- Storage facilities for accessory steel structures.
- 4 each 10.000 Barges. (Approx. 92 × 28 × 6.5 m), each equipped with 4 Casting Beds for the Foundations. The Barges had a ballasting system to keep the trim during the fabrication of the structures.
- 4 each Tower Cranes approx. 250 Tm, capacity was placed in pairs at each of the production positions.
- Cooling units for cooling of the fresh concrete to avoid early age cracking was installed on each of the production positions.
- Miscellaneous stair towers was used to gain access to the formwork during the production process.
- Two sets of steel formwork were in use on each of the production positions.
- Adequate number of poker vibrators for compaction of the fresh concrete.

Production:

On each of the production positions one Barge was used for production of four foundations in parallel.
The other barge was of to the Windfarm for the installation operation.

Sequence of casting operations:

- Casting of Bottom Slab.
- Casting of the bottom section of the shaft in the base of the Foundation.
- Three consecutive castings of the cylindrical and ice cone part of the shaft.
- In parallel with the casting of the shaft sections, the walls in the base are cast in two consecutive operations.
- Surface finish and possible repair is executed immediately after form removal in accordance with the procedures to be established.

Cooling of the fresh concrete after casting is made to avoid early age cracking.

Completion Works.

After finishing the casting the accessory steel structures were installed:

- The Cable pipes (J-tubes) inside the shaft and in the base.
- The Interior pre-fabricated steel platform was installed in the shaft on final position after ballasting.
- The Boat Landings and Ladder was bolted onto the shaft in final position as lifting frame did not allow for preinstallation.

Preparation for Towage:

Before towage to the Windfarm the Barges were ballasted to the required trim. All hatches and vent pipes to the ballast tanks were closed and secured.
Sea fastening structures were checked and secured.

Figure: Concrete Batching Plant

Form Works

Reinforcement Works

Reinforcement Works

Sea Bed Preparation

The main part of dredging took place with small hopper vessels equipped with hydraulic excavator of the back-hoe type. The vessels were anchored on legs. Dredging tolerance was held within a limit of +/- 0.30m.

The vessel itself dumped the dredged material at a nearby dumping site at sea. Final clean up on the bearing strata was done by grab. Checking of the bearing strata was done by 4 short CPT-tests.

A steel frame was placed and levelled at the dredged level as a guide for the installation of the stone bed. A levelling beam rotating on the frame did the final levelling. On the beam a small vehicle with high pressure water pumps secured that materials was pushed forward to allow the beam to move in the surplus material. The stone bed was delivered with a tolerance of +/- 0.020m.

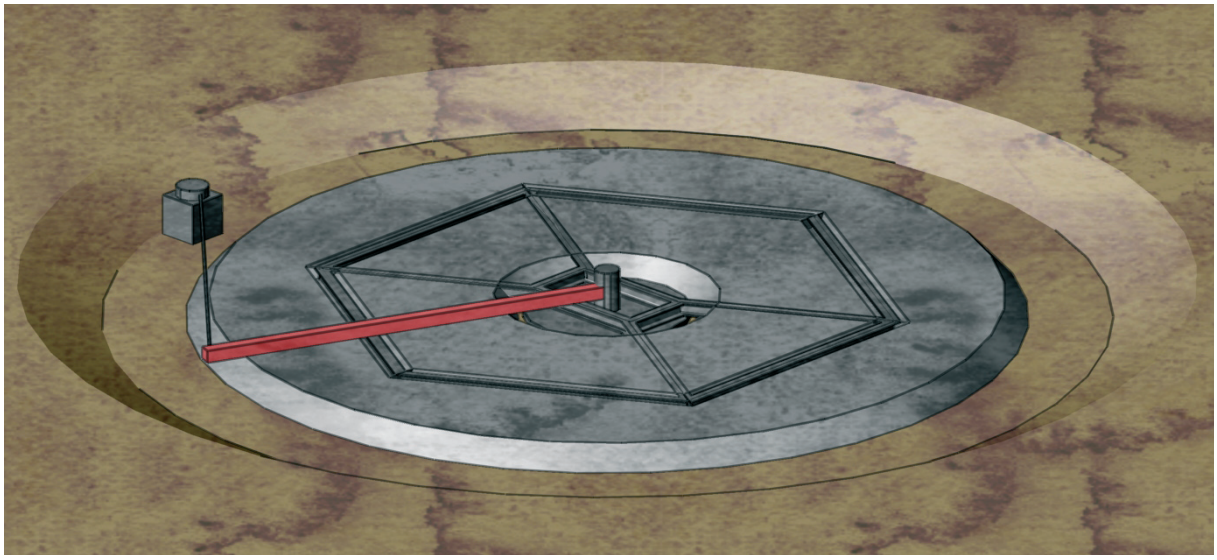


Figure: Steel frame and levelling beam

In a few positions the bearing strata was lower than the foundation level. Here a thick compacted stone bed was installed from dredged level to the underside stone bed. Compaction was performed in one operation in up to 3m thick layer by a vibrator (ICE 416) mounted on a heavy steel plate 2.1 * 2.6 * 0.075m.

Spill monitoring was performed during dredging operations. The bachoe dredger type gives very limited spill of less than 3-4%.

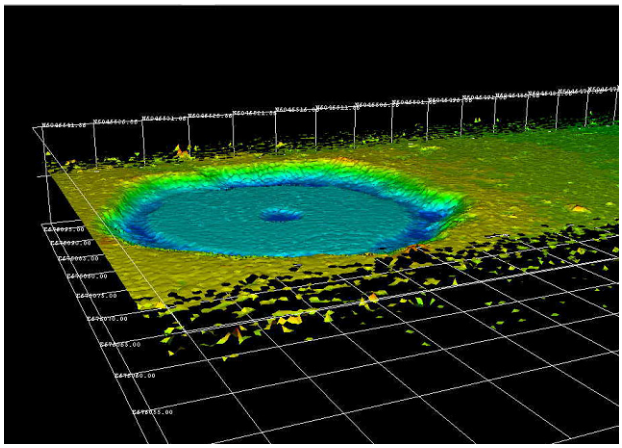


Figure: Multibeam survey of stone bed

Transport and Installation

The towage of the Barge with the Foundations to Nysted was done by use of one Tug Boat with a Bollard pull of 40 – 60 Ton. For the manoeuvres in the Harbour an auxiliary Tug was used to secure a safe operation out through the channel.

On arrival to the Windfarm, the Barge was with help from a service vessel type Multicat connected to a pre placed anchor, and preparations was made for the placing operation.

The Placing Vessel:

The lifting operation, for placing of the Foundations was carried out, by a specially equipped Crane Barge **EIDE V**. The vessel was also used successfully for installation of the Foundations for the Middelgrund Windfarm in Denmark.

The Crane Barge EIDE V is equipped with a four, anchor system and a Spud leg to secure the correct holding in place during the placing operation. The Barge is self-propelled, and had a supporting tug for anchor handling and assistance for the positioning operation.
The Placing sequence:

- EIDE V places itself on the side of the Transport Barge in front of the Foundation to be placed and is moored to the barge.
- The Sea fastenings on the Foundation are removed and at the same time the lifting frame is positioned around the ice cone.
- The Foundation is lifted from its place on the transport Barge that is continually ballasted to keep its trim.
- EIDE V leave for the position of the foundation and on arrival linked to pre-positioned anchors. Using the anchors and the Spud the exact position is secured.
- The Foundation is lowered into place on the prepared Stone Bed. During the lowering operation the position is constantly monitored and if required will be corrected by use of the anchors.
- After touch down and subsequent transfer of the weight of the Foundation onto the Stone Bed the position and level of the Foundation is controlled before the lifting frame is disengaged hydraulically and EIDE V can leave the position for its next operation after having lifted the frame above water level.
- The flexible part of the Cable pipes, are then extended from the Foundation onto the sea bed ready to receive the cables.

Risks: Waves, current and tides.

Action: Safe anchoring of transport barges. Safe sea fastening of foundations. Short installation time to fit within weather windows. Suitable equipment.

Figure: Barge with 4 foundations almost ready for transportation

Arrival at Nysted

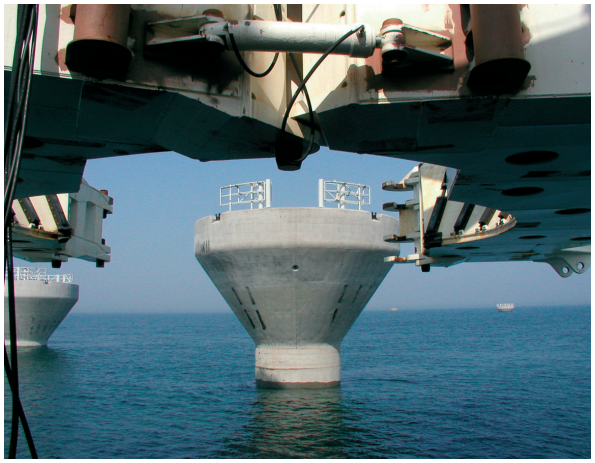


Figure: Installation

Installation

Ballasting

Ballast is required to obtain the necessary effective weight of the Foundation to withstand the various load situations of the combined system Turbine/ Foundation.

Ballast in the Shaft of the Foundation was well graded Olivine which is a high-density type of rock.
The material was placed from a Stone Barge by use of Grab. In some of the foundations ballasting in the shaft was done by sand as this was sufficient to obtain enough gravity for stability.

Ballast in the outer cells of the Base structure was NORIT stone installed by hydraulic excavator from a Stone Barge.

Figure: Filling the foundation shaft with ballast materialFilling the foundation shaft with ballast material

Scour Protection

The scour protection was a 2 layer system with armour stones 60-300 kg and filter layer 20-100 mm.

The materials was placed by a hydraulic excavator from a Stone Barge.

Hydraulic model tests at DHI was performed to verify stone sizes and extent of scour protection.

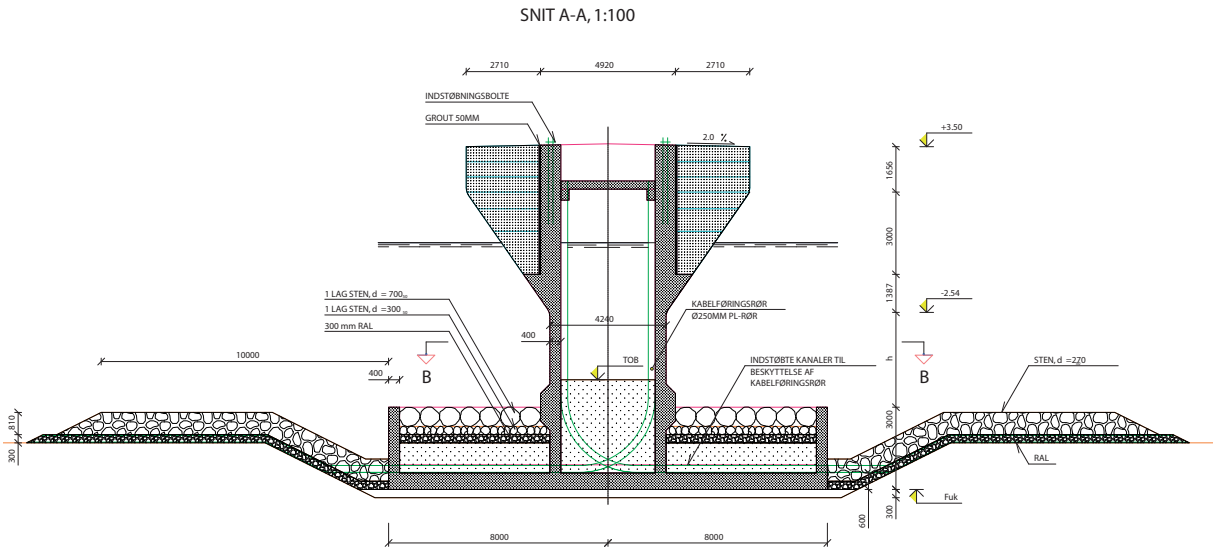


Figure: Scour Protection and ballast