STABILITY ASSESMENT OF ROCK BAGS AND ROCK ARMOUR AS PROTECTION OF SUBSEA CABLES LANDFALL AT AN OFFSHORE ENERGY ISLAND

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INTRODUCTION

The world's first energy island, the Princess Elisabeth Island (PEI) located about 40km offshore of the Belgian coastal zone, will house the transmission infrastructure to connect up to 3.5GW of offshore wind and to provide a connection point for interconnectors with neighboring countries. The island is foreseen to receive up to 95 individual subsea power cables, consisting of HVAC inter-array cables, export cables and HVDC cable interconnector bundles.

As the cables will be installed years after completion of the island, cables will be installed on top of the scour protection and toe, and installation of individual cables could be years apart. Compared to conventional cable landings at platforms, the cable entry in the caisson will be at relatively shallow water depths and at a vertical wall instead of a monopile or jacket structure. To minimize the risk of damaging cables due to displacements and related fatigue loads, it is the primary intent to stabilize the cables.

Although the design studies for cable stabilization is to be performed by the contractor(s) for cable installation, there was an opportunity for the Employer, Elia, to perform physical model tests on potential cable stabilization solutions during the verification physical model testing of the island's design. This would provide valuable insights in the behavior and functionality of conceptual design solutions, and could serve as a basis for subsequent design by the cable contractor(s).

BOUNDARY CONDITIONS

The indicative design of the island's perimeter protection including the installed cable, but without the cable stabilization, is shown in Figure 1.

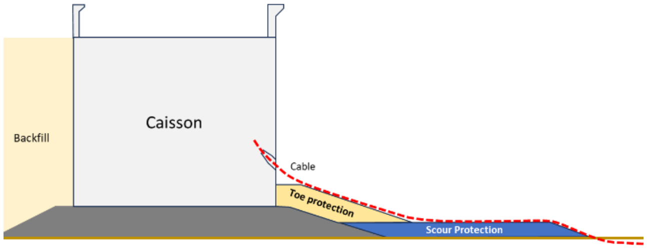

Figure 1: Schematized design of the PEI perimeter protection

The island has a rectangular shape of 520m by 230m and is oriented in the main direction of the tidal currents, going from SSW to NNE. Cables will land at the northern, western and southern side of the island. The depth averaged yearly velocity of the tidal current is about 1.5m/s, which is locally influenced by the presence of the island causing increased velocity near the corners, including vortices, and a deflected flow pattern going around the island. Although the morphological influence of the island on the seabed is minimized in design, scour holes will develop at the corners and siltation is most likely to occur at the island sides, which is expected to stabilize over time.

The dominant wind and wave directions are North and WSW, with 100yr RP design waves (H_s) up to 7.5m from Northern direction. This means that the dominant waves, and the governing design conditions arrive at the northern, western and southern sides of the island under a relatively large angle (>30°). In combination with the vertical island walls this results in a spatially varying, complex reflective wave pattern around the island which will be difficult to accurately assess using numerical tools.
As the eastern side of the island is most sheltered, a quay wall and small harbour for CTV vessels is located here. This is the main reason that no cable landings are present at the eastern side of the island.

STUDY METHODOLOGY

The feasibility design assessment for stabilization of the cables consists of a theoretical assessment as well as 2D and 3D model testing; often being combined with the design of the energy island. Based on progressive insights the studies have been adapted and extended over time. Final 3D physical model testing has been performed in December 2023.

During the feasibility design stage of the island the stability of additional layer(s) of both rock armour and rock bags on top of the toe protection has been assessed in 2D flume tests. The main focus of these tests was to investigate the impact of potential cable stabilization on the island's caisson design (i.e. wave forcing); nevertheless, the movement of rocks or rock bags could be observed from the images. These tests showed that rock bags were a promising solution, and that rock armour would not remain statically stable, but would form into a dynamically stable protection with limited movement. These tests were however for perpendicular waves only, where in reality the dominant and governing design waves arrive under an angle.

A subsequent theoretical assessment focused on deriving reliable hydraulic conditions around the island and assessing loads and rock stability based on the theory by Van Rijn (2019) for the combined effect of waves and currents. State-of-the-art numerical models were applied to predict the spatially varying (tidal) current velocities (TUDflow3d (de Wit, 2015)) as well as the wave orbital velocities (SWASH wave model (Zijlema et al., 2011)). Results of this assessment are presented in the (*yet to be published*) paper by De Wit et al. (2024).

The stability of potential cable stabilization design solutions was theoretically assessed using formulae from design standards and guidelines provided by suppliers. The theoretical rock stability assessment was considered representative for the Scour Protection area only, due to the applied methodology by Van Rijn (2019). Limited formulae are available for the toe stability in front of the caisson, where the standing wave pattern and wave obliquity is expected to have a significant impact. As this is a critical area for cable landing and stabilization, it was decided to investigate the stability of potential cable protection design solutions using 3D physical model testing during the feasibility design stage already. This also reduces the overall project risks and provides valuable input for future design engineering studies.
Therefore, it is recommended to investigate the stability of the cable stabilization design solutions for the toe area using 3D physical model testing.

As rock bags were found to be a promising solution, but also with largest uncertainty due to limited availability of stability formulae, initial 3D physical model testing on the stability of rock bags as cable stabilization was performed first during a 1-day time slot; see Figure 2. These tests focused on cable stabilization by rock bags on top of the scour protection and toe protection slope.

Figure 2: Rock bags installed over a scaled cable for 3D physical model testing at DHI

Subsequent physical model testing of various design solutions using both rock armour, rock bags, or a combination thereof, was performed in December 2023; after completion of the verification testing of the island design.

PRELIMINARY RESULTS

The theoretical assessment showed that the same rock grading as applied in the scour protection can be used for cable stabilization on top of the scour protection as well; having only limited rock displacement during extreme wave conditions. 8t rock bags were found to be theoretically stable on top of the scour protection. Toe stability was not assessed theoretically, as the Van Rijn (2019) theory is not applicable for rock stability here and the currently available theories on toe stability in front of a vertical structure have too varying results. The same is true for rock bags: no similar tests have been performed so far and therefore the theoretical stability of rock bags cannot be reliably assessed.

During the physical model testing of the PEI it was found that the toe rock structure was subject to high forcing, as the originally designed 3-6t toe did not remain sufficiently stable under storm conditions. This was mostly caused by wave breaking alongside the structure (i.e. parallel to the caisson), which was due to the obliquity of the waves. A solution was found by applying 4-7t High Density rock and a gentler toe slope. Nevertheless, the model testing learned that the wave breaking caused high turbulence at the crest of the toe, where the cable freespan is located.

Preliminary results of the physical model testing of extreme (design) storm conditions has shown:

- Good stability of 8t rock bags and 300-1000kg rock armour on top of the cable running over the scour protection;
- Good stability of 12t rock bags and 4-7t HD rock on top of the cable running over the (lower part) of the toe slope;
- Both rock bags and rock armour on top of the toe crest, i.e. at the cable freespan, showed displacements during 10yr and 50yr RP storm wave conditions.
- Displacements of rock bags and rock armour occurred during the highest individual waves only.
- Rock armour showed slightly higher displacement numbers than rock bags.
- Once a first rock bag was moved, subsequent damages occurred more easily.

Further results and analysis of the physical model testing will be presented in the final paper submission.

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