

# THE BELGIAN OFFSHORE GRID : TRANSPORTING RENEWABLE ENERGY FROM OFFSHORE TO ONSHORE

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The new planned offshore windparks at the Belgian Continental Shelf have to be connected with the Belgian high-voltage electricity network (grid) developed by Elia. A possible way for this connection is the development of an island on which high voltage offshore substations are installed. These substations are connected with the wind farms and can transmit the electricity with a few common cables to land. This paper highlights some benefits and design aspects of this concept, together with design aspects of the cable installation.

*Keywords: island, cable connection, offshore energy, breakwater, caissons*

## INTRODUCTION

Elia is responsible for managing and maintaining the Belgian high-voltage electricity network (grid) and intends to develop an offshore grid to ensure that the wind farms in the Belgian Part of the North Sea are optimally integrated into its onshore grid. The project entails connecting future wind farms to offshore high voltage substations.

To date, some of the wind farms have individual direct connections to the onshore grid. With the creation of an offshore grid, the remaining wind farms in the Belgian Part of the North Sea can be connected to high-voltage offshore substations that will be installed on an artificial island/platform which will, in turn, be connected to the onshore grid. There are many technical, economic and environmental benefits to this solution: it will be safer, more economical and more environmentally-friendly to develop a proper offshore grid than to continue connecting each wind farm individually as we do today, an approach that results in a higher amount of offshore cables and landfalls.

This offshore grid is able to be hooked up in the future to an international platform using direct-current connections. These make it possible to transmit greater quantities of power over longer distances. Some of Belgium's neighbouring countries, like the United Kingdom and the Netherlands, are also working to develop grids in their territorial waters in the North Sea.

Such an international platform would facilitate access to other types of energy, particularly hydropower in Scandinavia, solar Energy in the South of Europe, hydro-power from the mountains. These resources could be used in the event of there being insufficient wind on the North Sea, or they could allow storage of wind power when a surplus of energy is generated. This solution would enable Belgian consumers to be supplied with green energy, even when there is no wind!

One of the possibilities is to install the substation on an artificial island, ca. 35 km offshore the Belgian coast. The Island will also have a quay and laydown area for mooring of tugboats, heavy lift platforms and crew vessels. The island will have the possibility to facilitate the nearby wind farms. In the future, the Island can contain a substation for the international direct current grid.

The presentation will focus on the goals and the basic design solutions of the island.

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Following topics will be presented:

- Necessary buildings and general layout of the island
- Harbour requirements and facilities
- Hydrodynamic design conditions island
- Sea bed survey campaigns
- Erosion/sedimentation around the island
- Burial depth for the cables connecting the offshore substations with onshore
- Transport and load out of substations
- Possible sea defence structures
- Crossing of the cables through the sea defence

### OBJECTIVES

At the Belgian Continental Shelf wind farms with a total capacity of 2 GigaWatt are built or planned. For this reason, it is examined to develop a connection point in the Belgian part of the North Sea in order to maximize the investment value for the wind farm concession holders as well as for the community. A connection point, to which the new wind farms transport their electricity, and from which this electricity is transported to land with common cables, can reduce the total length of cables required and creates redundancy and improves reliability (in case 2 connection points are used). It also allows interconnection with other offshore projects (including the possibility of creating a hub for future offshore (Northsea) DC grid) and reduces the environmental impact. The reduction of cable length is illustrated in Figure 1. In the scenario with individual connections the total length of cables is twice the length of cables needed in the scenario with the connection points, while the crossing of existing cables and pipelines is reduced with 30%.

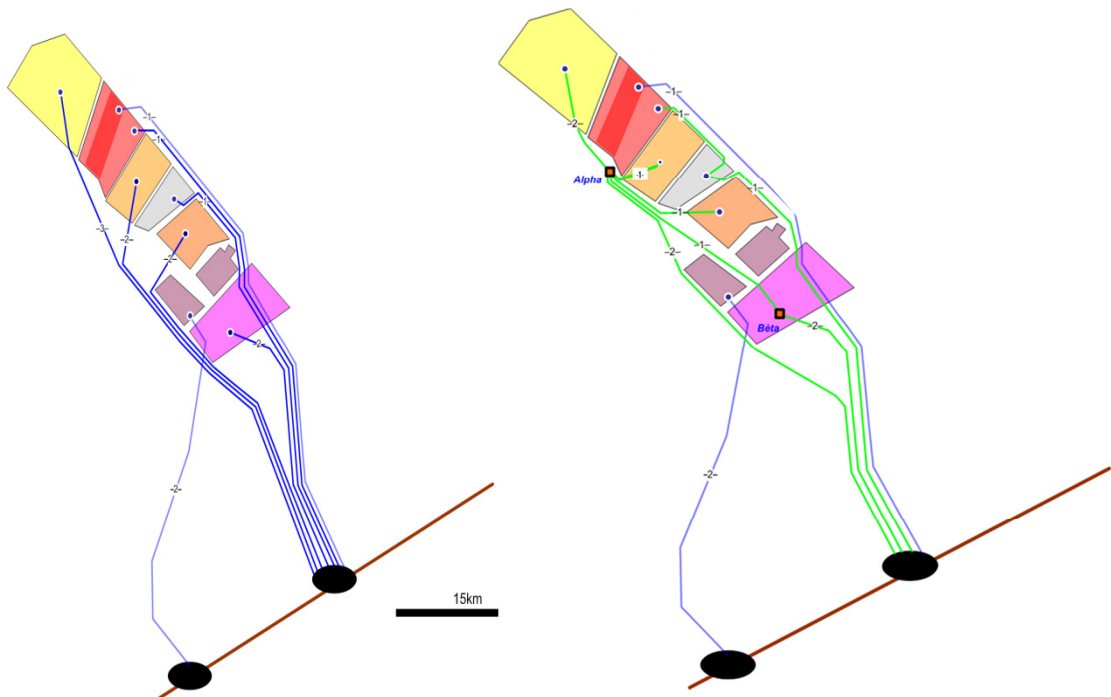


Figure 1 left: each wind farm connected separately with land, right: connection via 2 connection points

Many possible scenarios with number of connection points and the design of connection points (e.g. island, platform) are possible. This paper describes the conceptual design of a connection point using the concept of an island and the cable laying, as illustrated in Figure 2.

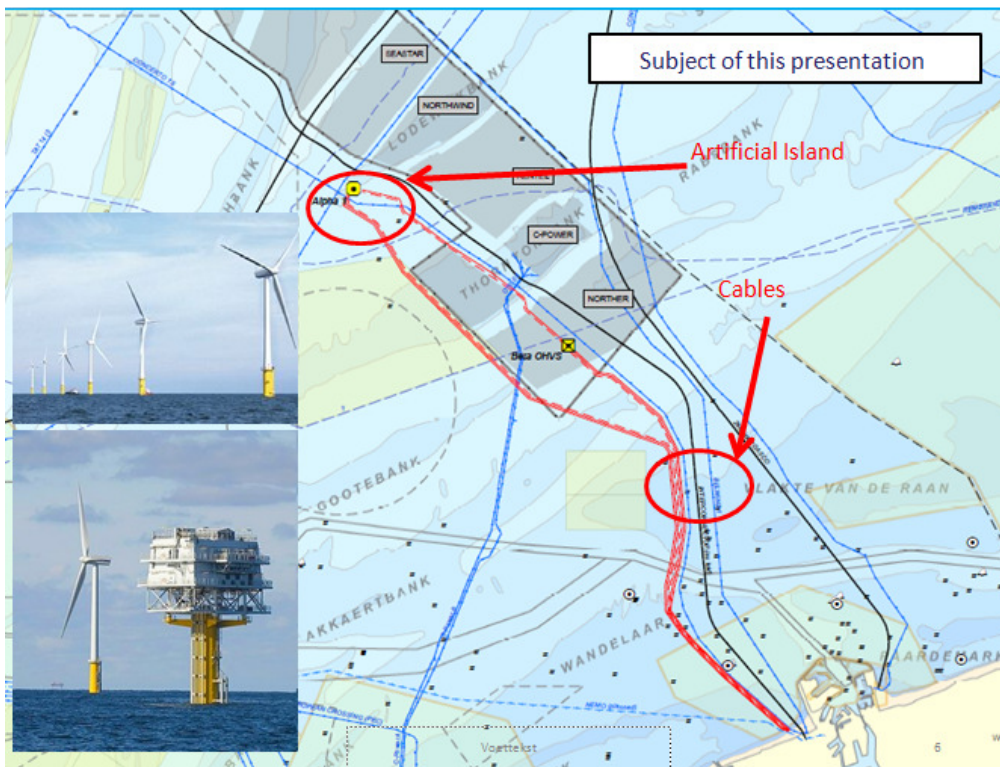


Figure 2 Subject of paper

## CONCEPTUAL DESIGN

The conceptual design of the island is performed in order to increase the knowledge for problems that can occur during the real design including interface problems (e.g. with the cable installation, the transport of modules,...), for a better identification of the Employer's requirements and to prepare the environmental impact analysis. It also provides a basic for a cost estimate and hence check the feasibility.

For the conceptual design following basic assets on the island were defined:

- Offshore high (alternating) voltage station (1 module of about 5.000 ton) (HVAC)
- Possibility for a High voltage direct current station HVDC (to connect different production areas in the North Sea in order to reduce weather dependency of clean energy) (3 modules of at least 7.000ton)
- Quays/harbor to facilitate offshore works and the mooring of a tugboat (to intervene if a ship drifts towards a wind turbine) during a defined percentage of time, in order to limit heli-transport
- Facility center/work units for the offshore wind parks

These requirements resulted in two concepts, illustrated in Figure 3 and Figure 4, respectively a concept where the island is protected with a rubble mound breakwater and caissons. The breakwater solution can be constructed at sea and is slightly smaller but required a harbor, in the caisson solution, ships can moor at each side of the island, e.g. depending on the wave direction. The caissons can be fabricated on land, but require a more difficult transport.

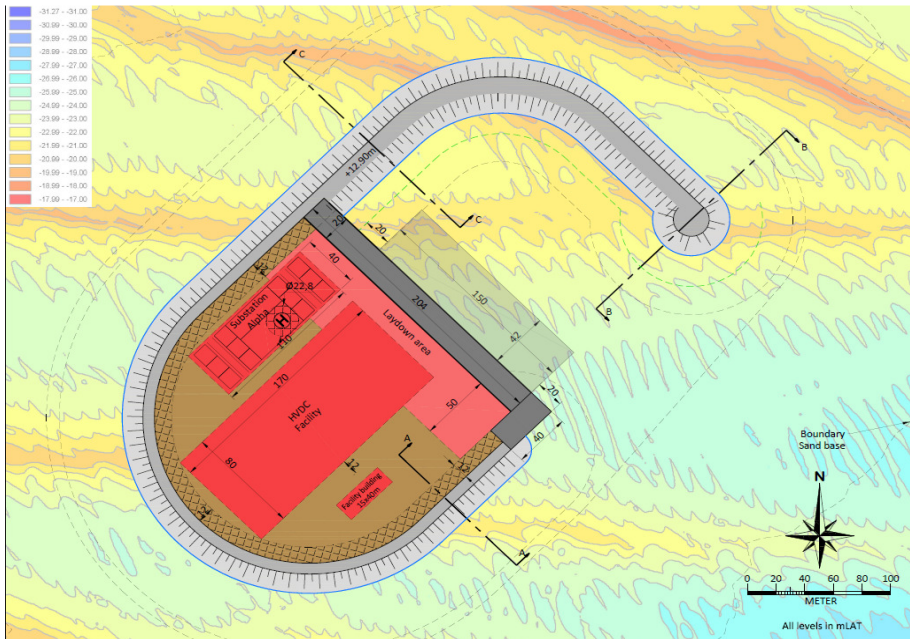
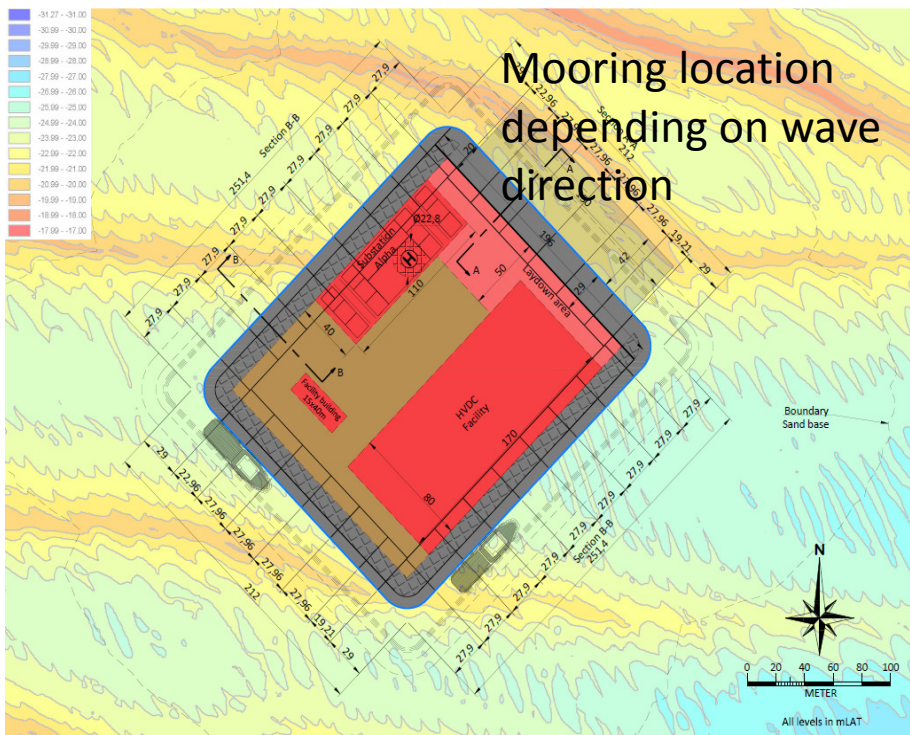


Figure 3 Island with rubble mound breakwaters



Mooring location depending on wave direction

Figure 4 Island protected with caissons

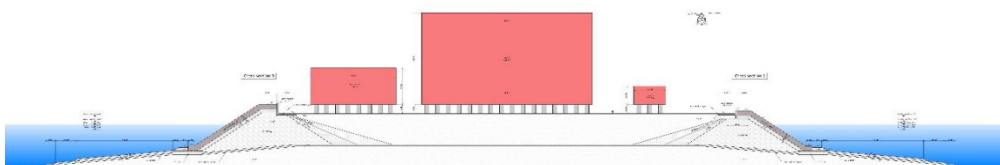


Figure 5 Cross section of island with rubble mound breakwaters



## BOUNDARY CONDITIONS

The site specific conditions, i.e. the conditions valid for the site without any infrastructure in place are obtained using measuring data and numerical modeling. In a second phase the site conditions are adapted, taking into account the structure itself (e.g. flow contraction, sheltering of waves, wave shoaling on the island base,...).

The site specific conditions necessary for the set-up of the Basic Design can be grouped in the following types:

- Met-ocean conditions (water levels, waves, currents, wind, ...);
- Geotechnical site conditions;
- Morphodynamic site conditions;
- Geographical constraints (presence of cables, wrecks, ...).

### Water level

Extreme water levels are a combination of tidal water levels (astronomical tide) and storm surge (elevation of the water level due to wind and pressure gradients). The storm surge offshore is almost the same as the storm surge in Ostend, based on comparison of water level measurements in Ostend (harbor) and Westhinder (offshore measuring location). The extreme high waters are determined based on this water level measurement and transformed to the project area (correcting for differences in astronomical high water levels).

The design extreme water level is about 6m LAT. However, e.g. for overtopping calculations, the directions of storms for which the island provides sheltering (e.g. the SE quay is protected for the severe NW storms) should not be taken into account. For this reason, for some applications the design water level can be lower.

### Waves

Both the normal as the extreme wave climate are important. Long term measurements (>25 years) of the Flemish Coastal Division at offshore locations are transformed (using numerical models) to the location of the island. These transformations are validated using a site specific measuring campaign.

An illustration of the normal wave climate is given in Figure 6

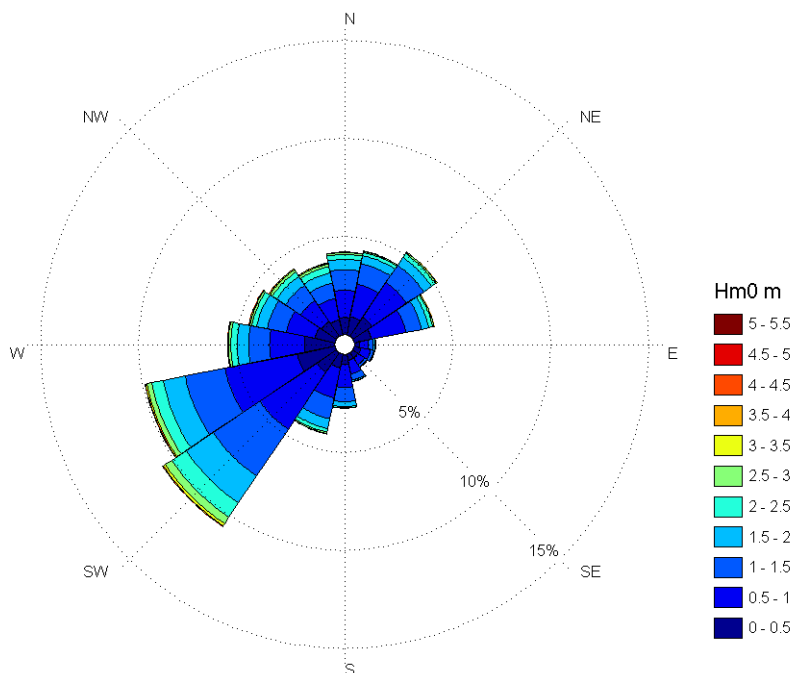


Figure 6 Normal wave climate

### Currents

A large scale Delft3D model of the North Sea (Figure 7) in which a detailed model (Figure 8) was nested, was applied to model the current velocities at the location of the island.

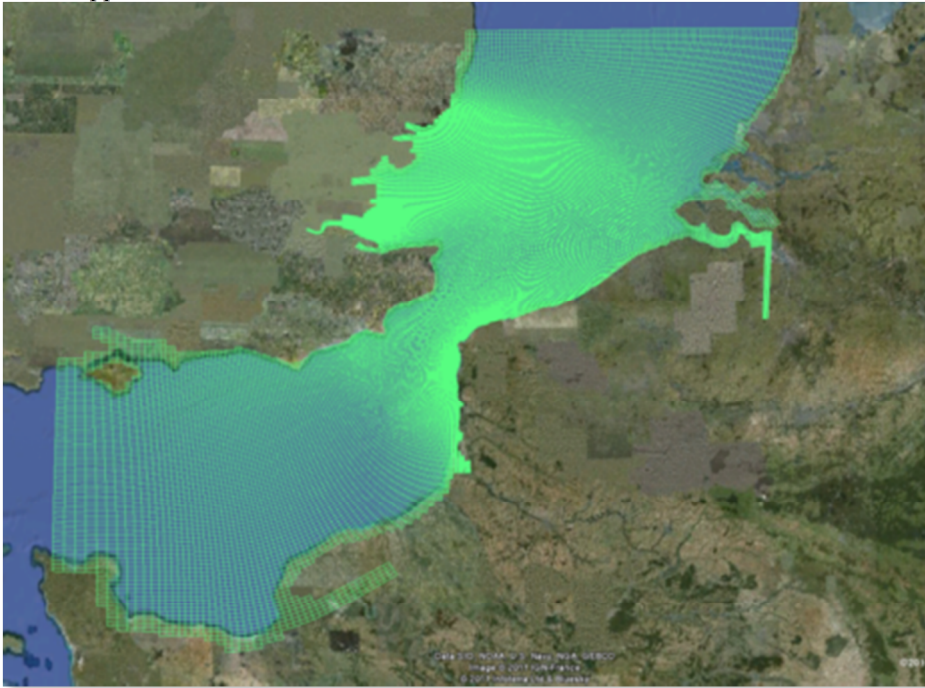


Figure 7 North Sea hydrodynamic model

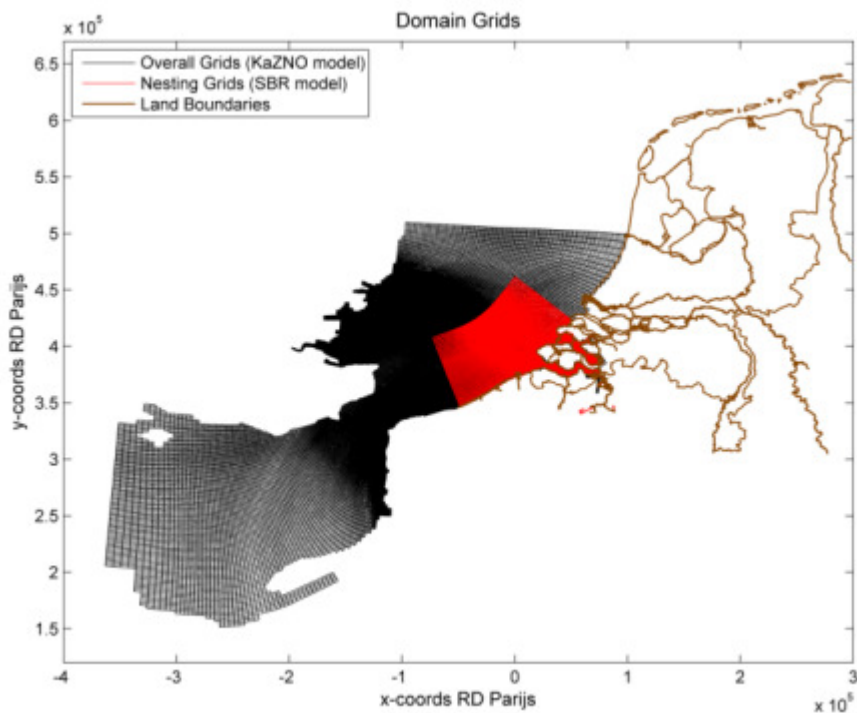


Figure 8 Nested hydrodynamic model

The results show that the current pattern is characterised by a consistent predominant current direction on the SSW – NNE axis, which corresponds with the tidal regime in the North Sea. The current regime is tidal driven and varies between 0.2 m/s and 1.1 m/s.

After the construction a strong flow contraction is observed. The maximum flow velocity is increased with a factor 2.

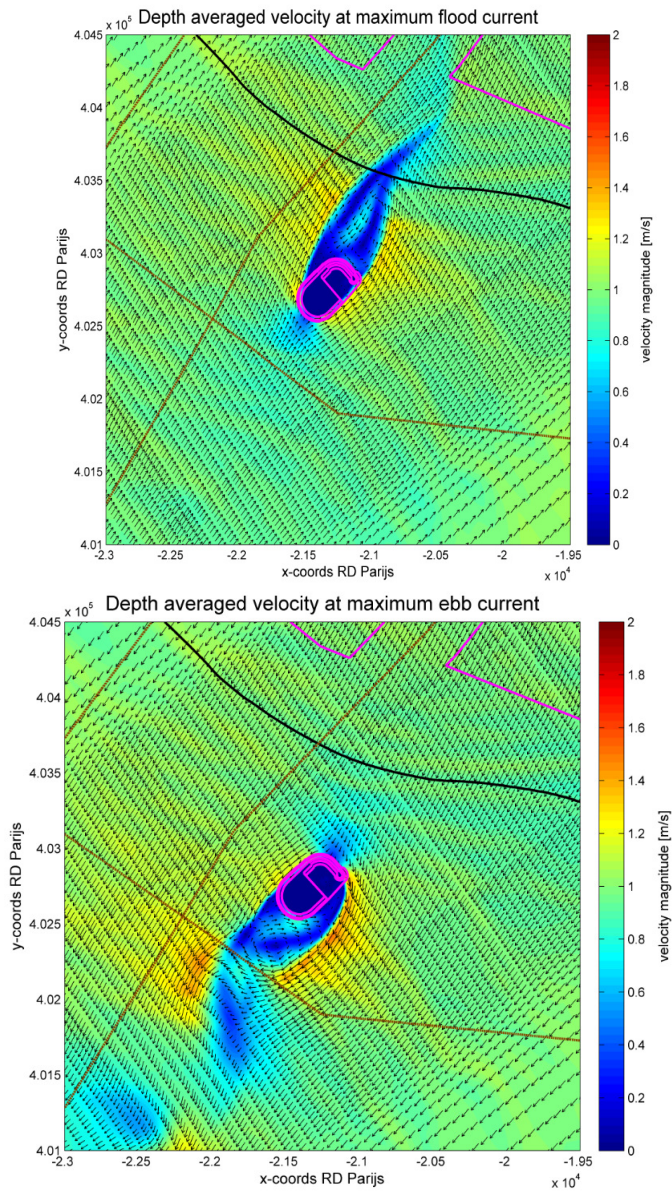


Figure 9 Modelled current velocities at maximum ebb and maximum flood after the construction of the island

**Morphology**

Using the previous discussed hydrodynamic results, the Delft3D model is also used to assess the morphological development for a period up to 25 years after the construction of the island. The erosion sedimentation pattern is illustrated in Figure 10.

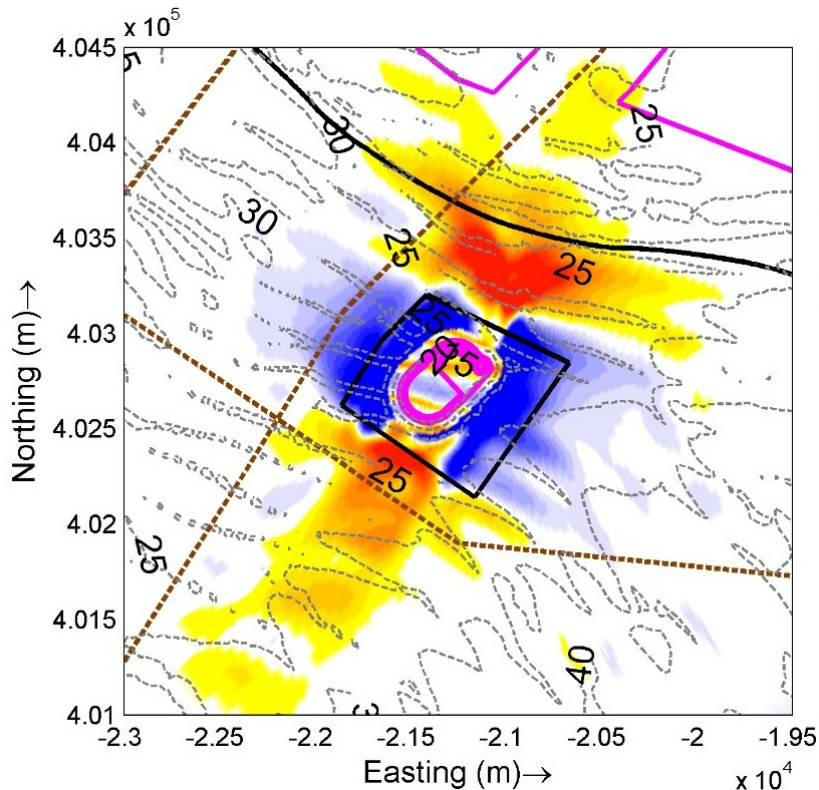


Figure 10 Modelled morphological development of the sea floor around the island (red is sedimentation, blue erosion)

#### Sea bed survey

The seabed survey consisted of a geotechnical and a geophysical investigation. The program can be summarized as:

- Geotechnical investigation
  - Offshore and onshore Cone Penetration Tests (CPT);
  - Offshore and onshore borehole sampling up to 60m depth.
  - Offshore Vibrocore
  - In-situ thermal resistivity / conductivity of the upper seabed layers (down to 3 m)
  - Laboratory tests.
- Geophysical investigation: detect objects, mapping of the morphological sea bottom and subsoil layering
  - A side-scan sonar survey: mapping of the morphology, seabed sediments and seabed anomalies (i.e. debris, ship wrecks, cables, pipelines, ...).
  - A magnetometric survey – UXO clearance: Detecting iron containing objects such as cables, pipelines wrecks, mines, etc.
  - A multibeam survey: sea bed topography
  - Seismic survey: Identify the internal geological structure and seismic layering of the subsurface.

#### DESIGN ASPECTS OF SEA DEFENCE STRUCTURES

Two options are possible for the construction of the sea defence structure: the sea defence is constructed directly on the sea bottom or first a sand base is installed on which the sea defence is constructed (in order to limit the amount of stones/rocks/armour elements and make the construction cheaper). In both cases, due to the erosion, some protection of the surrounding sea bottom (or sand basis) is required.

During storms wave overtopping of the sea defence is allowed as long as the buildings on the island are strong enough to resist the resulting impact forces on the walls. An optimum has to be found



between making the sea defence higher, using storm return walls, elevating the weak points of the buildings or making them stronger. The complex configurations of sea defence, storm return walls and buildings make it impossible to use literature to accurately estimate the forces on the buildings. For this reason numerical and physical modeling is required.

Based on the global stability and the (differential) settlements of the caisson walls, a good compaction of the sand fill is required in the neighbourhood of the caisson structures. Compaction is considered for the sand fill below and aside the caisson cross section, and over a height of ca. 11.75 m. A width of ca. 70 m is applied: 30 m seaward side of the caisson, 25 m below and 15m landward side of the caisson.

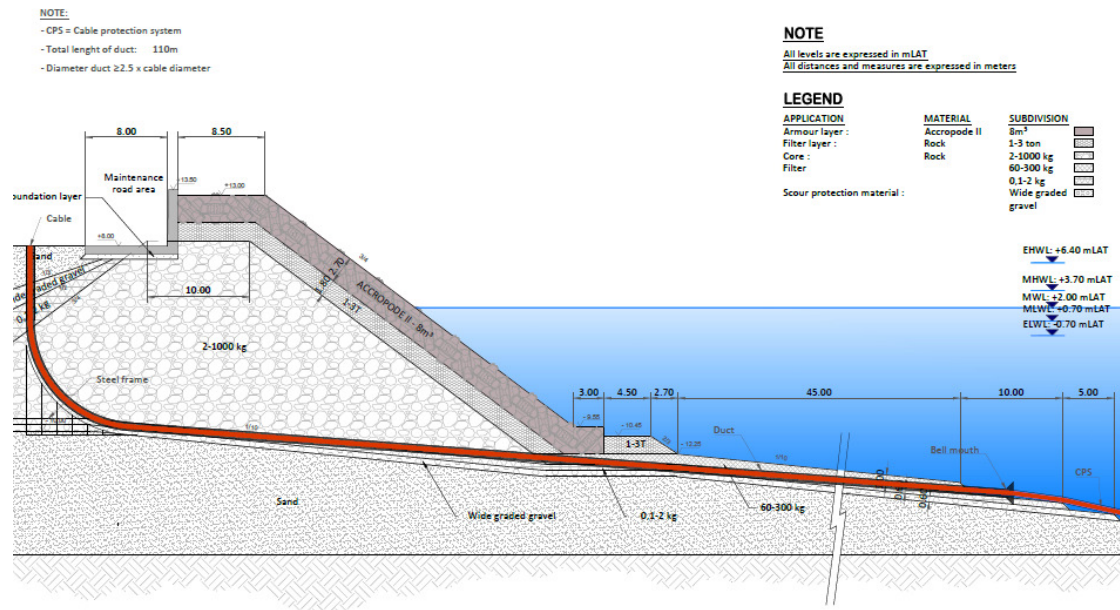
Below the heavy substations area, the required compaction depth will depend on the compaction degree that is measured in situ, after backfill of the internal part of the island.

The compaction of the sand is an important aspect in the cost calculations. Also the strengthening of the quays and the required facilities to transport the heavy modules (substations) to and on the island are an important design aspect, impacting the cost of the island.

**CABLE LANDING ON THE ISLAND**

Three possibilities for the cable landing are considered:

- a) Under the breakwater
- b) Under the armour layer
- c) Directional drilling



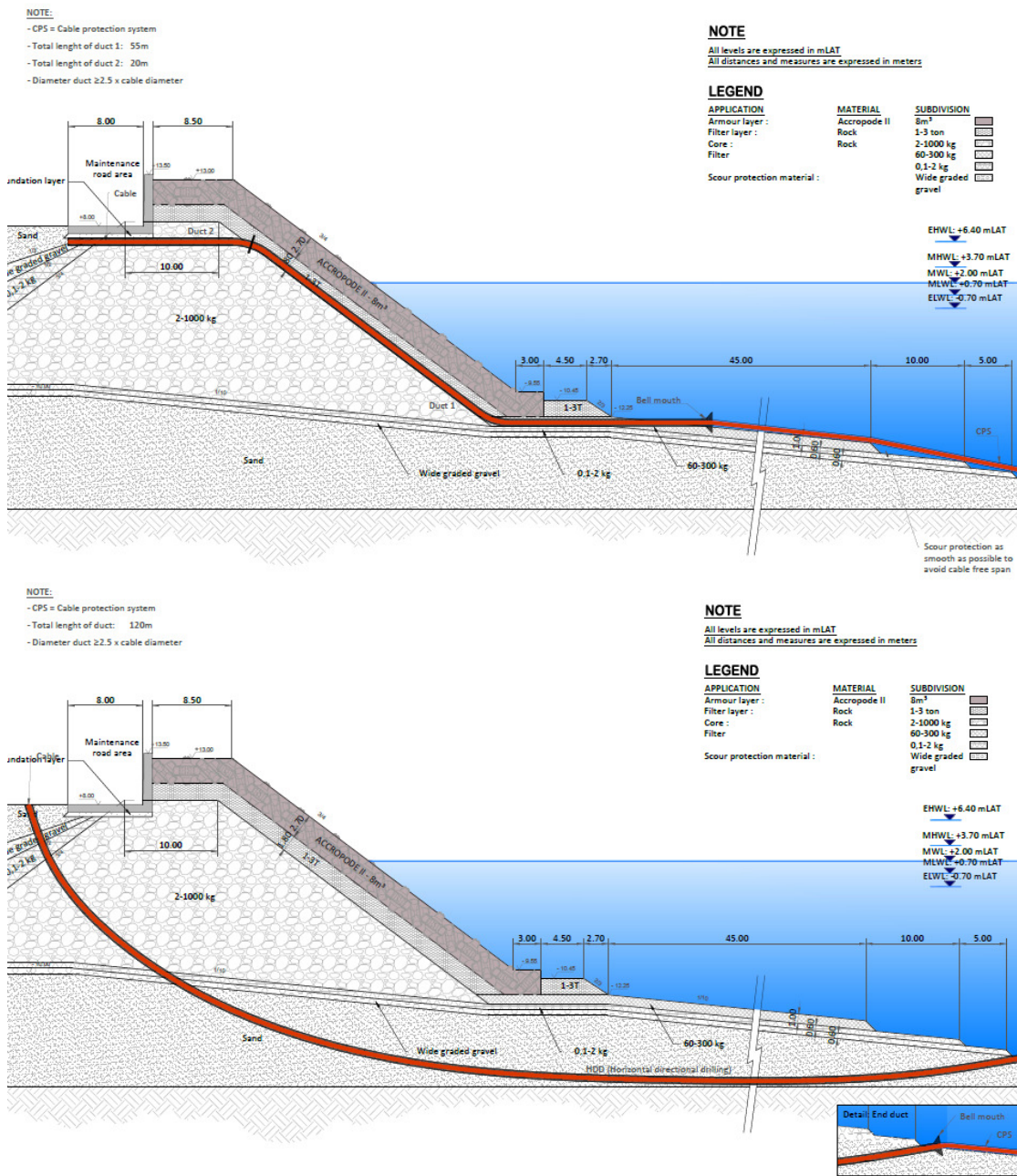


Figure 11 Three different solutions for the cable landing on the island: a) Under the breakwater b) Under the armour layer c) Directional drilling

The solution under the breakwater is positive to avoid problems during construction of the armour and filter layer, is sufficient regarding the thermal conductivity but the risk of damage of the vertical part during the construction (ship collision) is high.

The solution under the armour layer is positive for the thermal conductivity, but difficult for the construction of the filter and armour layer.

The directional drilling is the easiest for the construction of the breakwater, but can give severe problems for the thermal conductivity (lowering the efficiency of the cable).

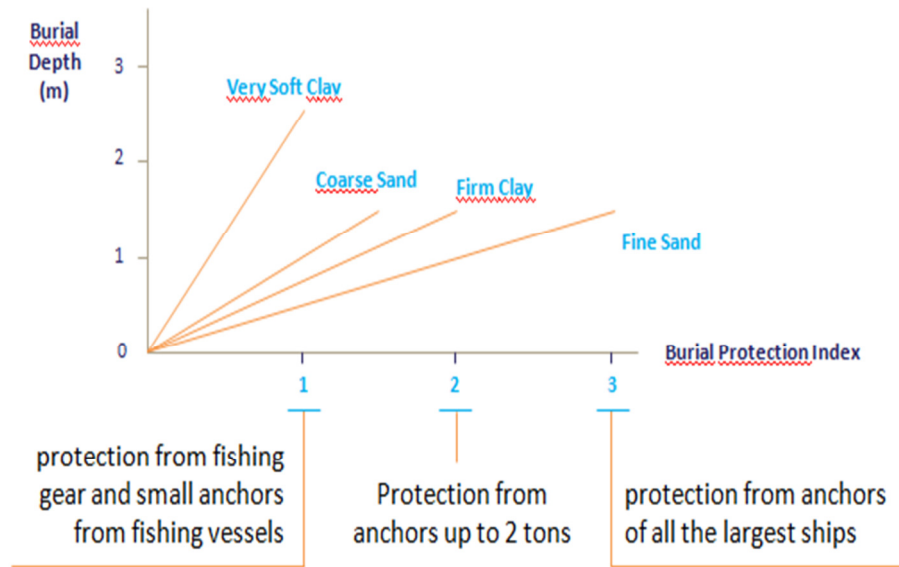
For the caisson solution, the cable landing can make use of the free space in the caisson itself.

The cables on the sea floor will experience the erosion and sedimentation around the island. This has important consequences for respectively uncovering of the cable and the thermal conductivity. A protection with stones is not evident since the anticipated extra scour around this protection. This

would require an extra complete protection of the sea floor with gravel or an extra burial of the cable (with the negative consequences for the thermal conductivity).

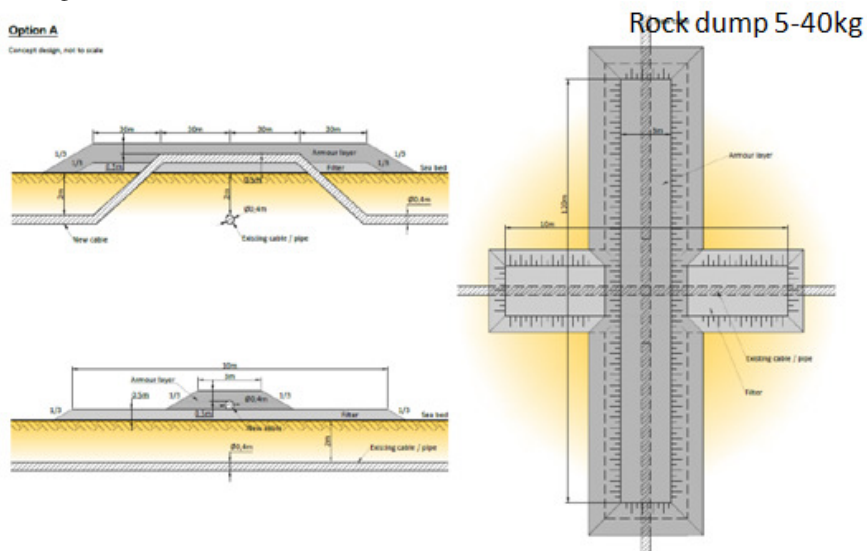
**CABLE BETWEEN THE ISLAND AND THE ONSHORE STATION**

The burial depth along the trajectory is determined by human activities (Fishing, marine traffic and navigation routes, third party cables, pipelines and requirements from existing or planned infrastructure along the trajectory) and by human processes (sand dunes, erosive areas, hard soil and required thermal conductivity). The required depth for anchoring depend on the size of the expected ships and the soil conditions as illustrated in **Figure 12**).



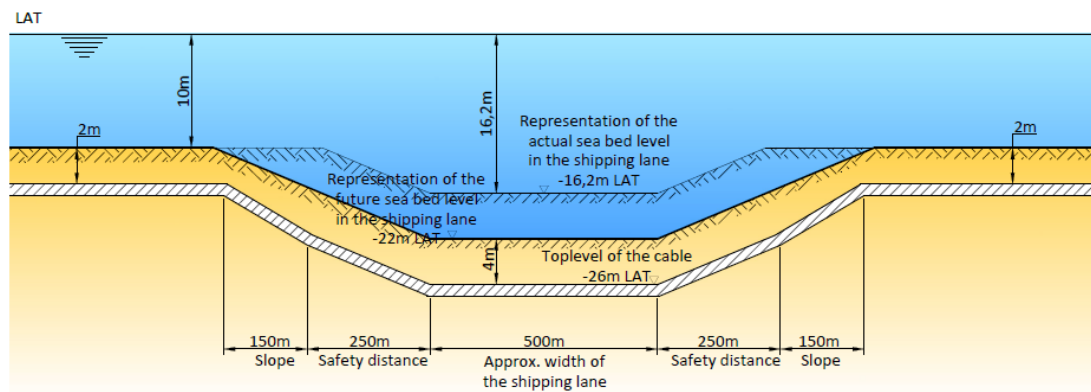
**Figure 12** Required burial depth for anchoring

The cable trajectory crosses a lot of existing cables, pipelines and navigation channels present on the Belgian Continental Shelf. For the crossing of cables traditional techniques are proposed as illustrated in **Figure 13**.



**Figure 13** Possible technique for cable crossing

For the crossing of a navigation channel (Figure 14) an extra burial depth should be taken into account to anticipate for future deepening of the channel and the higher risk of anchoring.



(\*) The representation of the cross section of the navigation channel "Het Scheur" are not based on bathymetric measures

Figure 14 Crossing of a navigation channel

## CONCLUSIONS

A conceptual design is drafted up and main points of attention are identified. The erosion around the island requires extra protection to guarantee the stability of the sea defence structure and also requires specific attention for the cable landing. The necessary compaction of the sand under the heavy modules and under the sea defence structure (in case of the use of a sand basis) and the necessary strengthening of the quay and roads for the transport of the heavy modules are important aspects in the cost calculation.

For the cable connection to land the burial depth is the most important issue.