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Bridging the gap - Optimizing onshore piled wind turbine foundation design by relaxing no-gapping criteria and assessing cyclic degradation

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20% material savings in foundations by replacing common no-gapping limits with detailed assesment of cyclic degradation of piles

RELEVANCE

The geometric dimensions of piled onshore wind turbine foundations are often determined by the no-gapping limit, which requires that no tensile loads occur on piles under normal operational conditions at the S3 load level. This current industry practice often leads to oversized and cost-intensive concrete foundation blocks due to increased material use, construction costs and environmental impact without adequately addressing the underlying cyclic degradation risks.

The proposed methodology shifts the focus from avoiding tensile loads in the piles at the S3 level to evaluating and limiting geotechnical capacity degradation under cyclic loading instead. This is done by using cyclic interaction diagrams.

Setting a limit on pile degradation allows for a more precise evaluation of risks from cyclic loading, leading to safer and more informed design decisions compared to conventional implicit limits. Similar methods are already common practice for design evaluation of offshore foundations.

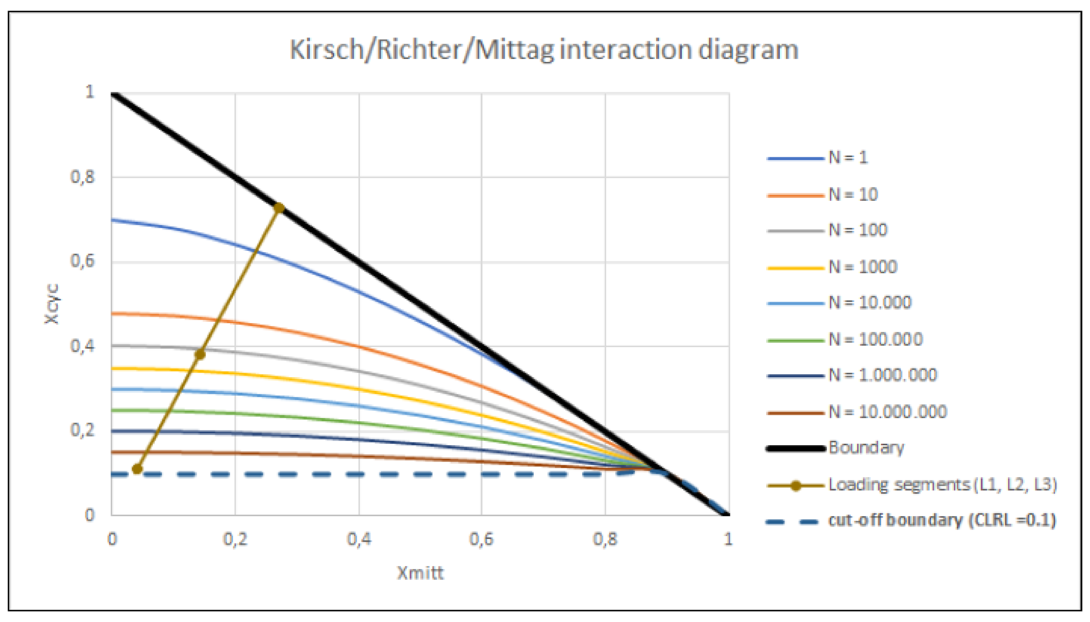
METHODOLOGY

The proposed methodology includes assessing the long-term geotechnical capacity degradation under cyclic loading using interaction diagrams from the EA-Pfähle guidelines in the serviceability limit state (see figure).

The Markov matrices for the overturing moment are related to individual pile load amplitudes for each load case. For each individual load case the resulting damage on te geotechnical bearing capacity is then calculated using interaction diagrams. With a logarithmic damage rule the post-cyclic pile bearing capacity is thereafter calculated for all load cases.

A geotechnical degradation limit of 25% for the post cyclic bearing capacity is proposed within this research to prevent any follow up failure mechanism from occurring.

The foundation stiffness, excessive pile deflection (SLS), reinforcement fatigue (FAT) and ultimate limit states (ULS STR & GEO) checks are thereafter performed using industry standard design codes and numerical models, ensuring full compliance with the IEC61400-6.



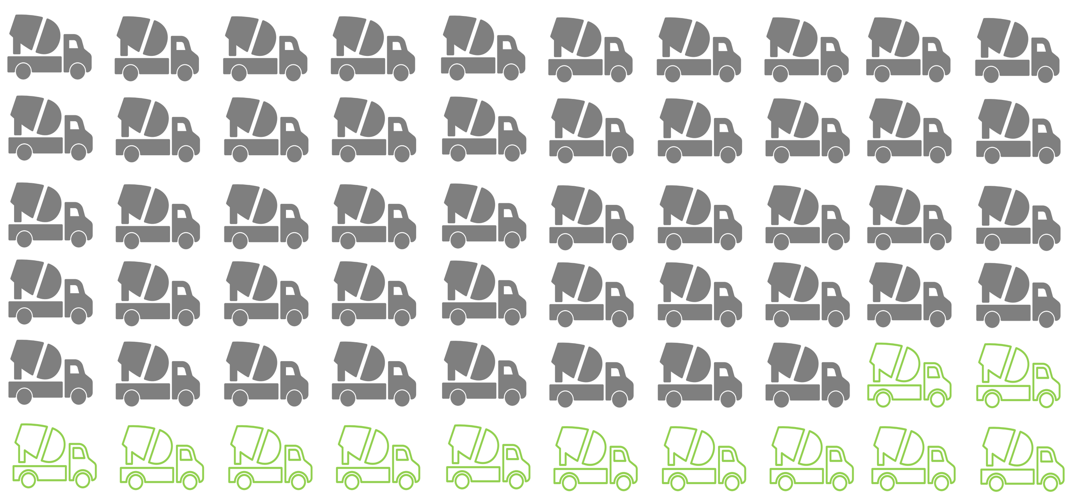
- Cyclic interaction diagrams and cut-off boundary according to the EAP
- Derived governing load spectrum from the Markov matrices

CASE STUDY RESULTS

As a preliminary design for a project in the Netherlands has been made. The proposed design method reduces foundation block dimensions while accepting a slight increase of pile length.

Estimated impact per foundation:

- Reduced concrete volume -20% (-12 truck loads)
- Lower costs of approx. €60k (-10% overall)
- Reduced environmental impact of 50t CO_2eq (-15% overall)



KEY DESIGN ASPECTS

When allowing for gapping in piled foundation design, the diameter of the foundation decreases, and the cyclic load amplitude on the piles as a result increases. This requires additional analyses on:

- Assessment of the pile-soil interface degradation (Geotechnical assessment)
- Assessment of the stiffness degradation of the pile (Geotechnical + Structural assessment)
- Assessment of the pile-foundation connection (Structural assessment)

Verification of the ultimate limit states according to standard practise.

Prefabricated prestressed concrete piles or Vibro-combination piles with a prestressed core are most suitable in the design of onshore foundations without gapping.

ADVANCING INDUSTRY ACCEPTANCE

Driving change in common design methodologies requires broad industry recognition and understanding of the proposed approach. The next steps include expert reviews to validate and refine the methodology.

The involved stakeholders are committed to knowledge sharing and collaboration to further advance this research. For more information, please contact one of the authors.

By challenging conventional assumptions and practices, this work demonstrates that significant optimizations are achievable. The proposed strategy enables the design of larger, more efficient wind turbine foundations while enhancing both sustainability and economic viability.

ACKNOWLEGDEMENTS

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