Understanding Geotechnical Risk in the Gulf of Bothnia for Sustainable Offshore Wind Development

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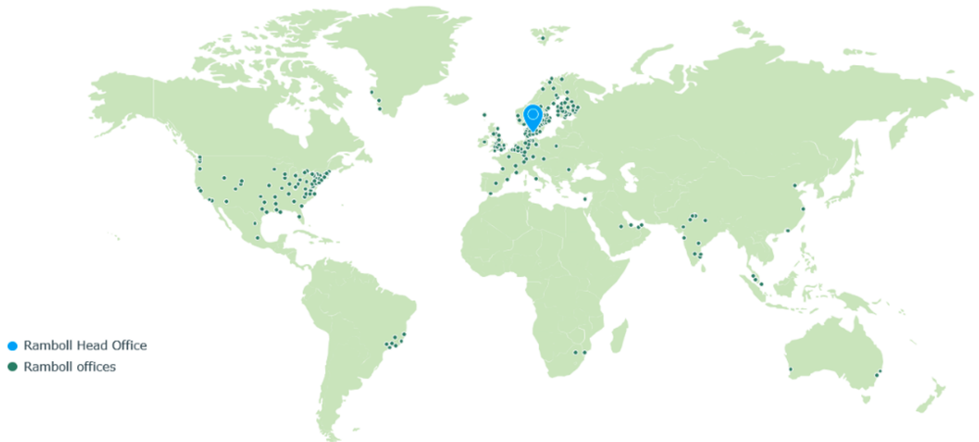
RAMBOLL

Ramboll is a global architecture, engineering, and consultancy company, delivering expertise and sustainable solutions to clients and partners.

Founded in Denmark in 1945, Ramboll today operates across 35 countries.

Buildings	Transport	Environment & Health	Energy	Water	Management Consulting	Architecture & landscape
26%	20%	24%	14%	7%	4%	5%

35	18,000	2.4 Bn
Countries covered by global office network	Experts	Global revenue, in 2024 across all markets



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Tampere University

Tampere University community consists of about 22,500 students and around 4,200 staff members from more than 80 countries.

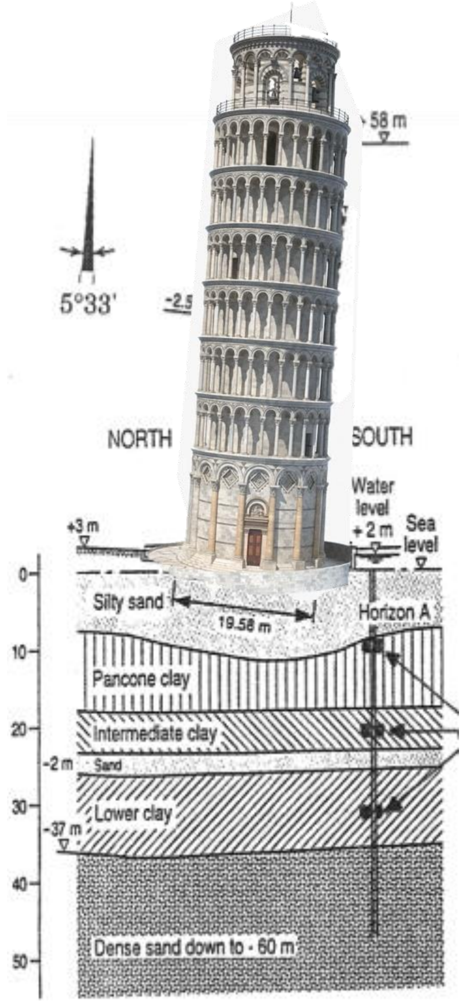
Research Centre TERRA
Geo
Road
Rail

Research Centre Terra is Finland's leading infrastructure expert.

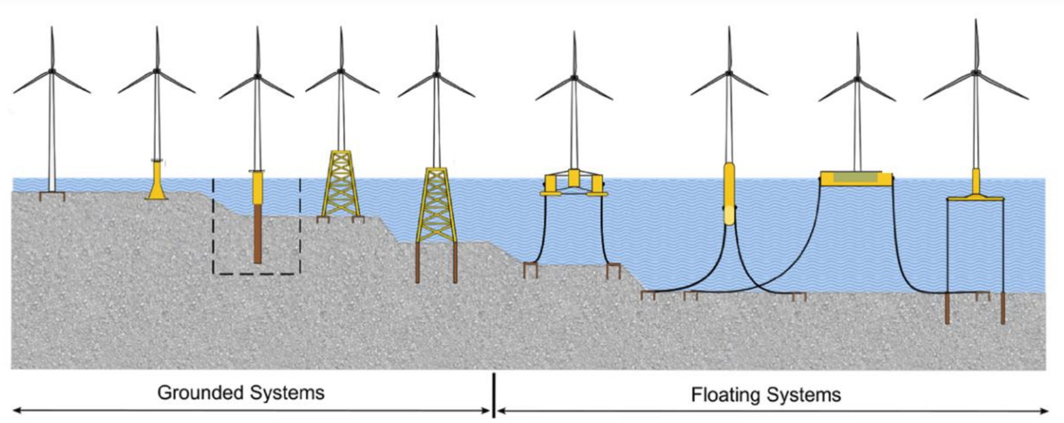
Main areas: geotechnics, earth structures, track structures and digitalisation of infrastructures, laboratory and measurement services.

The ground knows (while we don't)

Challenges	Soil is a complex, layered and variable material shaped by nature.
	Sustainable geotechnical design begins with the unseen and the unknown.
	Design must be cost-effective, resource-efficient, long-lasting, and resilient to a changing climate.
Question marks	What challenges does offshore environment bring to the design of offshore wind foundations?
	How can we balance safety and sustainability in our designs, especially when dealing with the uncertainties in the soil?
	How to fill data gaps in the Gulf of Bothnia?
Goal	**To understand how offshore geotechnical risk in the Gulf of Bothnia affects sustainable Offshore Wind development**

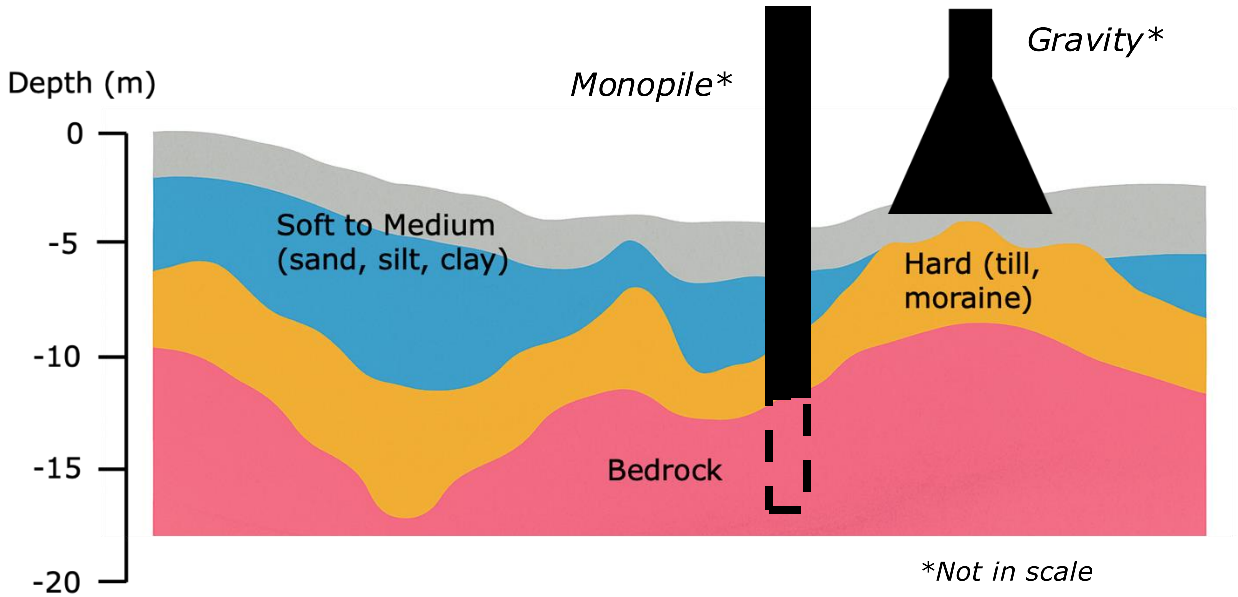


Seabed variability and Foundations in the Gulf of Bothnia



Jindal et al. (2024)

In Finland		
Water depths OK for grounded systems?	Too shallow bedrock for monopile?	Gravity foundations a better solution?



Most common offshore wind foundations

- Monopile (≈80% of OWF around the world)
- Gravity-based foundation (GBF)
- Jacket structure

Safe, Reliable and Sustainable Geotechnical Design

👷 **Safety** - always comes first

- Safety is the **first threshold** in any geotechnical design. Without it, no project is acceptable.

e.g. Wind turbine must not collapse

📊 **Reliability** - confidence in safety despite uncertainty

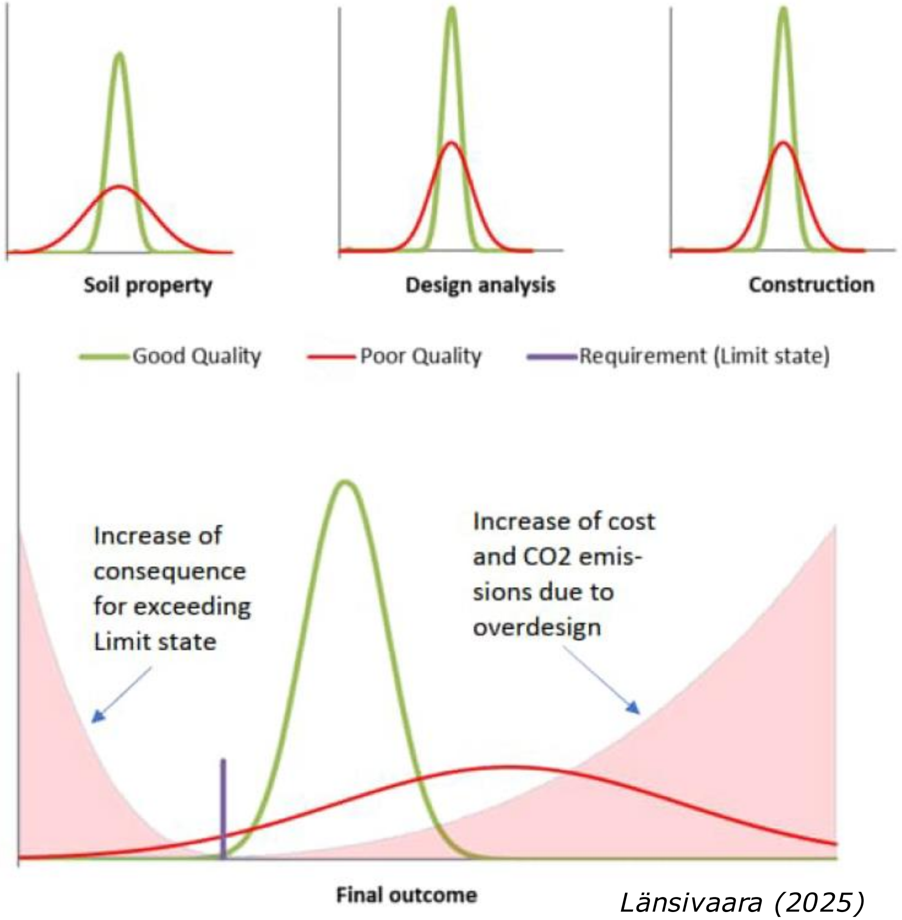
- Large uncertainty → Overdesign
- Low uncertainty → More reliable and cost-effective design

e.g. how sure are we about soil parameters?

🌿 **Sustainability** – right choices to save resources

- Smart use of resources with long-term impact in mind. Overdesigning means using more material, higher costs and more carbon.

e.g. larger foundation = more emissions



Länsivaara (2025)

Uncertainties in the process

Geological model

Soil conditions

- Geology
- Different types of soil sand rocks
- Layering
- Inhomogeneity

Geotechnical model

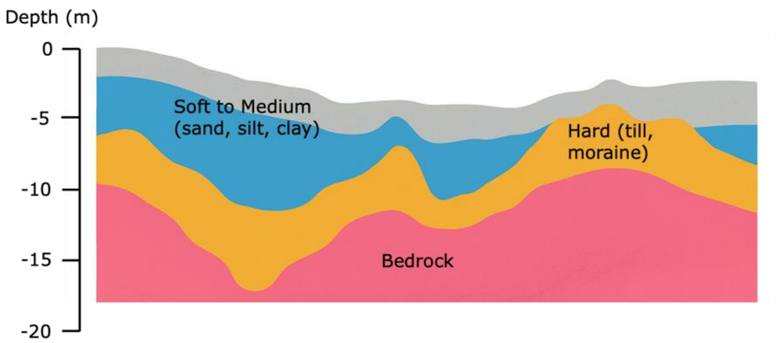
Soil behaviour

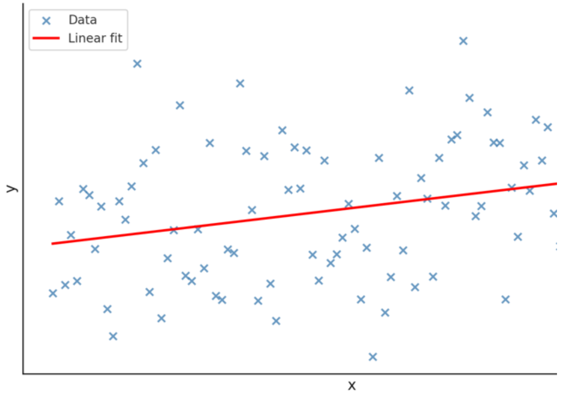
- Sampling and testing of soils
- Different results from different tests
- Derivation of design parameters

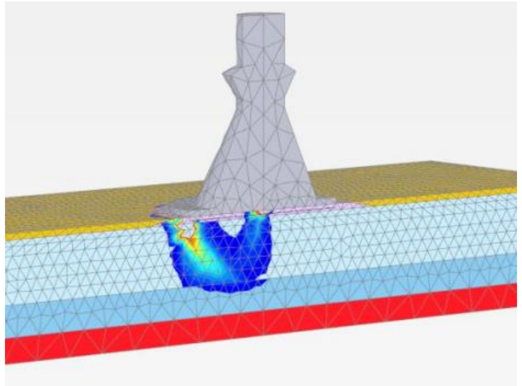
Engineering model

Design & analysis

- Hand calculations vs computer models
- Choose the right model for each soil
- Results affect how we build and operate





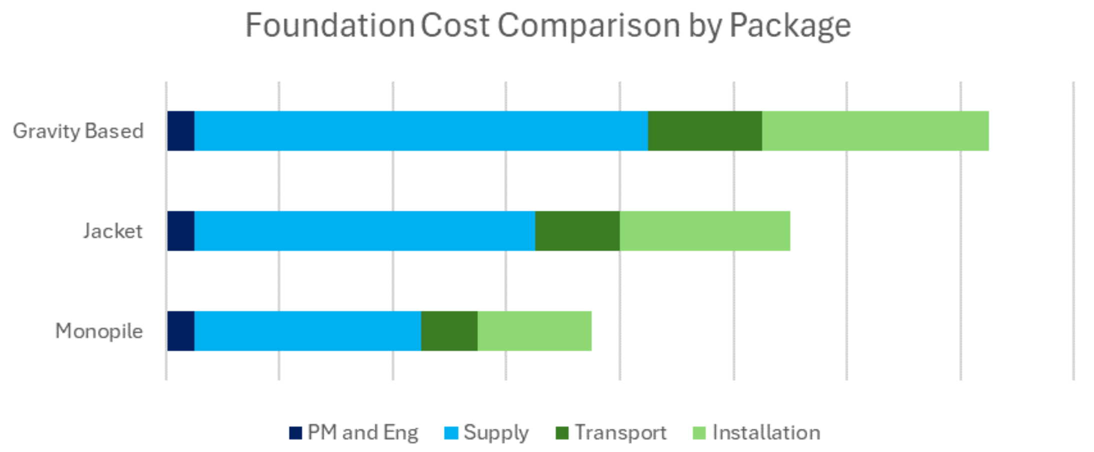


Understanding the Cost Drivers for Different Foundation Concepts

Each foundation concept has different strengths and weaknesses, each will have different cost drivers.

Increases to the mass or dimensions of a design are not only captured in increased supply costs but also reflected in the transport and installation strategy.

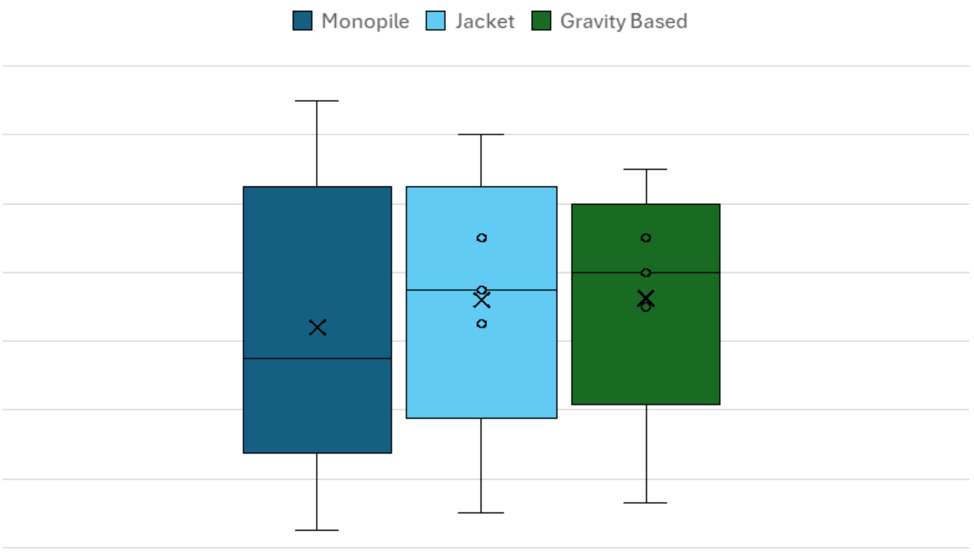
Concept	**Jackets**	**Gravity Based**	**Monopile**
PM and Eng	€	€	€
Supply	€€€€	€€€	€€€
Transport	€€	€€	€
Installation	€€€	€€€€	€€

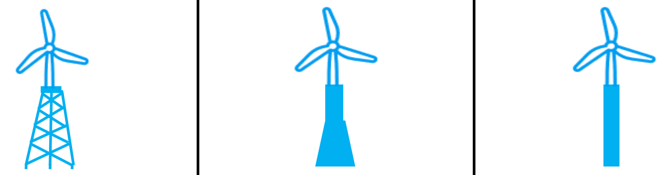


Probabilistic Approach to Capture Risk and Uncertainty

The base case costs for one concept may be lower than the others. However, the risks associated with that concept (*such as if drilling is required for monopiles*) may result in a much higher cost value, reflecting a riskier selection.

Total Package Cost for Each Concept





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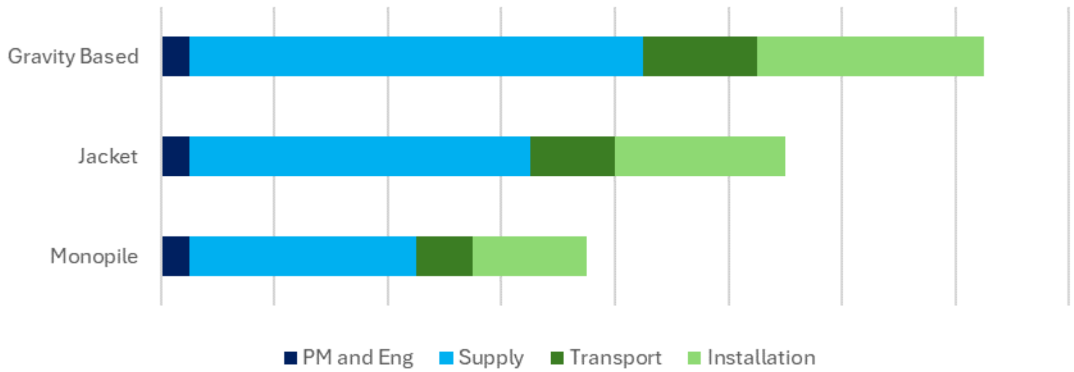
Transport	€€	€€	€
Installation	€€€	€€€€	€€

Foundation Cost Comparison by Package



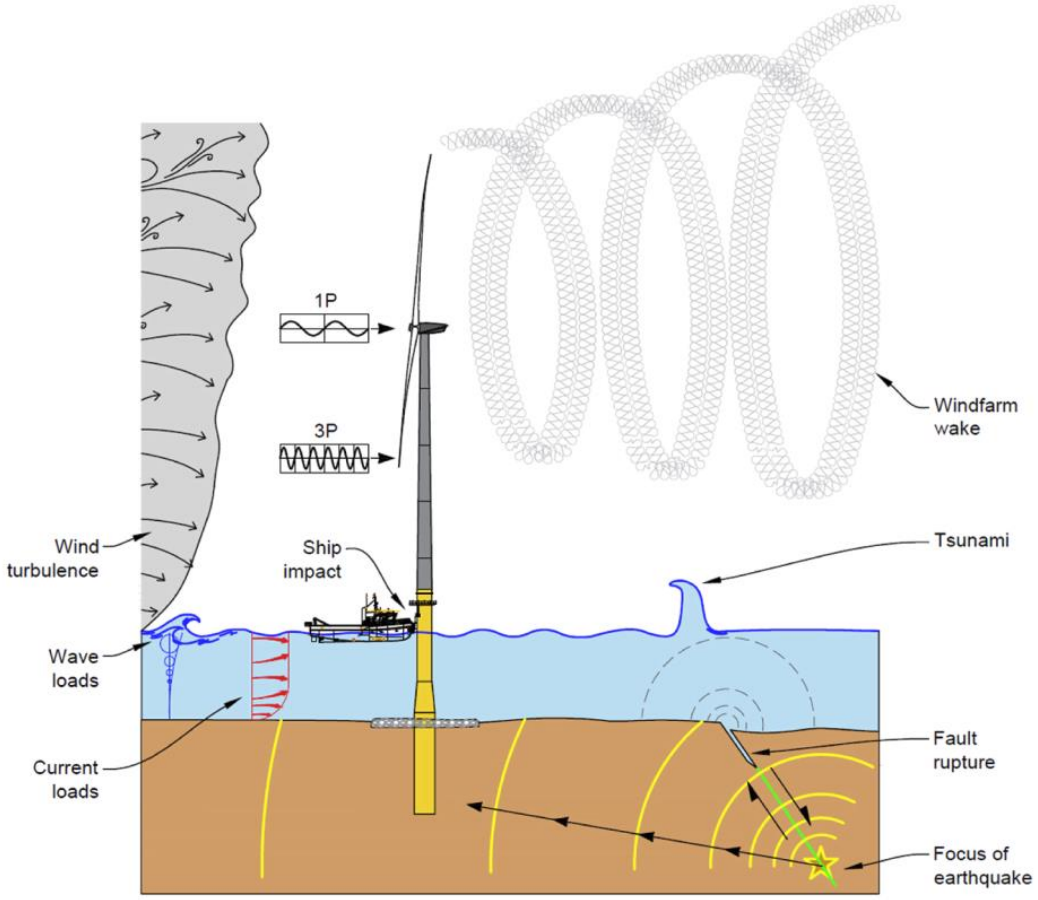
The offshore environment affects how soil behaves

- Environmental conditions impose significant loads on offshore structures
- Cyclic loads from wind, waves and ice
  - Soil properties change due to cyclic effects!

In the Gulf of Bothnia's conditions (*Gravity-based foundations*), **the mechanical resistance of glacial soils will be reduced by**

- Up to **30%** (till, compact moraine)
- Up to **40-70%** (sands and loose moraine)

Isometsä (2025) proposed initial factors to be used for **preliminary analyses and risk assessment** and in absence of site-specific data

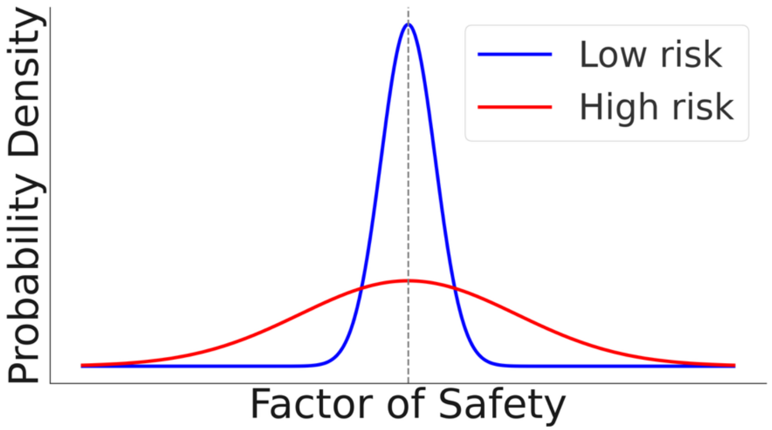


Jindal et al. (2024)

Role of data in risk mitigation

- Limited public geological data available from the Gulf of Bothnia, although non-public data exists
- Bathymetry data in territorial waters is classified for security reasons (*clearance required by the Defence Forces to process data in audited facilities*)
- Very limited geotechnical data available

High risk in early planning phase!



Filling data gaps with research projects

Tampere University

GLACIAL WIND (2025-2028)

Geotechnical characterization of glacial till and mixed sediments from the Gulf of Bothnia for Wind Infrastructure design

METAWIND (2025-2028)

Advancing geotechnical modelling of Offshore Wind foundations in the Gulf of Bothnia

Main Goal

Support developers in reducing early-phase risks in Finnish projects

Academia-Industry collaboration: partnerships possible!

Reflection & Recommendations

Do we understand offshore geotechnical risk in the Gulf of Bothnia?

- 💨 🌊 🧊 Offshore environment is challenging because of seabed nature and environmental factors
- ⁉️ Large uncertainties may result in unexpected costs and, in the worst case, a complete re-evaluation of your design
- 🌿 Design must be safe and reliable to be sustainable – We must avoid overdesigning!
- 📈 💥 Filling data gaps to de-risk early project phases in Finland: Tampere University's *Glacial Wind* and *MetaWind* projects

Recommendations

- **Project development**: Engage early with a competent and qualified geotechnical consultant with demonstrated offshore wind experience, understanding of local ground conditions, and authorisation to handle seabed data.
- **R&D**: Industry-Academia collaboration to address challenges in Finland's emerging offshore wind sector.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Thank you
Questions?

References

Jindal, S., Rahmanli, U., Aleem, M., Cui, L., & Bhattacharya, S. (2024). Geotechnical challenges in monopile foundations and performance assessment of current design methodologies. Ocean Engineering, 310, 118469.

Isometsä, V. (2025). Geotechical performance of gravity-based foundations for offshore wind turbines in the Gulf of Bothnia’s soil conditions. Master's thesis, V. Isometsä, University of Oulu.

Länsivaara, T. (2025). Foundation Engineering course material, Tampere University.