The application of caisson-type solutions to the current offshore wind energy market

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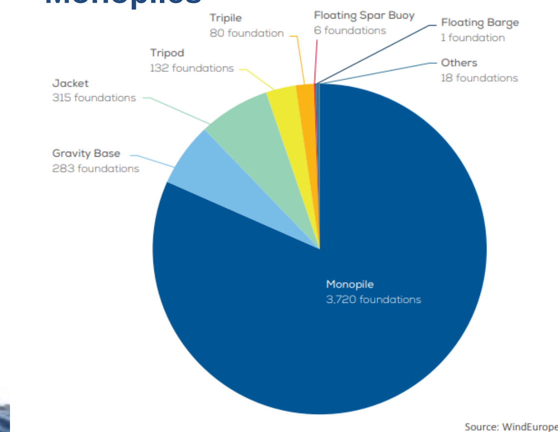
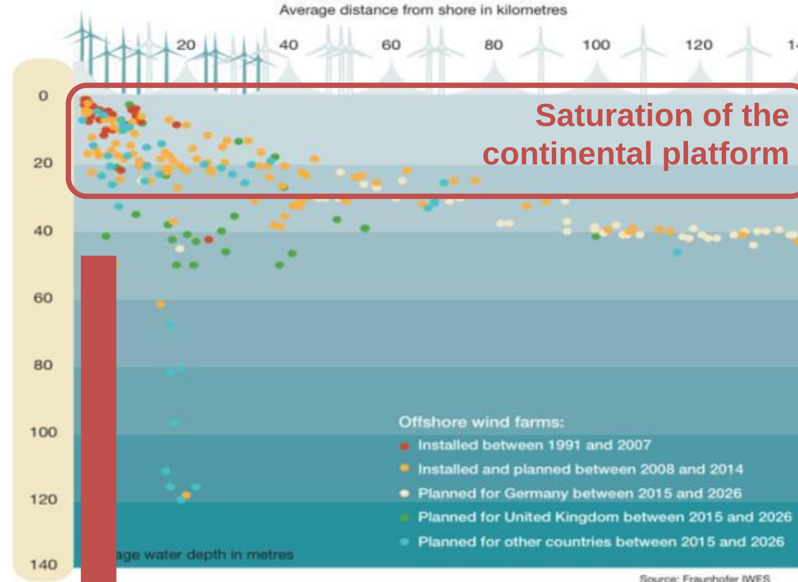
CONTENTS

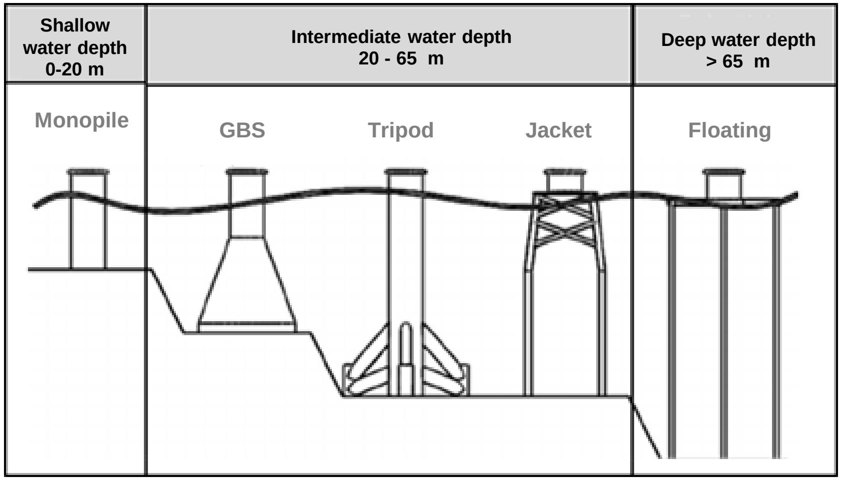
1. Introduction: saturation of continental platform

Current solution for offshore WTG foundations Monopiles





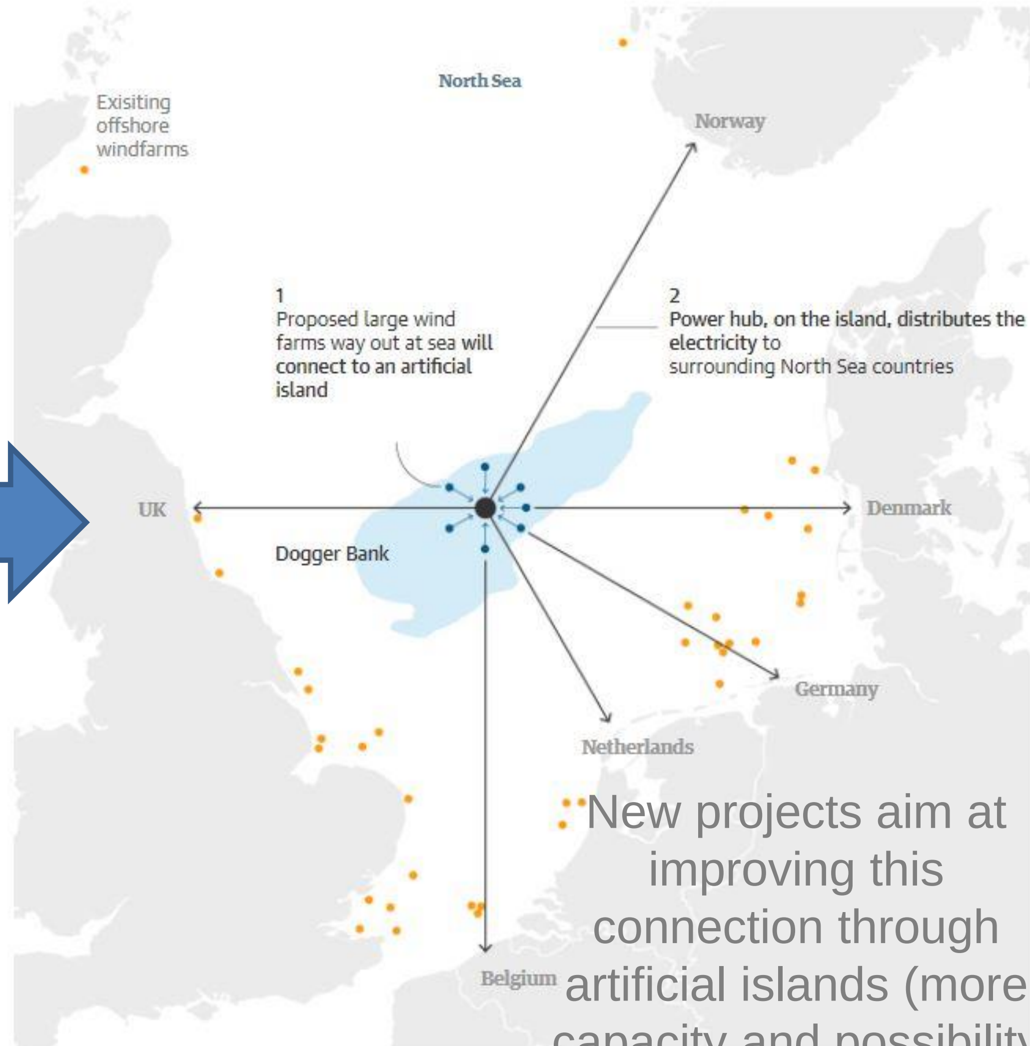
Need of new solutions for larger water depths that are as competitive as monopiles in shallow foundations



1. Introduction: current offshore situation

An issue that must be addressed is the Improvement in the interconnection between the wind farms and the distribution centres

Currently, the most common solution is similar to the WTG foundations with substations over monopiles/jackets



Guardian graphic | Source: Tennet

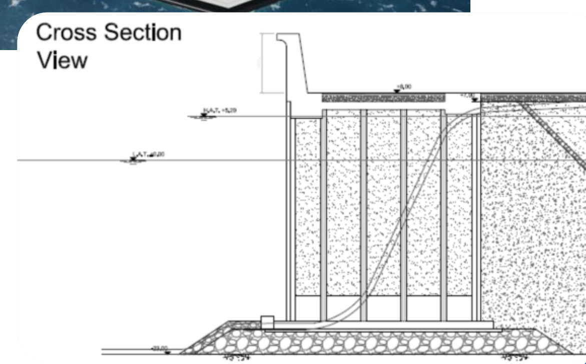
New projects aim at improving this connection through artificial islands (more capacity and possibility to convert to DC)

To overcome all these issues, caisson-type solutions emerge as an alternative for continuing the exponential growth of wind energy

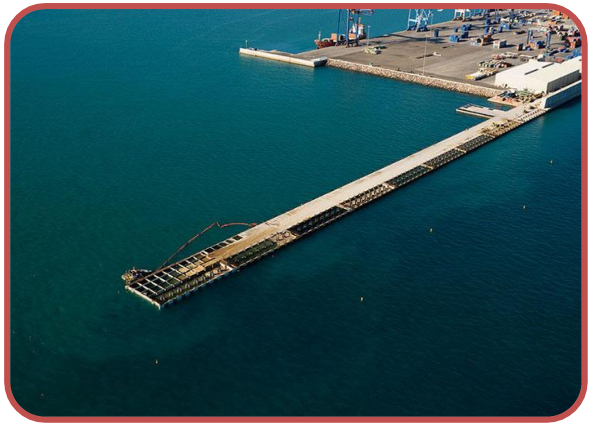
Regarding the foundations, caissons-type solutions act a gravity based and can optimize the cost in greater water depths

Foundation for Met Masts and Wind Turbine Generators

As for grid connection, the employ of caissons can be crucial for the development of artificial islands



Advantages of caisson solutions



Employ of well developed technology in port engineering

Cellular structures – so they are self-buoyant

Easy to transport by means of tugs

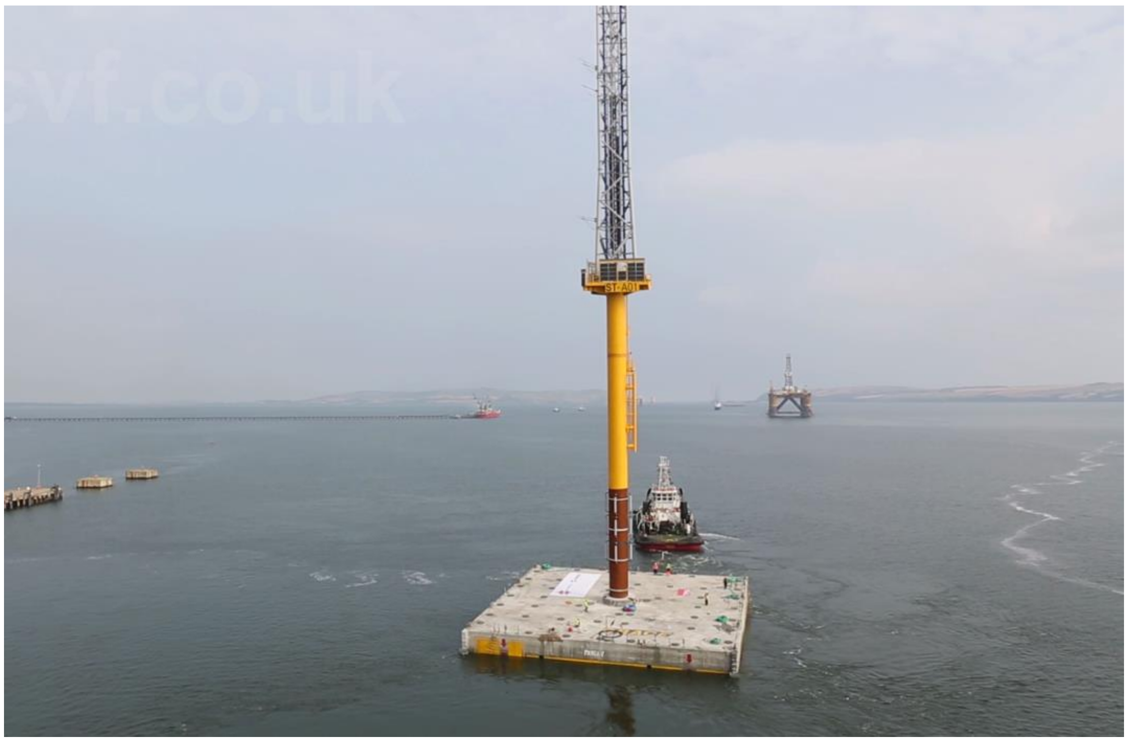
Easy to install by means of water/sand

Provide sufficient weight to withstand wave forces

Reduced construction time using floating docks

3. Met mast foundation using a caisson-type solution: Scotland

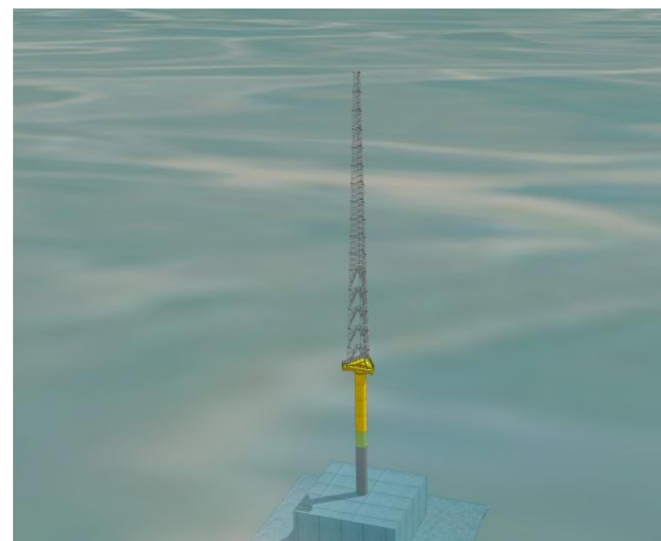
In 2014, two met masts installed in Moray Firth and Inch Cape (Scotland) pioneered the use of caisson-type solutions for the foundation of offshore Meteorological Tower



Main advantage of the solution: no need of scarce auxiliary maritime resources (e.g. heavy lift vessels and jack-ups)

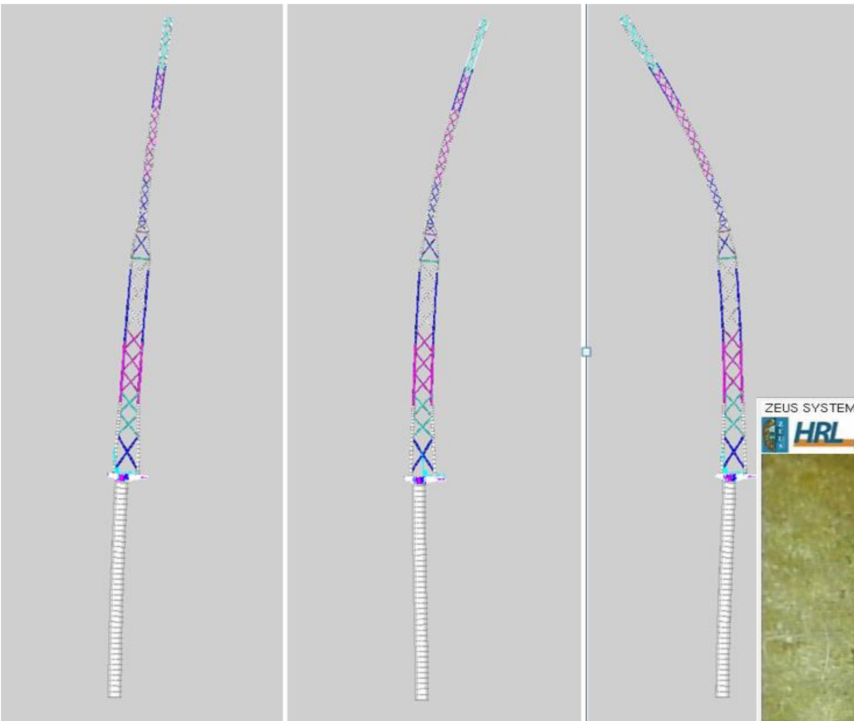
Key data

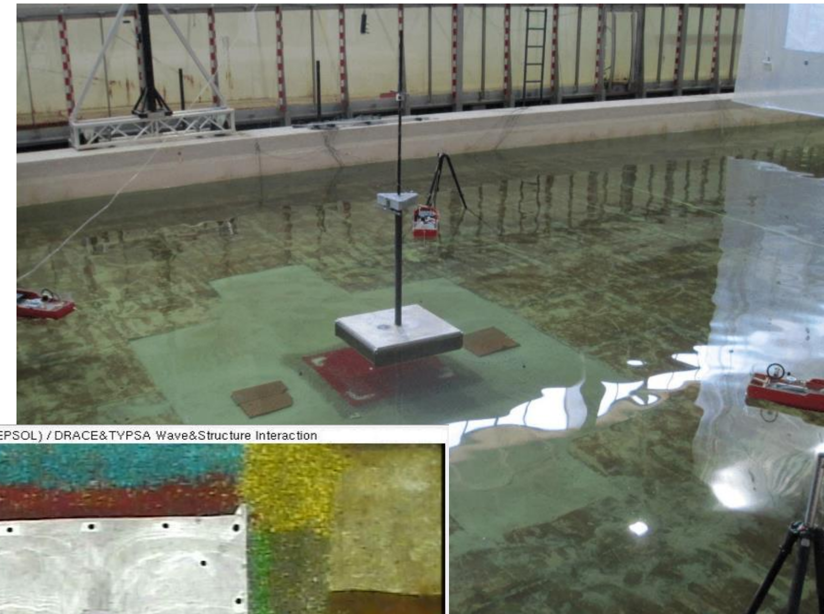
- Water depth: 50 m
- Caisson width: 33 x 32 m
- Caisson height: 17 m
- Shaft height: 40 m
- Shaft diameter: 3.5 m
- Lattice: 80 m



Hybrid structure: comprised of a concrete caisson and a steel shaft

Design and post-process of experimental campaign

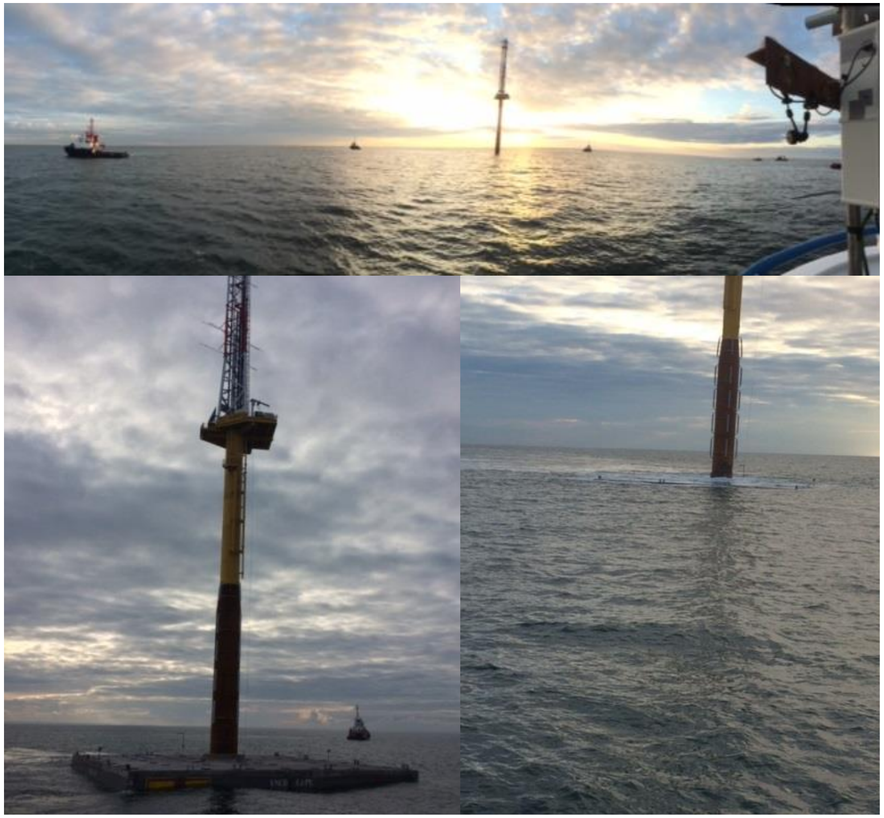


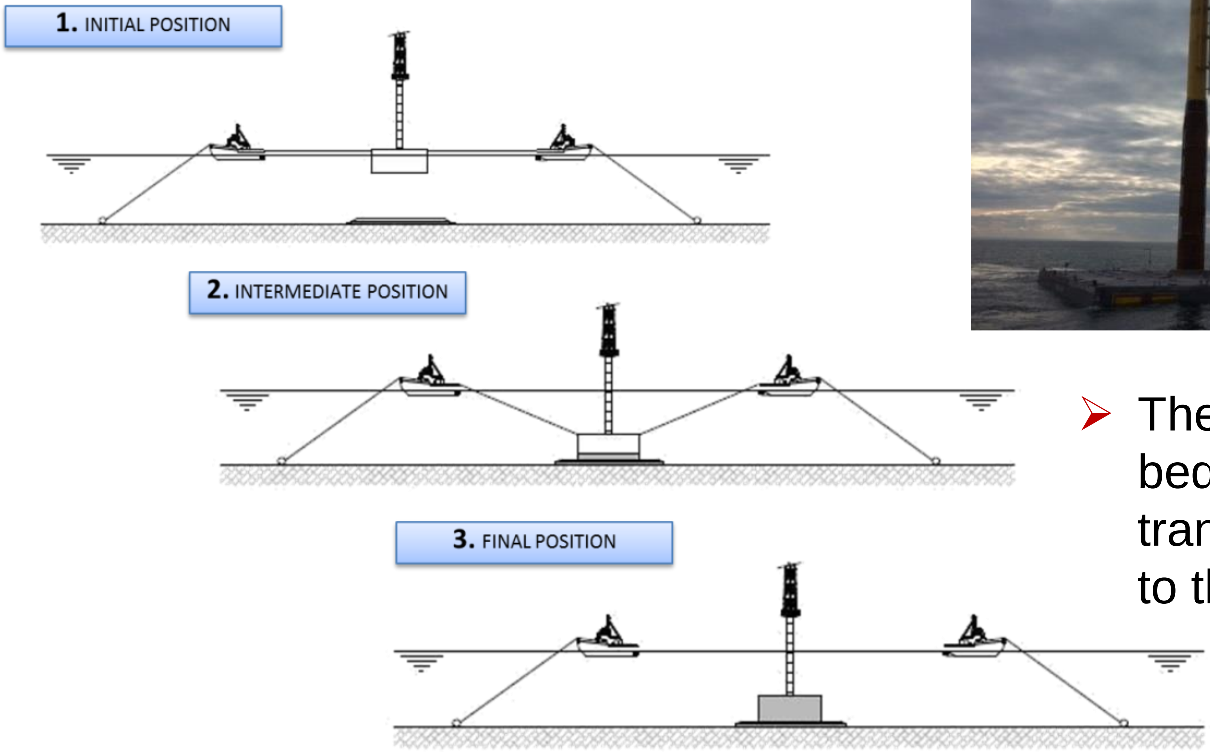


DESIGN CERTIFICATED BY DNV-GL

3. Met mast foundation using a caisson-type solution: Scotland

- Installation was conducted using the same tugs than those used during the towing
- The submersion of the structure was controlled by an autonomous system that pumped sea water into the cells of the caissons

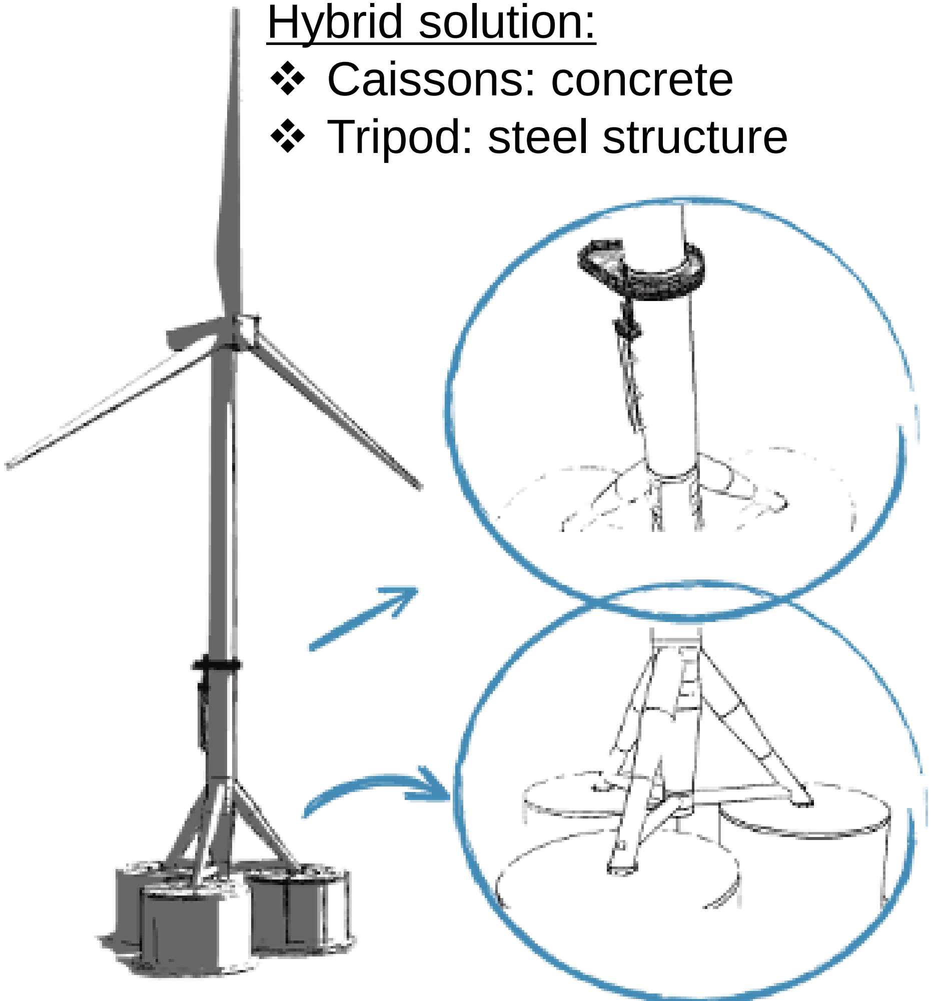




- The foundation is resting on a bedding layer, which contributes to transmit the weight of the structure to the sea bottom.

Gravi3® is the result of the work of TYPSA and HRL-UPM under the umbrella of EDPR with the objective of developing a Gravity Based Solution competitive in intermediate water depths → for this purpose Gravi3® combines advantages of tripod and GB solutions

Hybrid solution:
- ❖ Caissons: concrete
- ❖ Tripod: steel structure



The concept aims at resolving the main questions in the offshore market:

- ✓ Is possible to install competitively GBS at water depths greater than 40 m?
- ✓ Can the employ of Heavy Lift Vessels be reduced in the offshore field?
- ✓ Can a WTG foundation be fully assembled in sheltered conditions?
- ✓ Can a GBS be installed by means of sea water?
- ✓ Can the installation time be optimized?

Interreg Mediterranean MAESTRALE TYPSA

4. WTG Foundation: Gravi3®

- Supply chain optimization
- Employ of floating docks
- Need of simple tugs
- Reduction of service loads
- Good hydrodynamic stability thanks to the 3 caissons
- Reduced Environmental Impact
- Solution valid for several locations
- Wide Range of solutions

The interest of the solution is reflected by the fundings of the EU…

Co-funded by the Horizon 2020 Framework Programme of the European Union Grant No 691717

DEMOGRAVI3

Design of a WTG foundation in the coast of Portugal at a water depth of 45 m

edp renewables, acciona, A.SILVA MATOS, TYPSA, GDG, NEW ENERGY WORLD, Universidad Politécnica de Madrid, Fraunhofer, Global Maritime

As patent owner, TYPSA was responsible of the design of the structure

EXPERIMENTAL MODELLING

- Design of the laboratory tests
- Study of the transport (floating) and service (fixed) phases
- Evaluation of the behavior under different load scenarios
- Analysis and data post-processing

Tool for calibrating the models

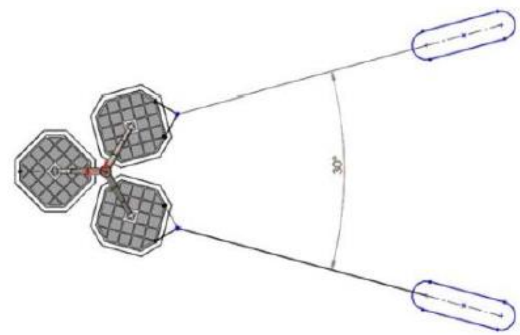
NUMERICAL MODELLING

- Validation of the numerical models
- Establishing of the basis of design
- Study of ULS, FLS and SLS
- Design of the geometry of the foundation
- Optimization of the structure

4. WTG Foundation: Demogravi3 Transport tests

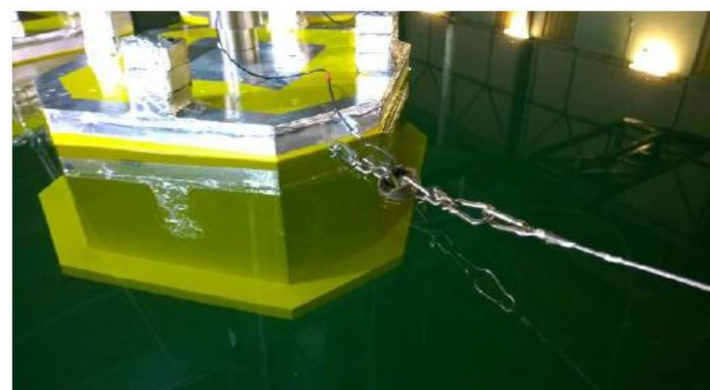
The tests were divided in 4 groups:

- Decay tests
- Calm water tests
- Seakeeping tests
- Transport with waves tests

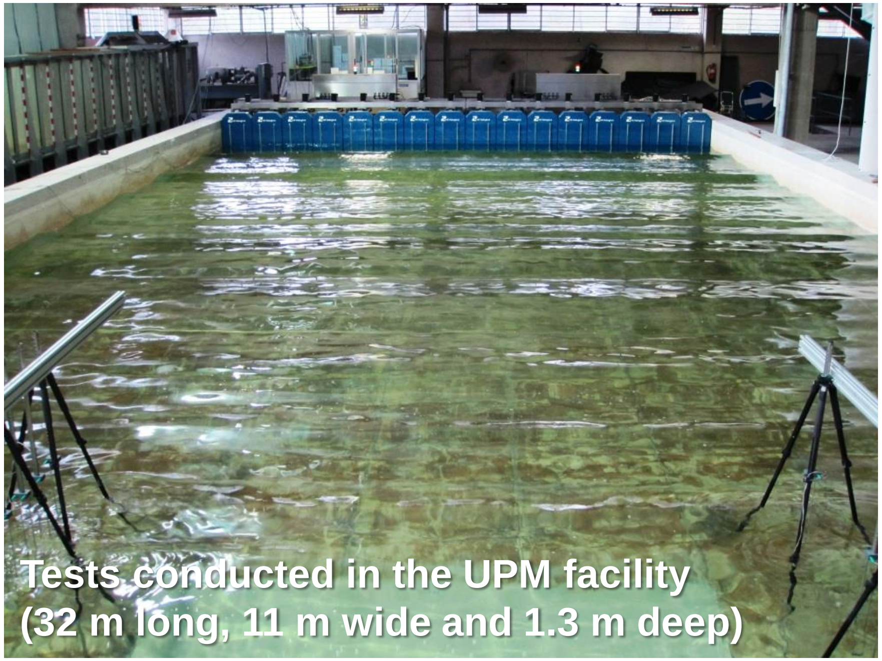


Instrumentation deployed:

- Load cell in the connection of caisson-tripod
- Load cells in the towing lines
- Accelerometer in the nacelle
- Optical track (Motion Capture Cameras)
- Wave height gauges



4. WTG Foundation: Demogravi3 Bottom fixed tests



Tests conducted in the UPM facility
(32 m long, 11 m wide and 1.3 m deep)

The tests were focused on:

- Extreme waves
- Different seed analysis
- Transference functions and resonance
- Service conditions
- Depth influence
- Wave direction effects

Instrumentation deployed:

- Load cells in the connection caissons-tripod
- 6-components dynamometer in the upper part of the auxiliary structure
- Pressure sensors in the caissons
- Wave height gauges
- Vectrino profiler

4. WTG Foundation: Demogravi3 Installation tests

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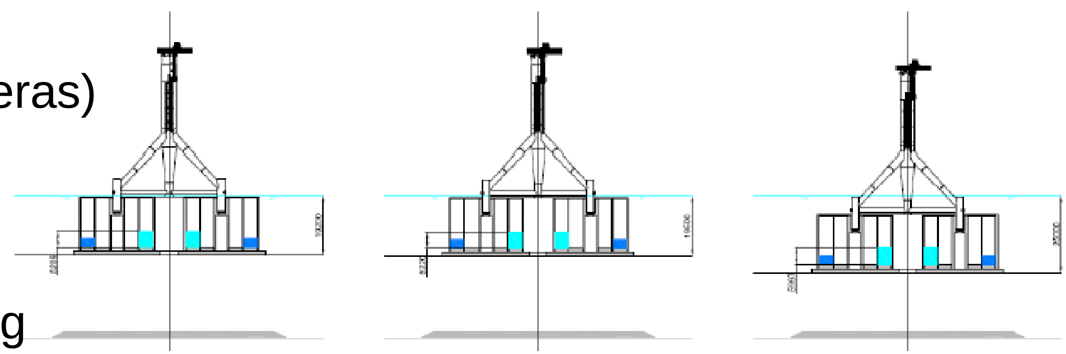
Tests conducted in the UPM facility by HRL

The tests were focused on:

- Different H_s conditions (from 1 to 3 m)
- Different T_p conditions (function of natural frequency of the structure)
- Evaluation of dynamic loading
- Different GM conditions

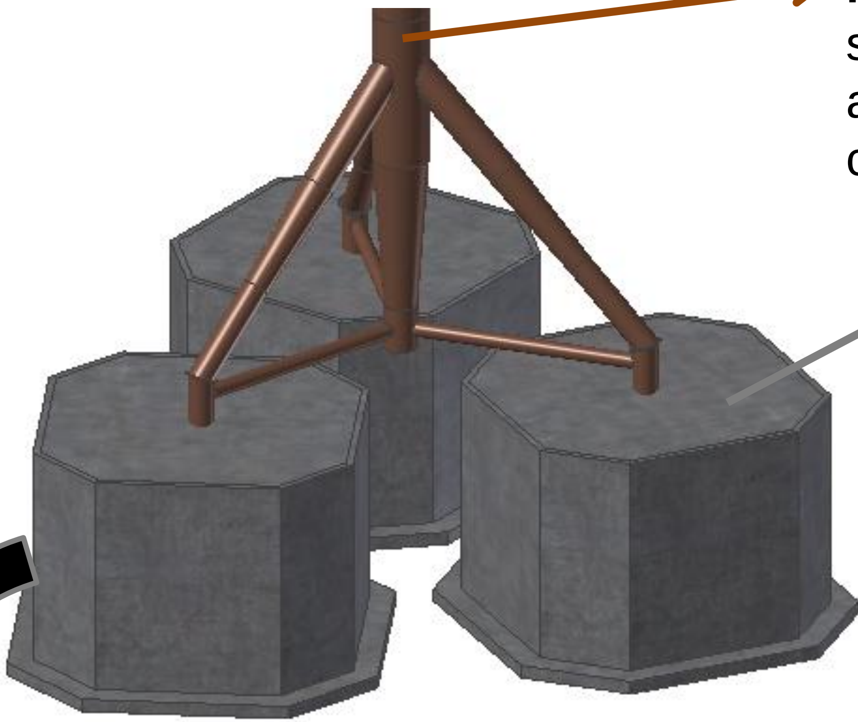
Instrumentation deployed:

- Optical track (Motion Capture Cameras)
- IMU for the tugs and structure
- Wave height gauges
- Pressure sensors
- Load cells in the mooring and towing lines



4. WTG Foundation: Demogravi3 Load Theories

Different load theories:

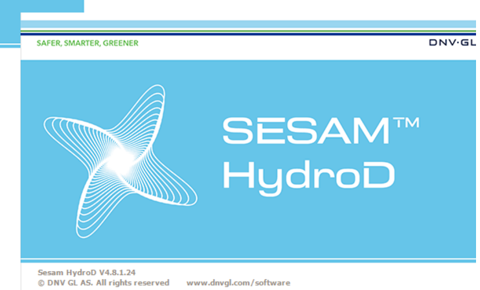


Morison's equation: Wave loading on slender elements associated to the inertial and draft forces (mass and drag coefficients needed)

Diffraction Theory: the structure modifies the wave patterns when waves pass through the structure due to its large dimensions. It is needed to be modelled by means of finite element models.

Modelling using SESAM
Boundary Element Method using potential flow theory

Hydrodynamic model **HydroD**



5. Artificial Islands: Advantages of caisson-type solution

Land reclamation in the history:

- Purpose of gaining space
- Near to the population
- Low water depths
- Mild wave climate
- Hydraulic filling and rubble mound breakwater

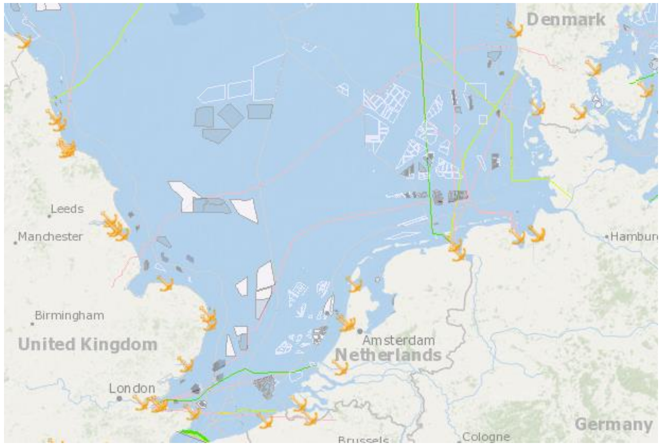
Artificial Islands

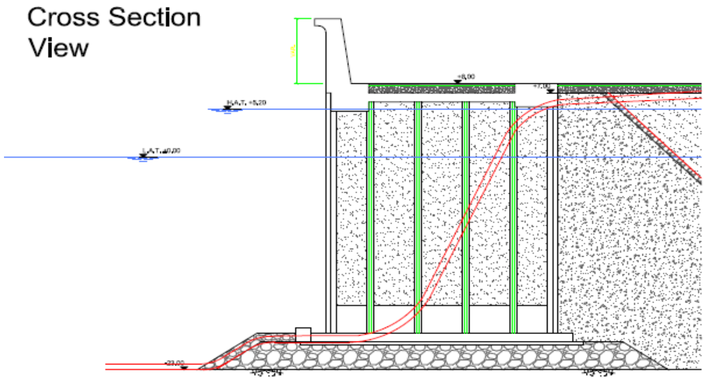
- Improving grid connection: 10/6 GW
- Creating a hub area for logistics
- Far from the population
- Water depths around 30 m
- More severe wave climate
- Need of large volumes of filling

5. Artificial Islands: caisson-type solution advantages

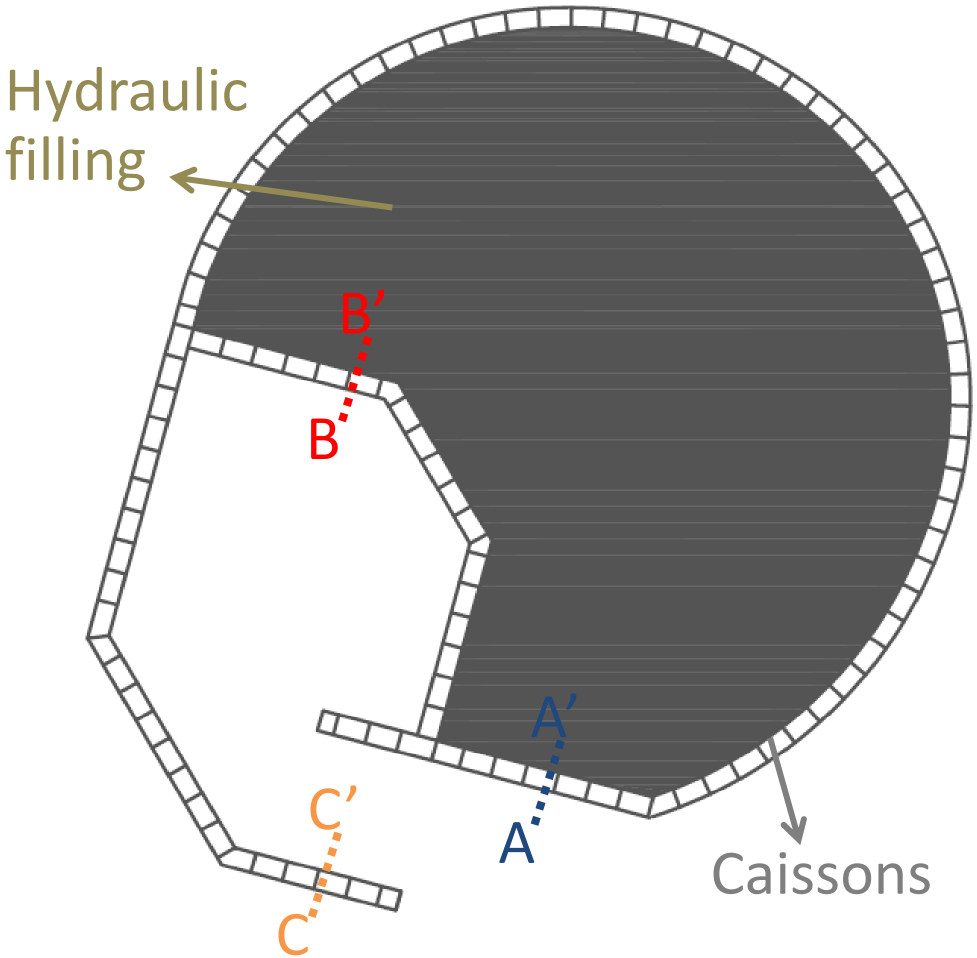
Advantages of caisson type solutions:

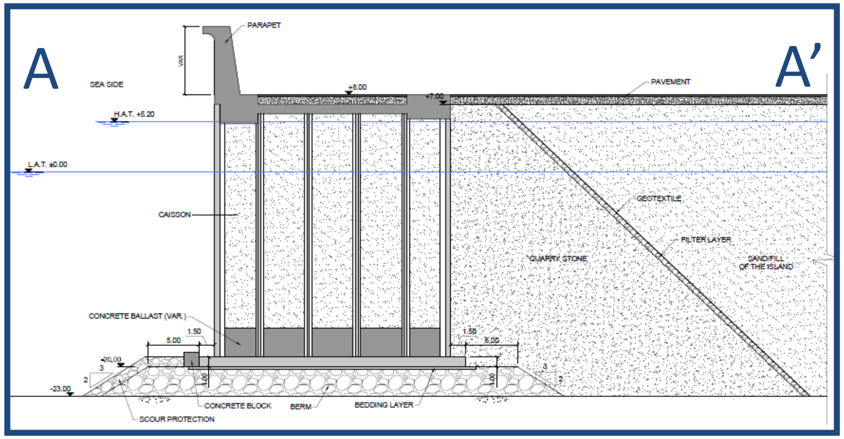
- ✓ More competitive for water depths larger than 20 m
- ✓ Less volume of hydraulic filling needed
- ✓ High density of wind farms in the area of North Sea (not many borrow areas)
- ✓ Reduced environmental impact
- ✓ Speed up construction method
    - ✓ Limit the damage during winter periods → material washed
- ✓ Rubble mound breakwater can induce wave breaking
- ✓ New caisson solutions (anti-reflection) can avoid high reflection coefficients
- ✓ Optimize the port space the employ of caissons
- ✓ Cable landing

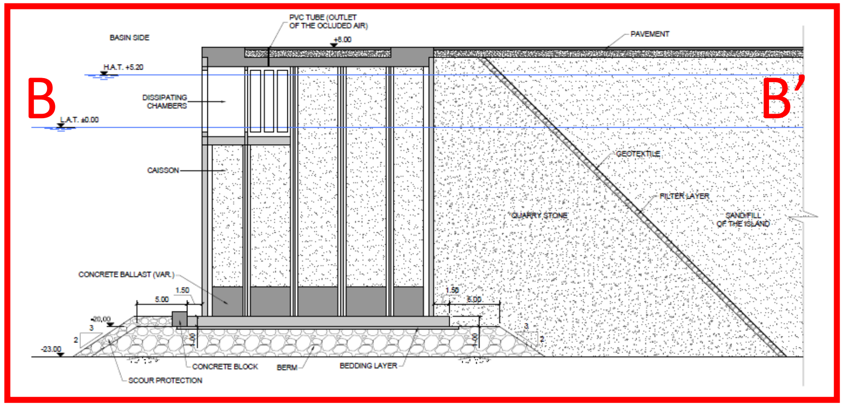


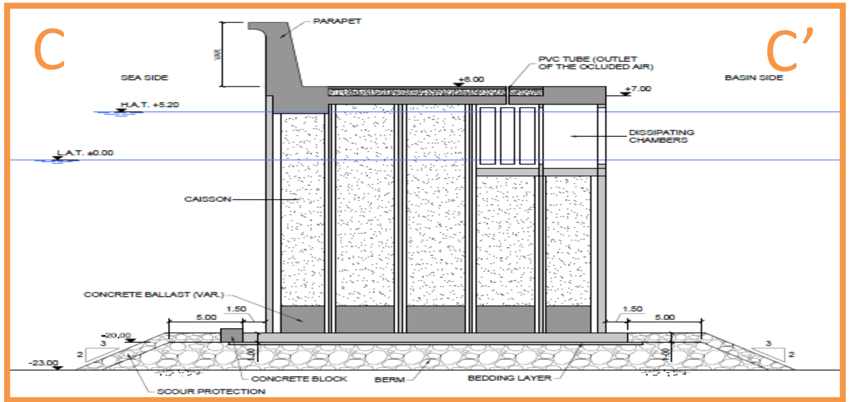


5. Artificial Islands: cross-section

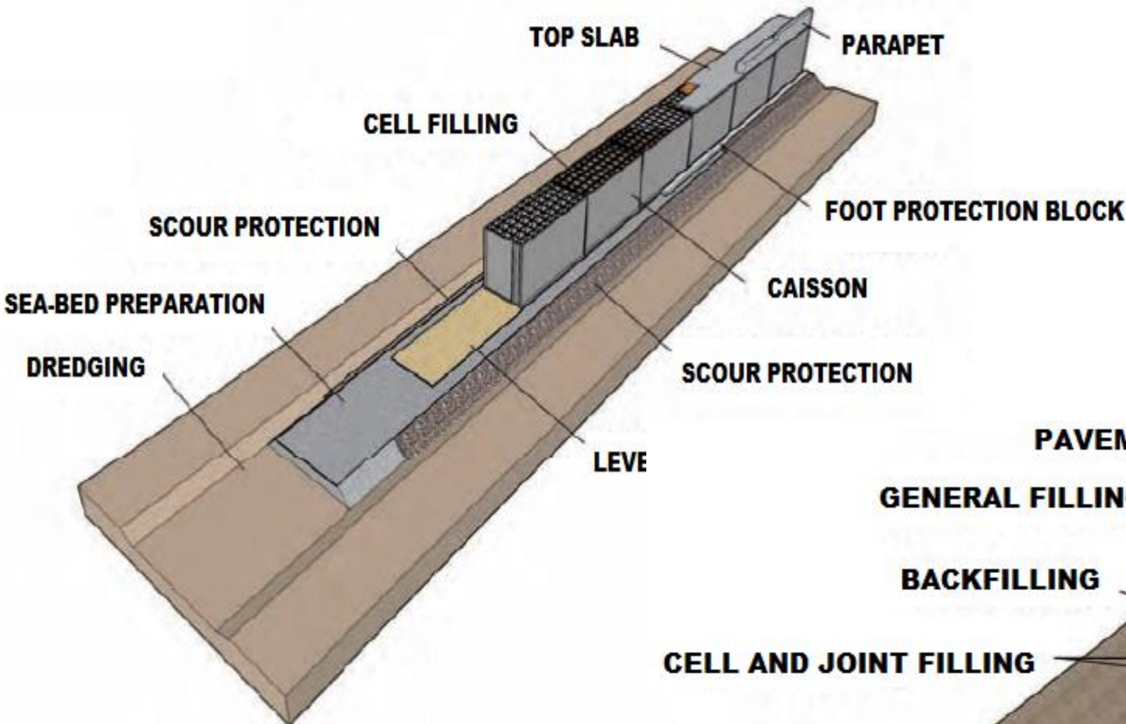




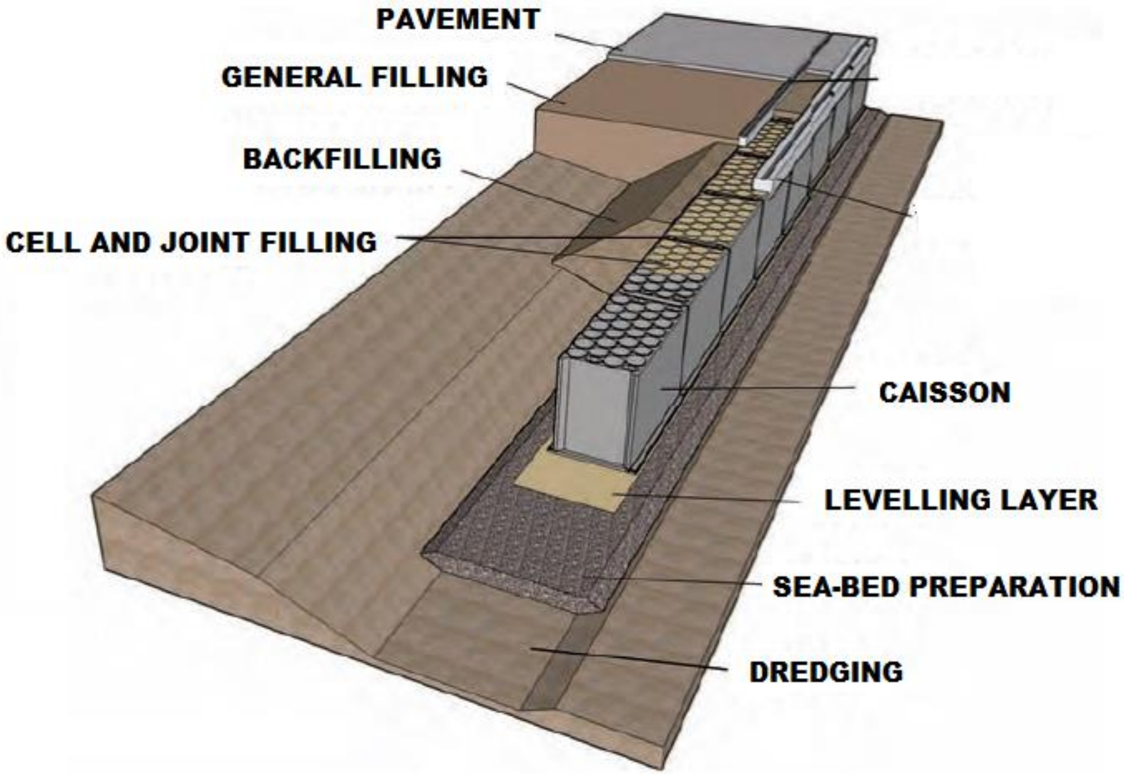




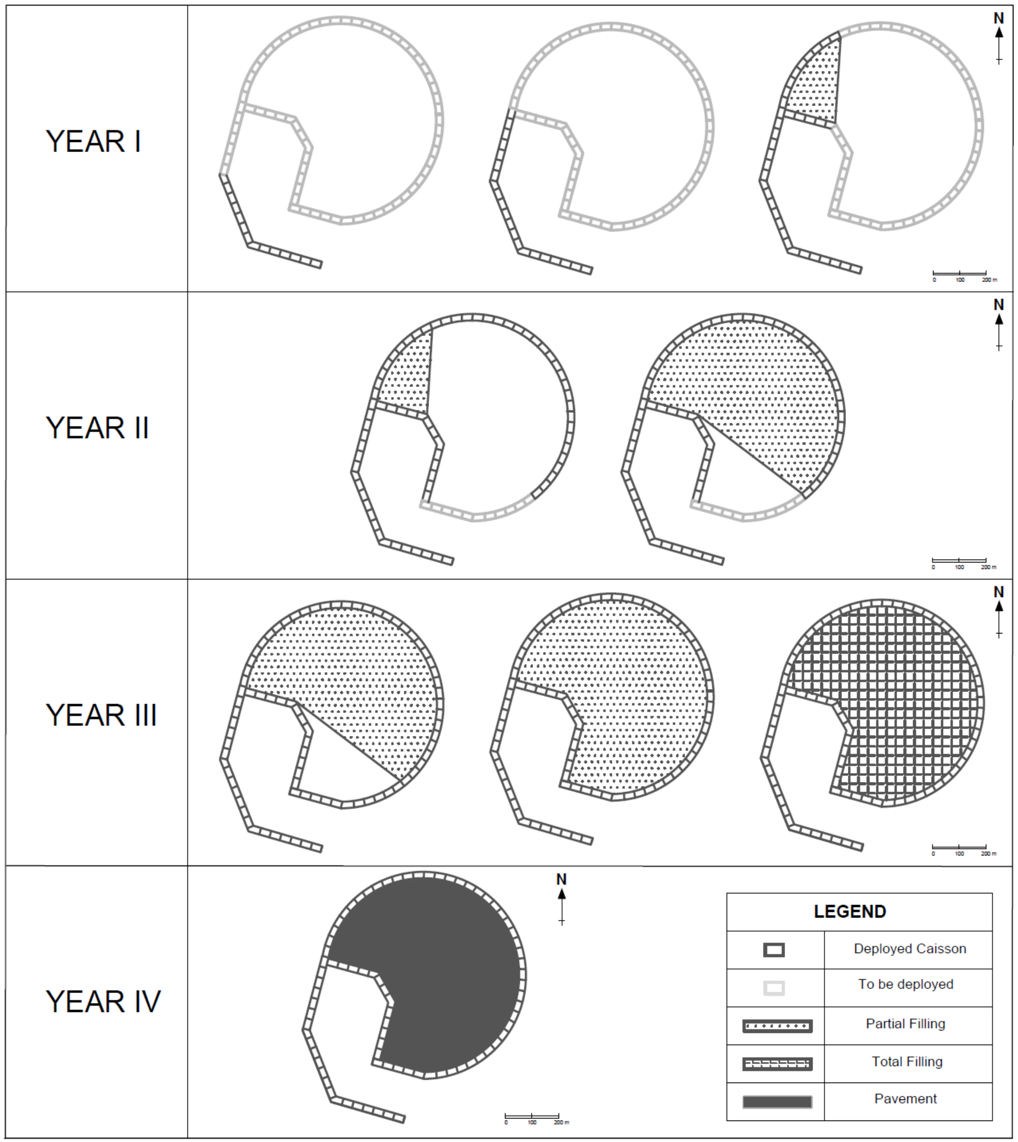
5. Artificial Islands: construction time



Construction approach for docks and breakwaters using caisson-type solutions



5. Artificial Islands: construction time



6. Conclusions

- Need to overcome the arising shortcomings of the market in order to continue with the current growth ratio

- Caisson type solutions can become instrumental
  - Well developed technology
  - Reduction of construction time
  - Absence of heavy lift vessels

- Application to different fields: foundations and artificial islands

- Development of a WTG foundation: Gravi3® that can lead to significant reductions of the CAPEX
  - Full design conducted
  - Main advantage of installation time and resources needed