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WHEN MONOPILES DON'T WORK: FIXED WIND FOUNDATION SELECTION

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BACKGROUND

Monopiles are the de facto solution for offshore fixed wind developments for good reason. They are a simple low-cost solution with well-established fabrication, transportation and installation procedures. However, the industry drive for larger higher power turbines and expansion into deeper waters is pushing the technical limits and feasibility of this field proven industry solution. As an example, the overturning moment for a 15MW turbine more than doubles in comparison to a 10MW turbine, necessitating much larger diameter monopiles and associated installation vessels and hardware.

OBJECTIVE

Case study for a location where monopiles prove to be technically challenging, considering development specific parameters, such as the turbine size, water depth, geotechnical conditions, environmental requirements, available installation vessels and local regulatory requirements.

The objectives are:

- estimate the limitations of monopile as a fixed foundation solution using water depth and turbine size as inputs.
- understand the key drivers when selecting alternate fixed foundation solutions to monopiles.

METHODS

Parameters & Weighting:

Fixed foundation selection for 15MW WTG, in water depths ranging from 40m-60m, considering the following parameters and site-specific weighting factor:

1. Manufacturability (22.5%)
2. Transportation (10%)
3. Installation (25%)
4. Design (7.5%)
5. Operation and IMMR (Inspection, Monitoring, Maintenance and Repair) (2.5%)
6. Environmental Impact (12.5%)
7. Decommissioning (20%)

Risk Based Rating System

Each parameter is scaled from 1 to 7. Lower scores mean that the foundation is more cost-effective and/or has a higher technology readiness level (TRL). Higher scores represent structures that are less cost-effective and/or have a lower TRL and consequently represent higher risk.

Scoring Matrix

Based on the parameters, weighting and rating system a risk-based scoring matrix is completed.

RESULTS

Bottom fixed foundation screening is carried considering gravity based, monopile, tripod/quadpod and jacket. Suction bucket designs are not assessed as they are extremely unlikely to be able to be installed with the prospect of shallow bedrock outcrops in the site (<10m).

To reach water depths up to 60m, support turbines up to 15MW WTG, and withstand extreme wind loads driven by harsh environment, the required wall thickness of the monopile could be up to 150mm, the diameter up to 11m and the total weight reach up to 2,400Te. Therefore for the case study, monopiles are scored the highest among all the foundation types assessed in terms of **manufacturability** and **installation** since they require wall thickness beyond the current manufacturing limits and their installation become a challenge due to the greater diameters and weight.

Regardless of the foundation type, the **transportation** can be optimised during the early stages of the project and the foundations be designed to be floated to their destination, consequently saving costs. However considering **port facility** the transportation of the gravity based is scored highest due to its large size (estimated footprint of more than 2,300m^2 at the base) and weight.

Design covers the structural response and technology readiness. Jackets are scored the lowest, since they can be designed for all types of soils. Gravity Based and Monopiles are scored the highest due to their low technology readiness level for deeper water depths and 15MW WTG.

In terms of **Inspection & IMMR**, the lowest score is given to the Gravity Base due to its massive concrete shape which requires less maintenance. On the other hand the highest score is given to the jackets which require a high number of IMMR activities due to their complex shape and assembly.

Environmental impact includes noise, spoil and disposal during installation and foundation footprint during operation. Jackets and Tripod/Quadpod score higher than Gravity Based or Monopiles since their installation require repetition of the installation process 4 or 3 times for one turbine location to install all legs, resulting in longer installation and noise exposition time. However there are noise mitigation systems available (e.g. bubble curtain) which if applied could reduce the environmental impact.

Decommissioning has a significant weight (20%) due to strict regional laws at the site of the case study. All piled foundations are scored as the maximum since, to date, no drilled piles of significant size has been fully recovered (considering underwater decommissioning).

Risk Based Screening Results

Based on the data available and at the screening matrix results the most robust design solution for the site of the case study is jackets (weighted score of 4.43), while the foundation with highest risk is monopiles (weighted score of 5.60).

In this case study jackets are the most favourable solution. They offer a safer solution for the deeper water depths in the site since their feasibility is field proven and their design can be optimised for the expected loads.

Figure 1 – Bottom Fixed Foundations Assessed

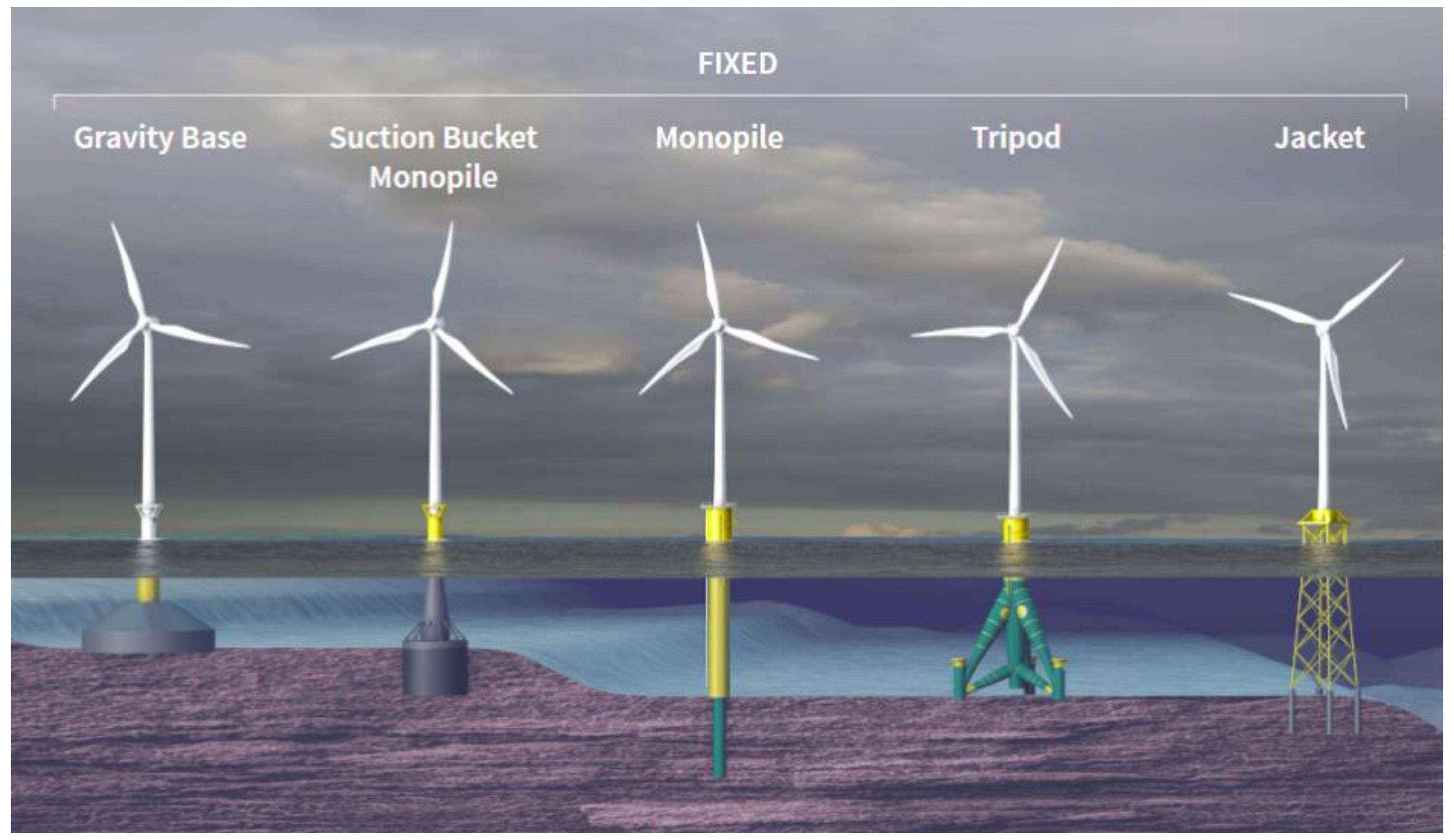

Table 1 – Foundation Types

WTG Foundation Parameter	WTG Foundation Types				
Seabed Interface	Gravity Base	Suction Bucket	Piled	Piled	Piled
Through-water Structure	Monopile	Monopile	Monopile	Quadpod	Jacket
Number of Legs	NA	NA	NA	4	4
Diameter at Seabed (m)	55	20	11	4	3.5
Leg Diameter (m)	NA	NA	NA	4	3
Spacing Between Legs (m)	NA	NA	NA	32m x 32m	30m x 30m
Footprint Area (m^2)	2,376	314	95	1,296	1,122

Table 2 –Risk Based Screening Summary Results

Criteria	Weight	Water depth 40m-60m with shallow bedrock				
		Gravity Based	Suction Bucket Monopile	Monopile	Tripod/ Quadpod	Piled Jacket
1. Manufacturability	22.5%	1.01		1.35	0.90	0.79
2. Transportation	10.0%	0.40		0.50	0.50	0.40
3. Installation	25.0%	1.06		1.25	0.94	0.94
4. Design	7.5%	0.53		0.53	0.23	0.15
5. Operation & IMMR	2.5%	0.08		0.08	0.13	0.13
6. Environmental Impact	12.5%	0.50		0.50	0.63	0.63
7. Decommissioning	20.0%	1.10		1.40	1.40	1.40
Score Summation with Weight		4.68		5.60	4.71	4.43
Selection			NA			Selected

CONCLUSIONS

As the boundaries for bottom fixed wind farms are pushed regarding deeper water depth and larger sizes of turbines, the screening process of foundations becomes increasingly important and more **complex**. The amount of research and expertise that goes into defining the weightings and determining the scores can be significant due to their dependability on **site specific** characteristics and supply chain. To achieve an accurate and thorough assessment, it is critical to understand the **full life cycle** and to analyse all parameters proposed.

For this case study, in water depths ranging from 40m to 60m and where shallow bedrocks are present, the screening exercise showed that jackets are the best solution when all parameters and weight factors are taken into account.

The deeper water depths increase the monopile risk and impose manufacturing, transportation and installation challenges, i.e. the piles may need to be longer, thicker and heavier. The largest monopile installed to date is in water depth of 45m for 9.5MW WTG [4].

Choosing the right foundation to **minimize cost and risk** to the offshore wind farm and the environment is critical to a successful development and to achieving **low LCOE**.

ACKNOWLEDGEMENTS

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REFERENCES

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