OPTIMISING SCOUR PROTECTIONS – RECENT CONTRIBUTIONS OF THE ORACLE PROJECT

Tiago FAZERES-FERRADOSA[1,2], Francisco TAVEIRA-PINTO[1,2], Paulo ROSA-SANTOS[1,2]

1. FEUP - Faculty of Engineering of the University of Porto, Department of Civil Engineering, rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal, tferradosa@fe.up.pt, fpinto@fe.up.pt, pjrsantos@fe.up.pt.

2. CIIMAR - Interdisciplinary Centre of Marine and Environmental Research of the University of Porto, Terminal de Cruzeiros do Porto de Leixões, Avenida General Norton de Matos, S/N, 4450-208 Matosinhos, Portugal.

ABSTRACT

Scour protections are a key component of bottom-fixed foundations, namely in gravity based foundations, jacket structures and monopiles commonly used for offshore wind turbines, oil and gas production units and more recently in wave or tidal energy platforms. The cost of the scour protection represents a considerable portion of the capital, operation and maintenance expenditures of the overall investment. Therefore, both the industry and the scientific community devote many studies and research projects focused on its cost-benefit optimisation. In addition, the rising concern of climate change effects and need for lifetime extension of offshore platforms coupled with repowering activities represent new challenges to the design of these elements, which are typically designed to last 25 years, with or without re-filling operations. The ORACLE project has been focused on design optimisation of scour protections in marine environment, by means of improved reliability under long-term conditions. This project includes the physical modelling of optimised dynamic and wide-graded scour protections and the probabilistic assessment and quantification of safety. The present work provides a brief overview of the most recent results of ORACLE. Latest results include the early developments of a new methodology to analyse bathymetric profiles and to compute the damage number and a probabilistic methodology to optimise the median stone diameter of the armour layer.

Keywords: Scour protections; ORACLE; Optimisation; Marine Energy; Offshore structures.

1. INTRODUCTION

Scour protections play a key role in ensuring the structural stability of offshore foundations and structures. For example, while in slender structures, as the monopile foundations for wind turbines, they are important to avoid the increase of free span length and thus keeping the natural frequency under the proper design intervals, in larger foundations, as the gravity based, they are important to avoid differential settlements and uneven loads distribution. However, the cost related to scour protections is considerable, thus making them a key target for cost-benefit optimisations. The design and consequent optimisation of rip-rap scour protections, in marine environment, registered notable advances over the last 10 years, namely, with the introduction of new concepts, such as the dynamic and wide-graded scour protections, fully detailed in Fazeres-Ferradosa *et al.* (2019) and Schendel *et al.* (2014), respectively. However, the reliability of such optimisations, when compared to traditional design, *i.e.* based on the concept of critical shear-stress (see De Vos *et al.*, 2011), has only been characterised recently by Fazeres-Ferradosa *et al.* (2018). The knowledge on the reliability of scour protections in marine environment is rather recent and Fazeres-Ferradosa *et al*. (2019) notes that the industry is still in much need of detailed analysis that accurately quantify the probability of failure of these and similar rubble-mound structures. In addition, the people with sufficient knowledge to design scour protections, optimised or not, is very reduced, which adds up to the stakeholders' confidential policies that motivates a lack of knowledge sharing among the scientific and industrial community regarding this matter. From this scenario an important problem arises: there is a need a for cost-benefit optimisation and reliability improvement, but the lack of knowledge sharing and design expertise makes it difficult to obtain systematic and constant contributions that can be scaled-up to a full industrial implementation.

Finally, under the climate change context, the offshore industry now faces the urgent need for a proper design of maritime structures and foundations that can present longer life cycles and be more sustainable. In this sense, the need to extend the lifetime of already existing scour protections and to design new ones adapted to climate change effects, are crucial contributions to increase the competitiveness of the marine energy sector. In order to provide a direct answer to these needs, the R&D ORACLE project – offshore risk analysis for climate change adaptation and lifetime extension – is focused on the development of an open source online Decision Support System (DSS) that guides the user through a proper optimised design of a scour protection that is both resilient to climate change and reliable in long-term life cycles, *i.e.* more than 25 years and up to 50 years. The present research provides a summary of the latest developments made through ORACLE.

2. PHYSICAL MODELLING AND SYNERGIES WITH PROTEUS

The optimisations proposed in the ORACLE project are mainly based on two design concepts: i) dynamic scour protections, which allow for a controlled movement of the armour units of the rubble-mound top layer; ii) wide-graded scour protections, which do not require the use of a granular filter layer, as a unique layer of wide-graded stones is applied at the bottom of the foundation.

These concepts are rather recent, and the existence of benchmark data is yet to be fully available to the community. Scour protections with dynamic armour layers have shown to optimise the median size employed in the armour layer from 20 to 80 %, when compared to statically stable scour protections, where no estimates are yet available for wide-graded solutions. Further physical model tests are needed to increase the knowledge of these solutions. Hence, the ORACLE project included a major upgrade in the Hydraulics Laboratory of the Faculty of Engineering of the University of Porto, whose primary goal was to adapt the existing current-flume to an irregular and regular wave-current flume able to properly represent common marine conditions that act on marine energy foundations, as the offshore wind farms at the North Sea. Figure 1 provides a record of the changes made and the wave paddle installation. Presently, experimental facilities allow testing typical foundations at a geometric scale between 1:35 to 1:50 (depending on the type of foundation), respecting Froude's similitude. A maximum water depth of 0.7 m, with a maximum regular wave height of 0.35 m and a maximum averaged-depth current velocity of 0.3 m/s is currently available. Further detail are given in Chambel (2019). Nevertheless, the ORACLE project only includes testing at 0.35 m of water depth, maximum irregular wave heights up to 0.14 m and an averaged-depth current velocity of 0.15 m/s. The tests foreseen at the new wave-current flume largely extend the range of hydrodynamic conditions available in the literature, including the largest data sets on dynamic scour protections, *i.e.* De Vos *et al.* (2012) and Fazeres-Ferradosa *et al*. (2018b).

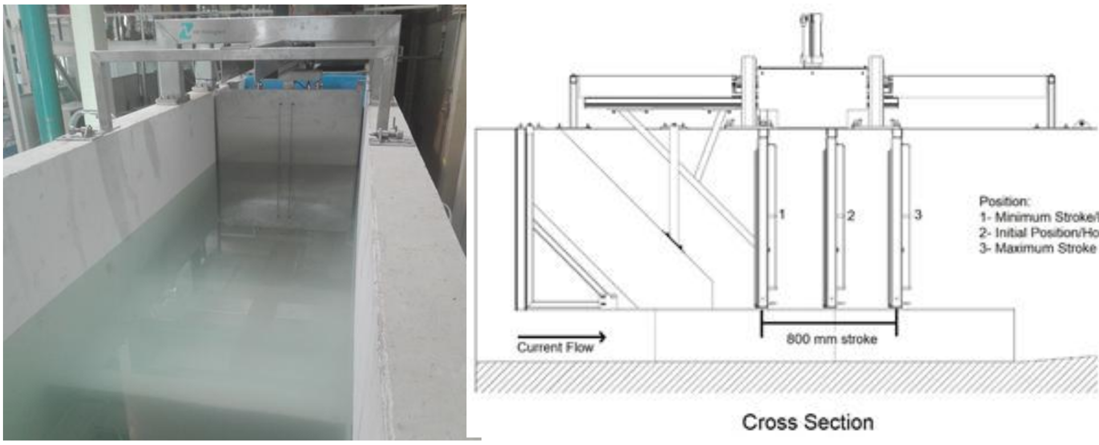

Fig. 1 – Front view of the paddle with filled flume up to 0.5 m water depth (left) and side-scheme of the wave paddle, maximum stroke and inlet for current flow (right).

The adapting works performed at the wave-current flume took the first year of the project along with the preliminary publications concerning the Fazeres-Ferradosa *et al*. (2018b and 2019) studies and the preliminary tests performed by Chambel (2019). Therefore, in order to maximise the outcomes of the present research, the ORACLE team was able to create synergies within other European projects, such as the PROTEUS (see Chavez *et al.*, 2019), which included large scale scour protection tests (geometric scale of 1:8 and 1:16.7) at the Fast Flow Facilities in HR Wallingford, UK. Throughout the cooperation with PROTEUS an extension of the experimental conditions for physical modelling was achieved. A novel methodology to analyse damage at scour protections and rubble-mound structures has been proposed and a new set of 15 tests of large-scale benchmark data was acquired.

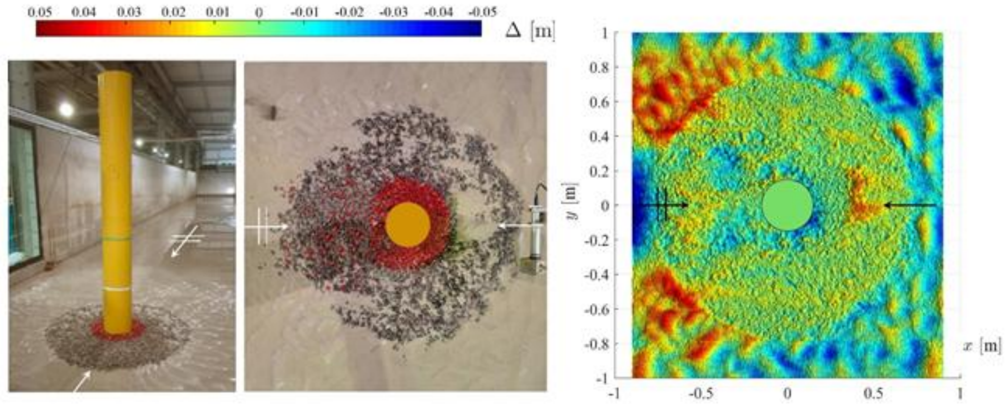

Fig. 2 – PROTEUS scour test 4: a) Side-view of monopile foundation (D_p=0.30 m) and scour protection (water depth, d=1.2 m). b) Top-view of damaged scour protection, waves from left, current from right. c) bathymetric profile after 3000 waves.

3. RECENT RESULTS

The reliability analysis and long-term behaviour of scour protections remains as a complex topic of research. Fazeres-Ferradosa et al. (2019) provides an extensive review of the main challenges yet to be solved. In addition, such challenges are discussed in light of the scope covered by the ORACLE project. Recently, there are two key challenges that have already been tackled despite the need for further research and knowledge acquisition regarding their generalisation.

The first topic covered is the need for a systematised methodology to assess and quantify the probability of failure of scour protections. This has been presented earlier in Fazeres-Ferradosa *et al.* (2018) with a simplified model that considers the statistical uncertainty related with met-ocean data. Figure 3 provides the probability curves derived for the case study of Horns Rev 3 offshore wind farm, which have been developed for dynamic and static scour protections. The curves allowed for a definition of a "design zone" for which the median stone size of the rubble-mound units (D_{50}) could be reduced without aggravating the probability of failure (P_f). These probabilities were derived considering the joint behaviour of the significant wave height and the peak period at the referred location. At the current status of the project, this model is now being extended to a higher dimension model, which will consider these variables plus the correlation with the waves' direction and the averaged-depth current velocity.

The second challenge being tackled concerns the uniformization of the procedure used to compute the damage number introduced by De Vos *et al.* (2012) to define the dynamic stability. The damage number based on De Vos *et al.* (2012) definition has been calculated based on the analysis of the bathymetric profiles, acquired in through physical modelling. Such analysis implies the post-processing of the bathymetric data based on a spatial analysis made for local regions, *i.e.* sub-areas (see Fazeres-Ferradosa *et al.*, 2019 for further detail). Recent results, from the ORACLE and PROTEUS tests, show that the division of sub-areas highly affects the calculation of the damage number, thus no consensus exists on the most adequate way to analyse the bathymetric profiles. The ORACLE project has proposed a new methodology that presents sub-areas that can overlap each other to better capture localised scour at the protection. The novel methodology has two key advantages: i) overlapping sub-areas enables a better insight on damage occurring at the armour, while not being dependent on the type of foundation being assessed and not being influenced by the fixed limits of the former sub-areas; and ii) enables the definition of the statistical distribution of damage at the scour protection. The statistical distribution of damage allows for a deeper analysis of the protection's behaviour, as it is possible to address characteristic values, such as the standard deviation of damage and its quantiles, while the former methodologies only addressed the maximum value of the damage number. Figure 4 shows an example of the behaviour of the standard deviation with respect to the size of the sub-areas for the PROTEUS test of Figure 2.

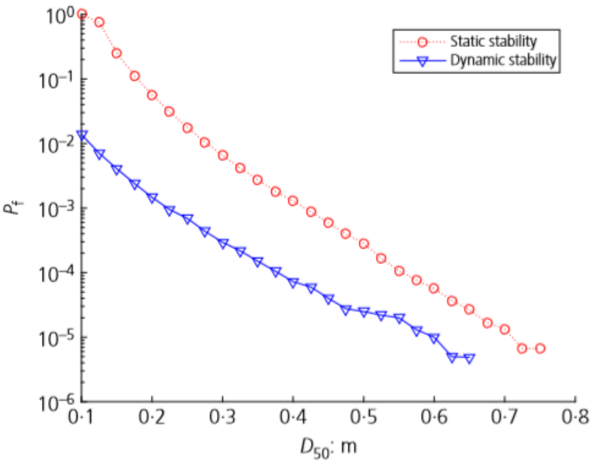

Fig. 3 - Relationship between D_{50} and P_f for scour protection of a monopile at Horns Rev 3 offshore windfarm, considering the failure mode 'erosion of the top layer'; N=3000 waves, ρ_s=2650 kg/m^3, d=18 m (Fazeres-Ferradosa et al., 2018).

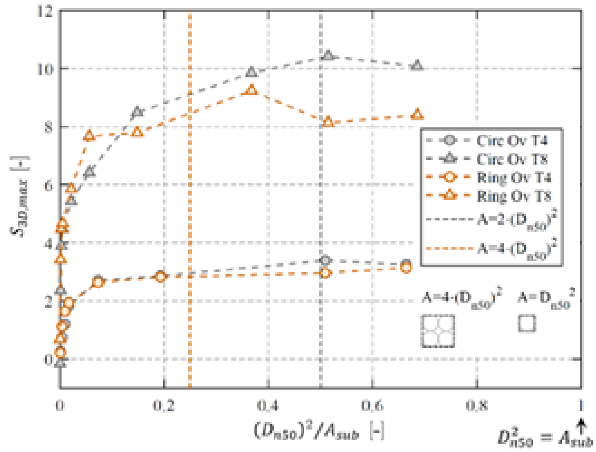

Fig. 4 -Variation of the maximum damage number (S_{3D}) of test 4 and 8, plotted against the ratio of the nominal median stone size and the sub-area size (D_{n50}^2/A_{sub}) for sub-areas with a circular and a ring shape.

4. CONCLUSIONS

The ORACLE project is now moving into its second half with the online implementation of the Decision Support System, for scour protections' optimisation and risk assessment under climate change and lifetime extension scenarios, being its main target. The most recent results include the improvement of the facilities of the Hydraulics Laboratory of FEUP, thus now being possible to perform physical modelling activities at small and intermediate scales, with waves and current combined. This enables not only a more realistic modelling of scour protections in marine environment, but it also unlocks interesting applications to other research areas of the ORACLE's team, namely, the study of wave energy converters, oil and gas platforms, 2D studies applied to natured base solutions and conventional solutions for coastal protection. In addition, the project has developed a new multi-variate model to quantify the probability of failure of scour protections. This model extends the probabilistic design methodology presented in Fazeres-Ferradosa *et al.* (2018). Finally, a novel methodology to calculate damage numbers at scour protections was achieved, with the advantage of allowing for the definition of the statistical distribution of damage. These and upcoming contributions of ORACLE will be incorporated in the DSS, which aims for an added value to both the scientific and industrial stakeholders of the offshore energy sector.

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