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CONCRETE BREAKWATER FOR THE GREATER TORTUE AHMEYIM PROJECT FOR BP IN MAURITANIA AND SENEGAL

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ABSTRACT*: In 2017, BP started the tender for the GTA project (LNG export from Senegal and Mauritania). EIFFAGE submitted a proposal with an alternative solution (composite caissons breakwater) and developed a FEED from April to February 2019, in order to optimize the proposed solution, prior to construction.*

Remote location of the project (11km from the coast, and 220km from ports) leads to specific challenges and design adjustments for the concrete caissons. Indeed, in-situ concreting was proscribed and consequently, caisson roof needed to be installed at the prefabrication yard, before filling operation of the caisson.

An innovative 10 lobed concrete caisson was developed to suit with Senegal facilities, weather conditions, construction stages and allowing concrete volume saving.

The permanent presence of the LNG production vessel at the offshore port requires a special consideration for the transmitted waves in case of extreme storms.

An intensive 2D and 3D physical models study, coupled with mooring studies and a slight adjustment of the caisson design allowed confirming proposed design and optimizing the rocks quantities and gradings to be produced in Mauritania.

All those optimizations were approved during the FEED stage of the project and resulted in a significant saving for the project, prior to start the EPC contract early 2019.

KEYWORDS: Caissons, Breakwater, Offshore, Waves transmission

1. INTRODUCTION

The BP Tortue Development comprises a subsea production system at minus 2850m tied back to a pretreatment Floating Production, Storage and Offloading (FPSO) unit, which subsequently transfers gas to a near-shore hub for Liquefied Natural Gas (LNG) production and export.

Phase 1 will provide sales gas production, domestic supply and generate around 2.5 MTPA of LNG to Mauritania and Senegal. The Phase 1 FPSO, which is located in 100-130 m of water, will process inlet gas from the subsea wells located across a number of drill centres by separating condensate from the gas stream and exporting conditioned gas to a hub, where LNG processing and export will occur.

The Hub, which is located in shallow water on the Mauritania and Senegal maritime border, 10 km from shore, comprises a breakwater to protect marine operations, including LNG processing and carrier loading. A single Floating LNG (FLNG) vessel will condition the gas for LNG export.

A figure showing the project overview is provided in the figure below.

Figure 1: GTA project overview

The breakwater design started during the bid stage of the project at the end of 2017, by proposing an alternative design for the breakwater adapted to the project specific conditions and the regional facilities. The design has been continuously improved and optimized during the FEED stage from April 2018 to February 2019, based on a collaborative approach between the Client and the Contractor. This partnership allowed for significant savings in concrete, rocks and dredging quantities.

This paper deals with the offshore breakwater optimizations during tender and FEED stages of the LNG hub terminal project.

Figure 2: LNG hub terminal overview at end of FEED

2. BREAKWATER TYPE

Initial hub location was looked for water depth of 18m and 23m and as such, initial breakwater type was a rubble-mound structure. However, the relocation leaded to review the type of design as on 33m isobaths, a wide footprint was required, whereas a composite breakwater (caisson on berm foundation) allows for a significant optimization of dredging and rocks quantities, and consequently, on rocks mining, rocks transportation and rocks installation activities.

Dredging is required to remove a soft clay layer on top of the natural ground, over a few meters, at both extremities of the breakwater (in dark blue areas mainly). The light blue area represents an outcrop, where the dense sand sublayer raises and corresponds to the natural seabed.

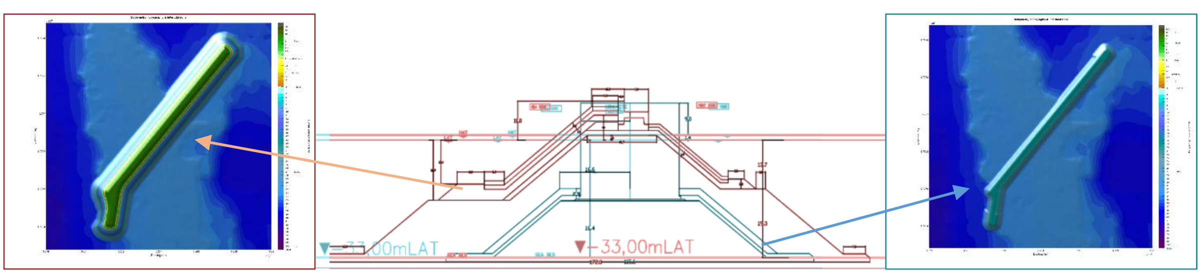

Figure 3: Rubble-mound vs composite breakwater footprints

Change on breakwater type allowed a rock quantities drop from 5.8 to 1.1 million cum.

3. CONCRETE CAISSON OPTIMIZATION

A lobed caisson allowed for a significant reduction of the concrete volume compared to a rectangular caisson. However, with 4-lobes caissons of 28m long, installation weather windows number would have been insufficient to install 42 quatrefoils caissons.

A rectangular caisson would allow fulfilling the length required by installation weather windows; however, it was considered uneconomical because of the concrete quantities.

Due to limited space at the yard, required equipment and water depth for caisson offloading, it was also required to limit the dimensions of the caisson.

Hence, it was decided to increase the length of a lobed caisson as much as practicable, without increasing its width and with a limit in height equivalent to the width. The 10-lobes caisson based on a 28m width is twice longer than the 4-lobes one and matched with the minimum length requirement to limit number of caissons installations. It allowed for a significant concrete saving compared to the rectangular caisson, and also for an easier solid ballast filling sequence since cells number is much less.

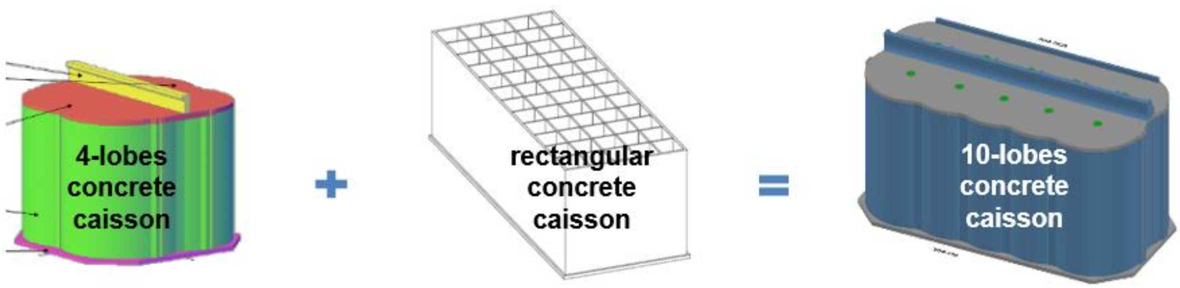

Figure 4: 10-lobes caisson genesis

Final concrete caisson design concurred with dimensions of 31.5m height (including a 4m crown wall), 28m wide and 54.5m long. Each unit weights about 16 000 tons.

Due to project remote location (220 km far from facilities), works at the port location had to be minimized, leading to different impact on caisson design compared to a near-shore breakwater. As such, caissons needed to be fully achieved before offloading and transport to port location.

That means that caisson would have to be ballasted after their achievement. Consequently, top slab has been casted as a roof, without being supported by the solid ballast as it can occur when top slab is achieved in-situ.

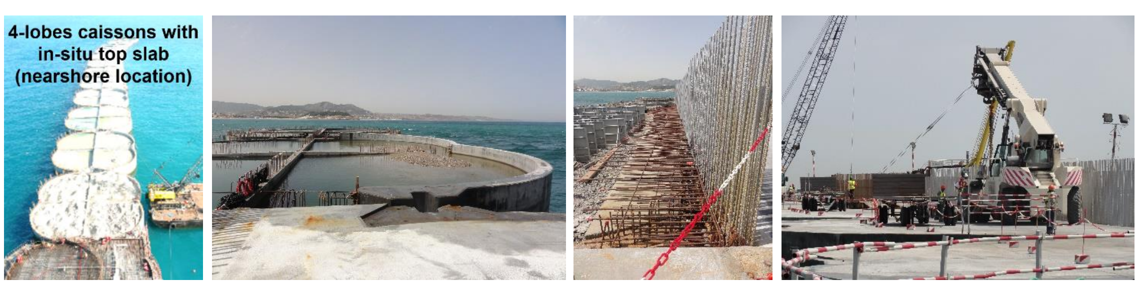

Figure 5: In-situ top slab and crest wall achievement, proscribed due to remote location

Furthermore, development of the breakwater design aimed to validate overtopping and transmission criteria of the juxtaposed caissons without a continuous crest wall and top slab between the caissons, which avoid concreting in-situ. Philosophy was fully validated with 2D and 3D physical model tests.

4. ROCK BERM FOUNDATION OPTIMIZATION

Different aspects of the breakwater design could impact the rock quantities to be produced, transported and installed for the foundation.

Greater Tortue Ahmeyim breakwater geotechnical stability is driven by the bearing capacity of the foundation, which has been studied with dedicated numerical models and supported by mechanical tests for the definition of a friction angle and a compressibility parameter. Results of the numerical models allowed:

- Verifying that the preliminary approach, based on PIANC recommendations was suitable,
- Studying the different loads cases and approving the foreseen slopes sea and port sides.
- Defining an adequate estimate of the expected settlement of the foundation, after caisson installation and solid ballast filling, to avoid material overconsuming.

Top elevation of the foundation before caissons installation and slopes of the foundation have been defined accordingly. In addition, by steepening as much as possible the slopes, it allowed reducing the breakwater footprint, and then optimizing again the dredging.

Transmission and overtopping criteria drove the final top elevation. Those criteria ensure that permanent vessel is safely moored behind the breakwater even for extreme events.

Breakwater foundation is made of :

- a core to fill the volume between caisson bottom slab and the natural ground. Core material permeability impacts the transmission through the foundation.
- a bedding layer required for caisson laying, which is a specific material that ensures smooth distribution of loads and ensures friction with the caisson, to avoid sliding.
- an armour to protect the core and the bedding layer. Armour shall withstand extreme event waves conditions (up to 10 000 years return period) and ensure hydraulics stability of the breakwater foundation. The armour optimization was important to limit the number of gradings to be produced and to reduce its exposure to waves.

From the quarry production point of view, it was important to ensure continuity between rocks grading categories, which limits losses during production.

All those optimizations allowed for mitigation of the environmental impacts, which are linked to breakwater construction.

4.1 Design parameters evolution

Crest elevation definition was driven by the overtopping discharges and transmitted waves height behind the breakwater. The optimization of the crest was of upmost importance to save an important amount of rocks.

During the FEED, a continuous development influenced the design waves to be accounted for, as well as the design criteria to be considered for the transmitted waves towards the FLNG vessel. EIFFAGE worked in a collaborative approach to incorporate the changes into the breakwater design and physical model tests campaign.

The following figure presents the evolution of the design criteria for transmitted waves behind the breakwater, whereas the next one, presents the evolution of the design waves conditions and return periods to be considered, with regard to transmission criteria.

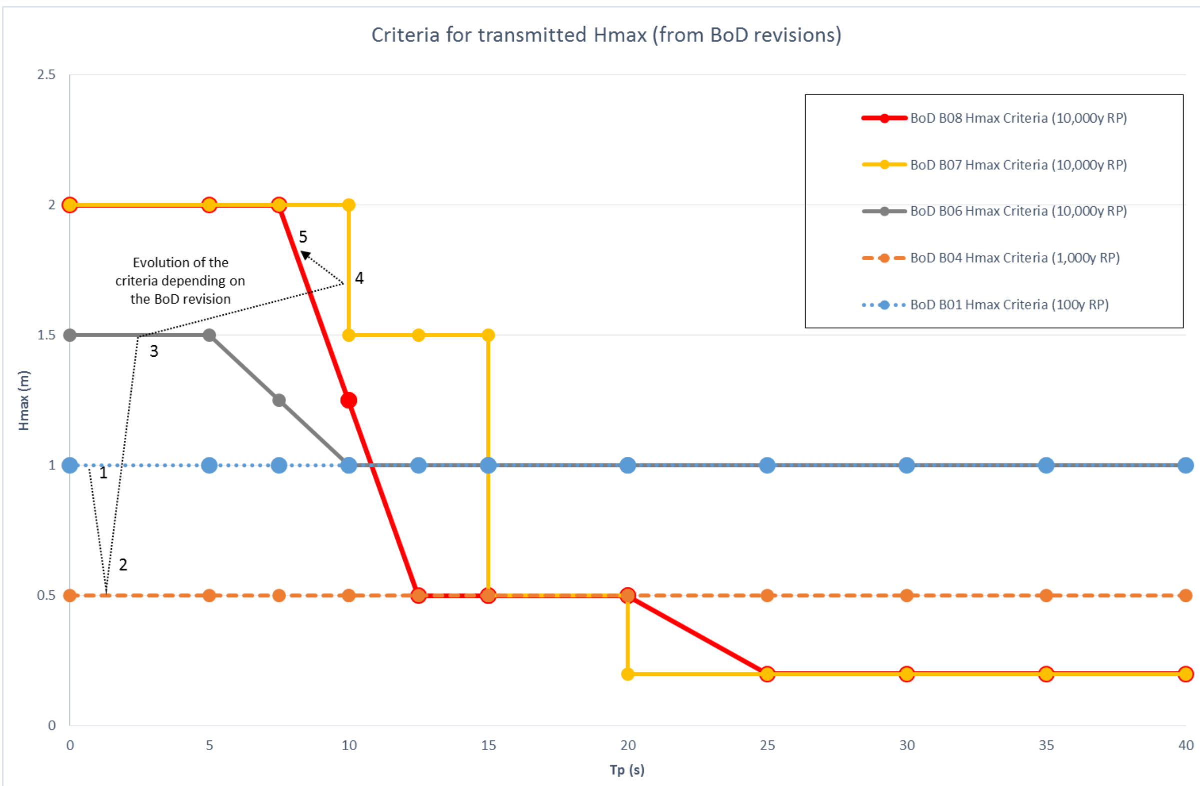

Figure 6: Evolution of the transmission criteria at FLNG location

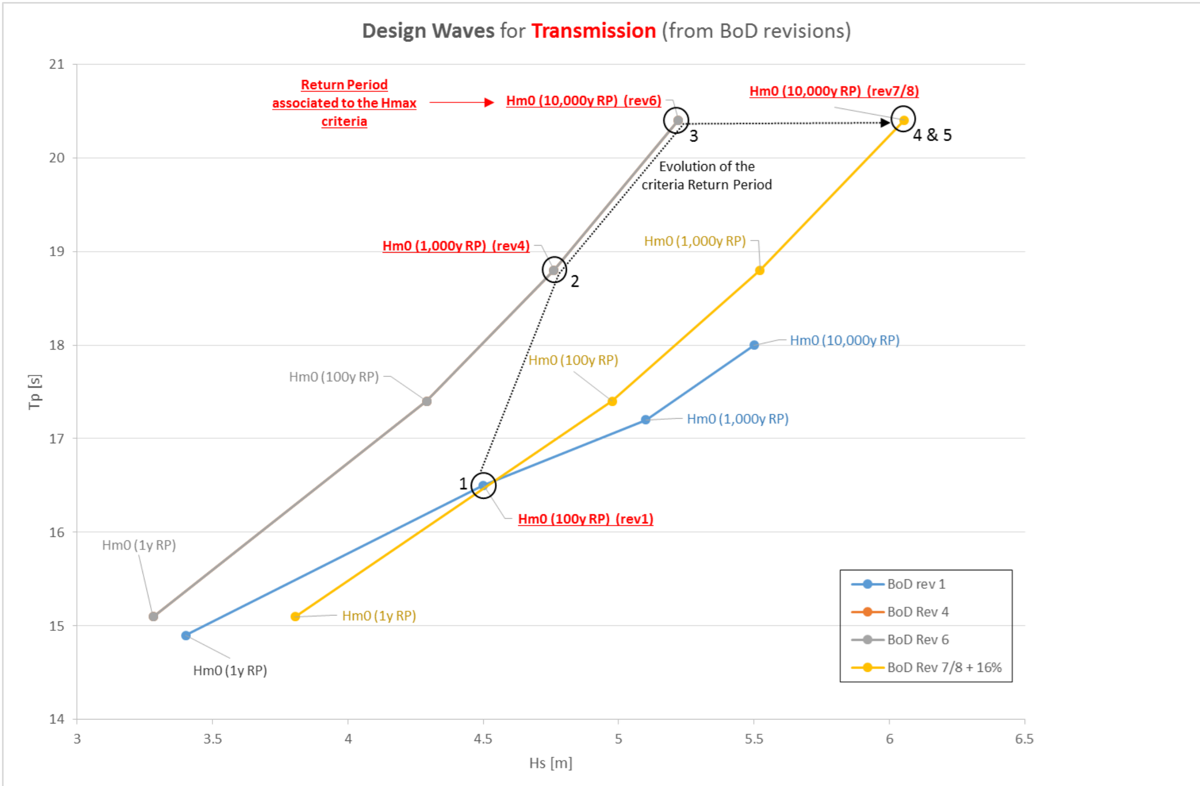

Figure 7: Evolution of the design waves characteristics to verify the transmission criteria at FLNG location

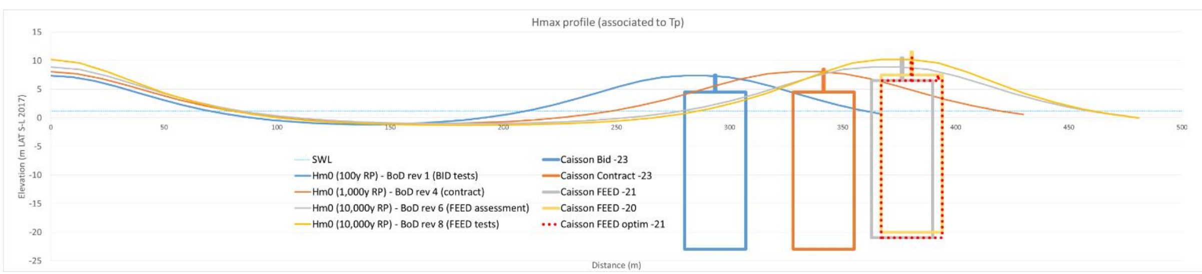

Figure 8: Caisson elevations evolution depending on design waves and transmission criteria

4.2 Physical model tests results - Crest elevation

To optimize as much as possible the foundation quantities, a strong collaboration between 3 parties (Client, Engineer & Contractor) allowed specifying and running a full intensive physical model tests campaign (with 2D & 3D models) during the FEED stage.

Results have been jointly analyzed to account for the breakwater performance and the behaviour of the FLNG mooring system, to check that motions and loads were acceptable.

Figure 9: Pictures from the flume and basins tests campaign

The flume tests allowed for the validation of steeper slopes on trunk part for sea and port sides of the foundation. Proposed armour rocks were proven stable under extreme waves conditions for the trunk section. Deep analysis of waves overtopping permitted to find a way to reduce the transmitted waves on the lee side. Indeed, the addition of a 1m high crest wall on the rear part of the caisson top slab showed equivalent performance with a foundation elevation 1m higher.

Conclusions on 2D tests are:

- Foundation elevation can be set at -20m with a rear wall of 1m on the caisson (instead of -19m with the caisson initial design)
- Rocks slopes can be steepen on the trunk part without affecting the foundation hydraulic stability
- Overtopping volume measured are acceptable for a safe navigation behind the breakwater under a 10y return period extreme waves conditions

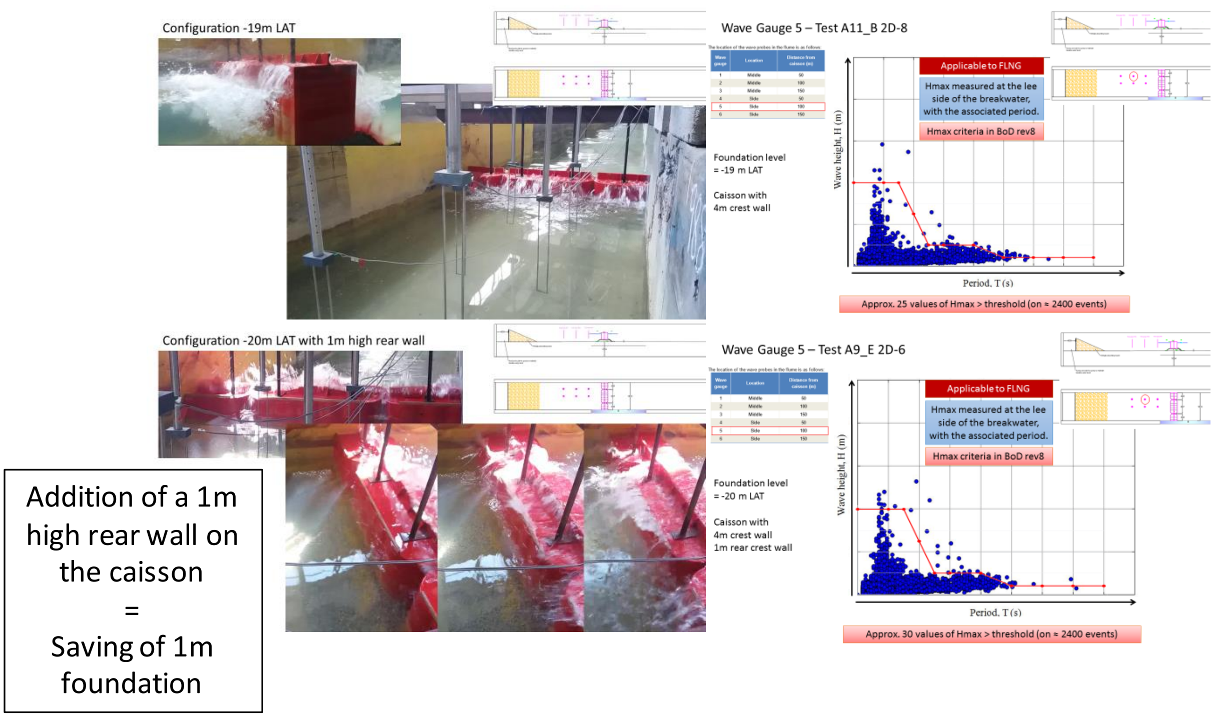

Figure 10: Transmission results for top of foundation at -19m without rear all on caisson (top) & -20m with 1m rear all on caisson (bottom)

The basin tests allowed for the validation of the steeper slopes at roundheads and elbow for sea and port sides. The 3D basin configuration has been set to model the bathymetry and the crossed sea states that occur at the project area. Thus, waves direction were accounted for in the model and the crest elevation have still been optimized by 1m (i.e. finally with a top of foundation at -21m)

Conclusions on 3D tests are:

- foundation elevation can be set at -21m with a rear wall of 1m on the caisson
- rocks slopes can be steepen at roundheads and elbow without degrading the foundation hydraulic stability
- rock armour can be removed on the port side
- same rock armour grading can be used at trunk, elbow and roundheads

Conclusion from physical model test campaign, have been integrated to design and bill of quantities.

4.3 Physical model tests results - armour & slopes

Elevation varied along the FEED development, impacting the footprint of the breakwater. Increase of elevation due to design criteria and design waves evolution has been mitigated by integration of steeper slopes, removal of the armour on the hub side and optimizations based on physical model tests.

The figure below presents the evolution of the typical section during the FEED.

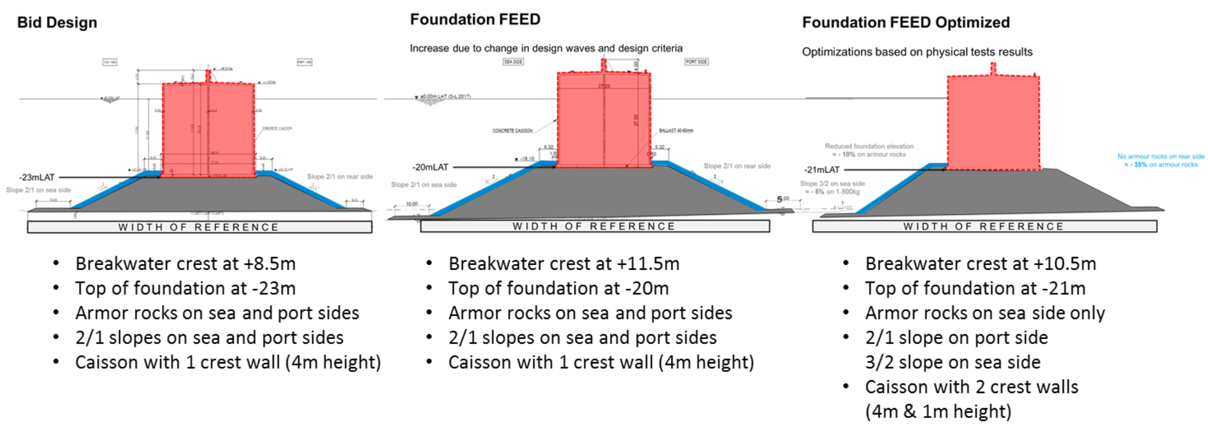

Figure 11: Breakwater typical section evolution

4.4 Evolution of Quantities for the foundation

The variation of quantities due to increase of design waves has been almost completely mitigated by FEED optimizations. Finally, performance of the breakwater have been significantly improved at a limited cost.

The figure below presents the evolution of the breakwater bill of quantities during the FEED.

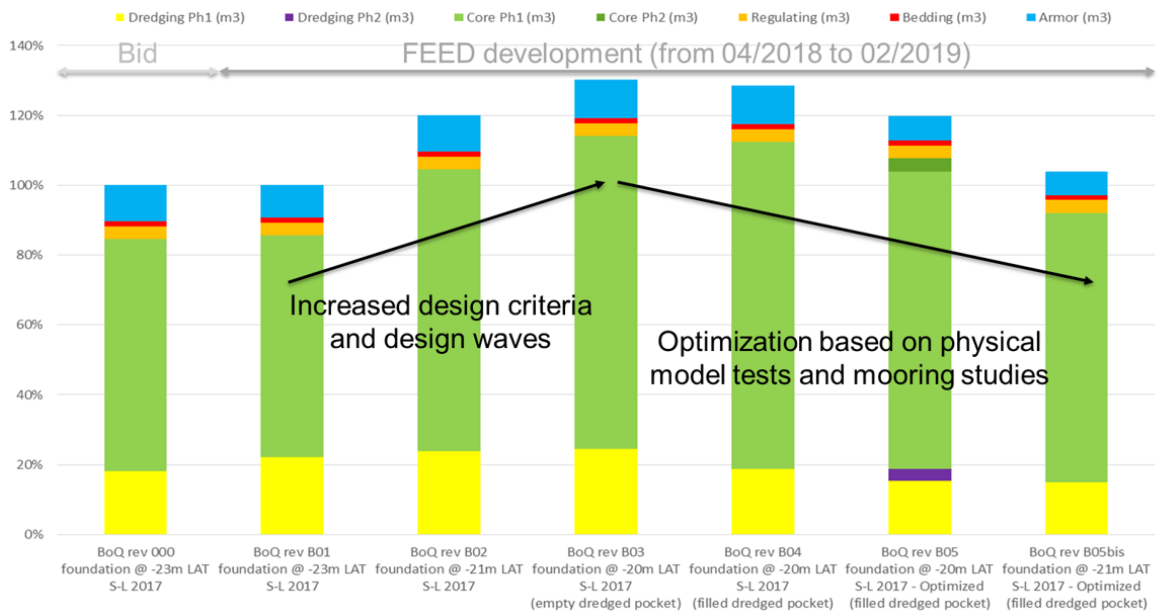

Figure 12: Bill of quantities evolution

4.5 Junctions between caissons

Due to permanent waves conditions that occurs in the North Atlantic Ocean, caissons installation is not an easy operation and a specific tolerance for installation was required to cope with this environmental constraint. The consequences on the design were:

- The use of installation aid fenders to avoid any damage of the concrete caissons
- An unusual nominal distance between caissons of a half meter,
- The definition of an innovative solution:
    - rigid enough to limit wave transmission trough the junctions,
    - flexible enough to adapt to the final shape of the junctions whatever the final caissons positions are and whatever the settlements are,

A "fit for purpose" solution was developed to match with those specific requirements. However, the tested configuration for the physical model tests presented two impermeable keys at the junctions. This configuration was leading to scouring issues due to high velocities of fluid passing below the impermeable key, between the caissons bottom slabs.

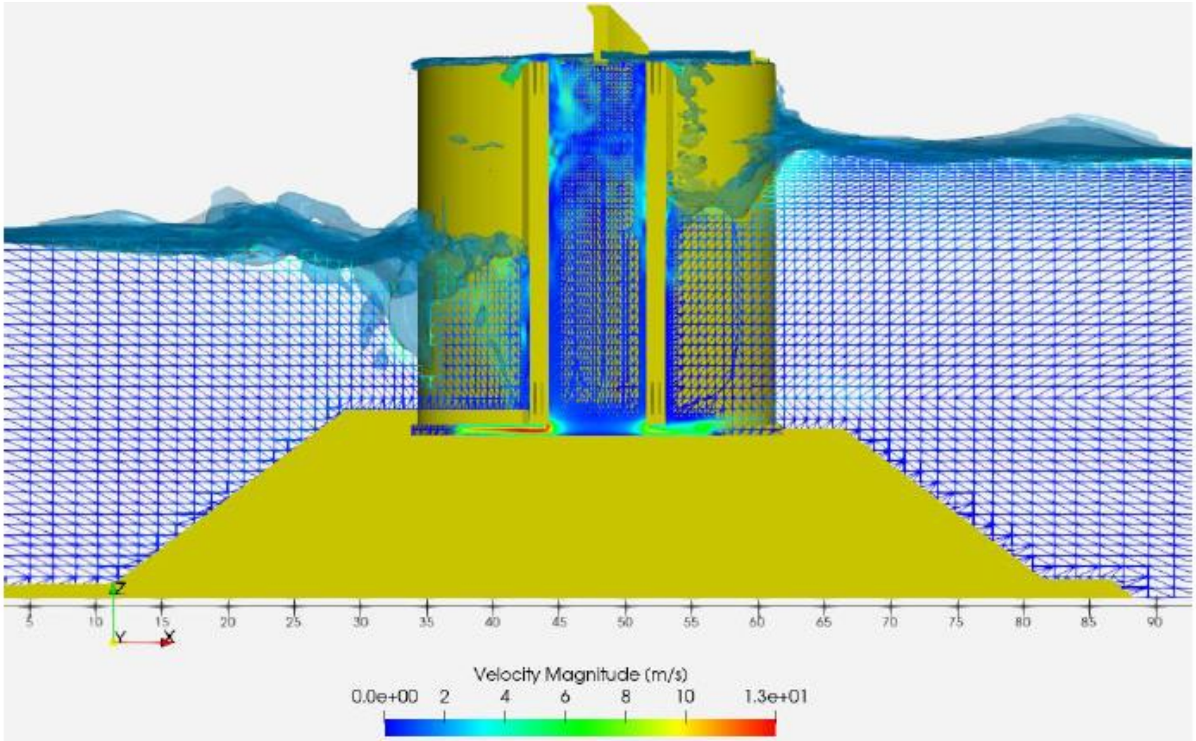

Figure 13: Velocity magnitude in the liquid area

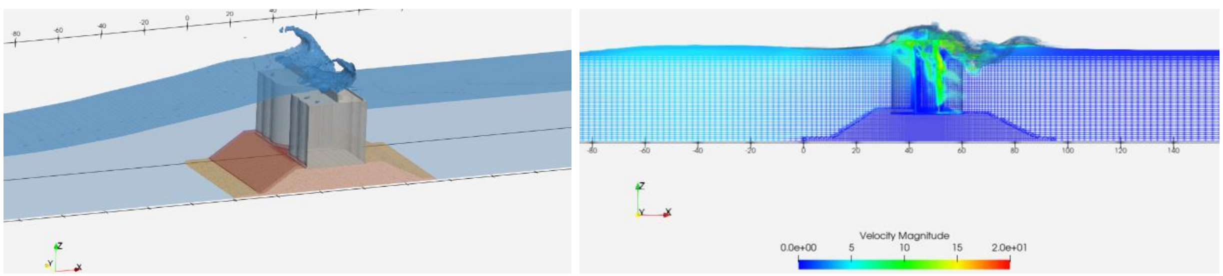

Figure 14: Example of the overtopping run, for the single impermeable key (sea side)

In order to improve the solution, an optimized configuration with only one impermeable key on the sea side has been tested. Since scouring physical tests were not focussing on transmission, a CFD numerical model has been prepared and run in-house to support the analysis and prove the suitability with regard to the transmission criteria.

To check that transmission is in the same order of magnitude for the configurations, it was required to run:

- One simulation with the maximum wave height, which leads to a significant overtopping and some short waves created behind the breakwater, due to the discharge volume of water passing over the caissons. (named “overtopping on the figure below”)
- One simulation with a non-overtopping wave, which leads to a transmission through the foundation and the junction, with a long wave observed on the lee side of the breakwater (named “non-overtopping” on the figure below).

Results of the simulations have been captured on the breakwater lee side, at the same distance than FLNG vessel is, compared to the caissons. They are presented on the figure below, with H (m), the amplitude of each transmitted waves extracted from the simulations and T (s), the period of each corresponding wave.

Transmission through the foundation is very low in amplitude, however, it maintains an equivalent period compared to the incident wave, while overtopping waves creates short waves, with a higher amplitude, behind the breakwater.

Since the results of the two simulated configurations were in the same order of magnitude, it was approved to continue with a single impermeable key, which was also bringing more satisfaction with regard to scouring issue.

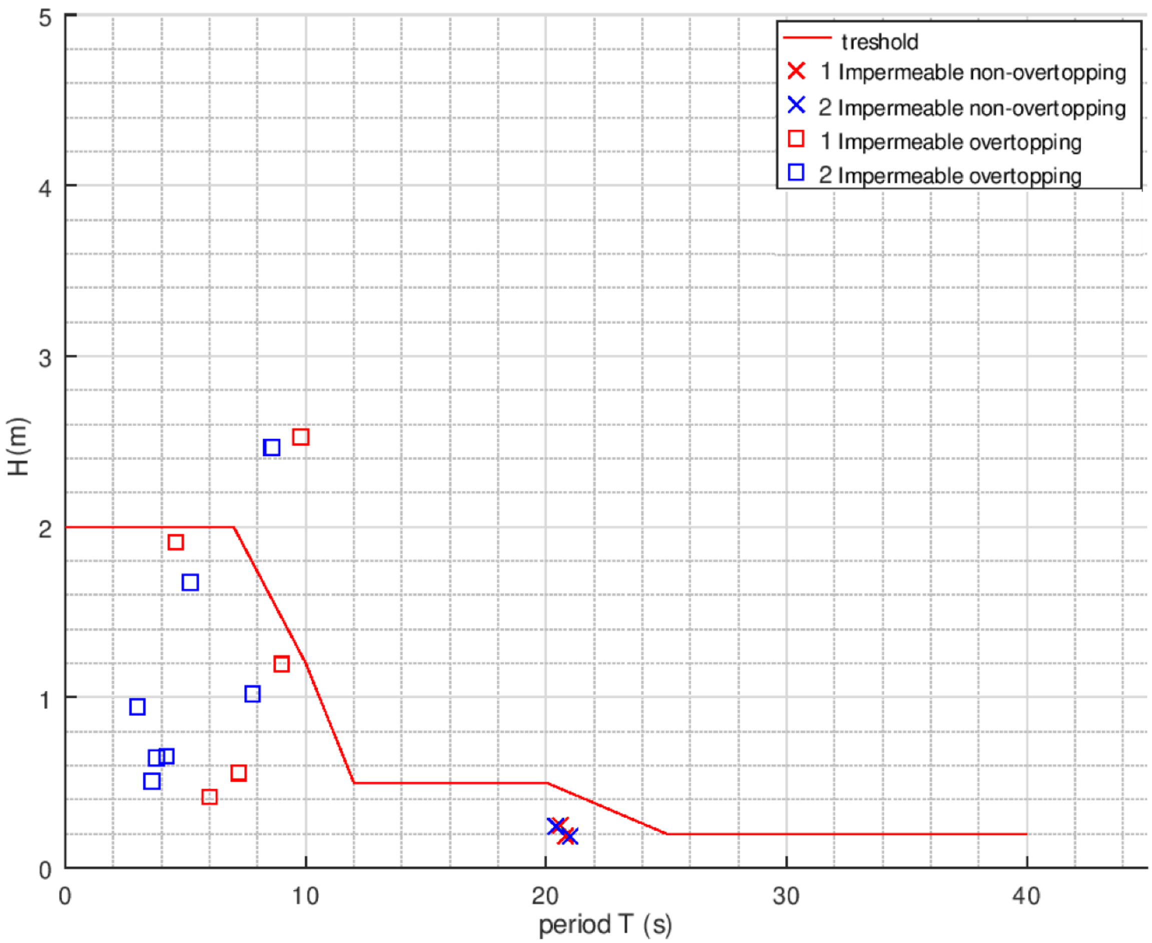

Figure 15: Resulting (H, T) couples of parameters of the transmitted waves, in each scenario

5. REFERENCES

MARCOM report of Working Group 28, 2003. *Breakwaters with vertical and inclined concrete walls*. PIANC.