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Wind-turbine rock anchored foundations

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Leading Expert, Sweco Finland

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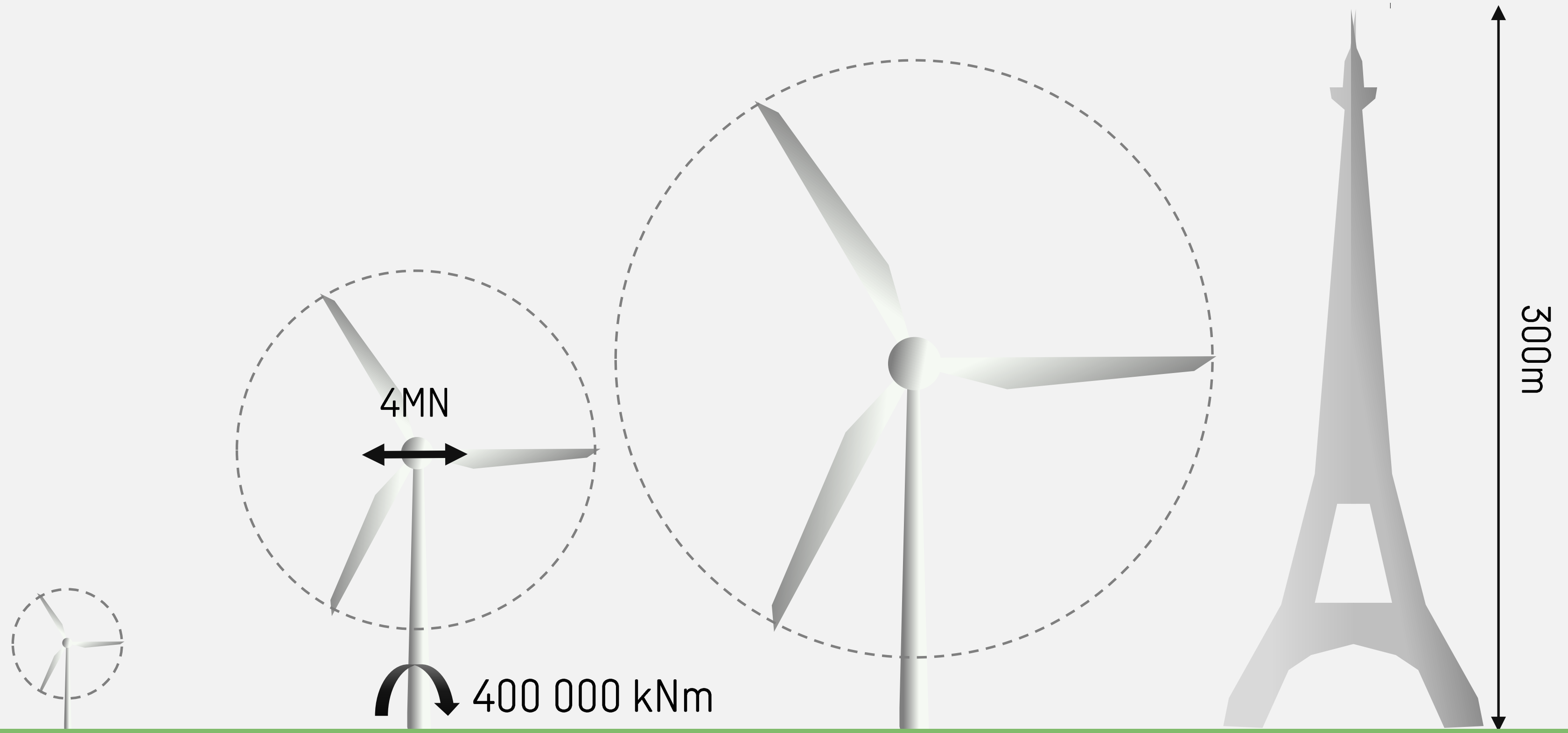
Size of windmills has increased dramatically



1991
Rotor diameter: 35 m
Capacity: 0,5 MW

2025
Rotor diameter: 165 m
Capacity: 10 MW

2035
Rotor diameter: 250 m
Capacity: 17 MW

Windmill foundation types

Gravitational foundation

Rock anchored foundation

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Insights to Modern Rock-Anchored Foundation Design

- For wind turbines anchored into bedrock are called cage-rock foundations. Traditionally these foundations have been designed conservatively against rock cone weight.
- Key contributions of the Peikko white-paper include:
  - The introduction of an enhanced methodology for assessing rock mass strength, emphasizing the efficiency of using anchor bars.
  - The guidelines for the design approaches are informed by comprehensive geotechnical data.
  - The validation of finite element models with a calibrated Mohr-Coulomb material model reflects a wide range of rock conditions and offers a more accurate prediction of foundation behavior.
  - Strategic advice for managing design considerations in scenarios with limited geological data, including optimizing rock cone volume for improved stability.

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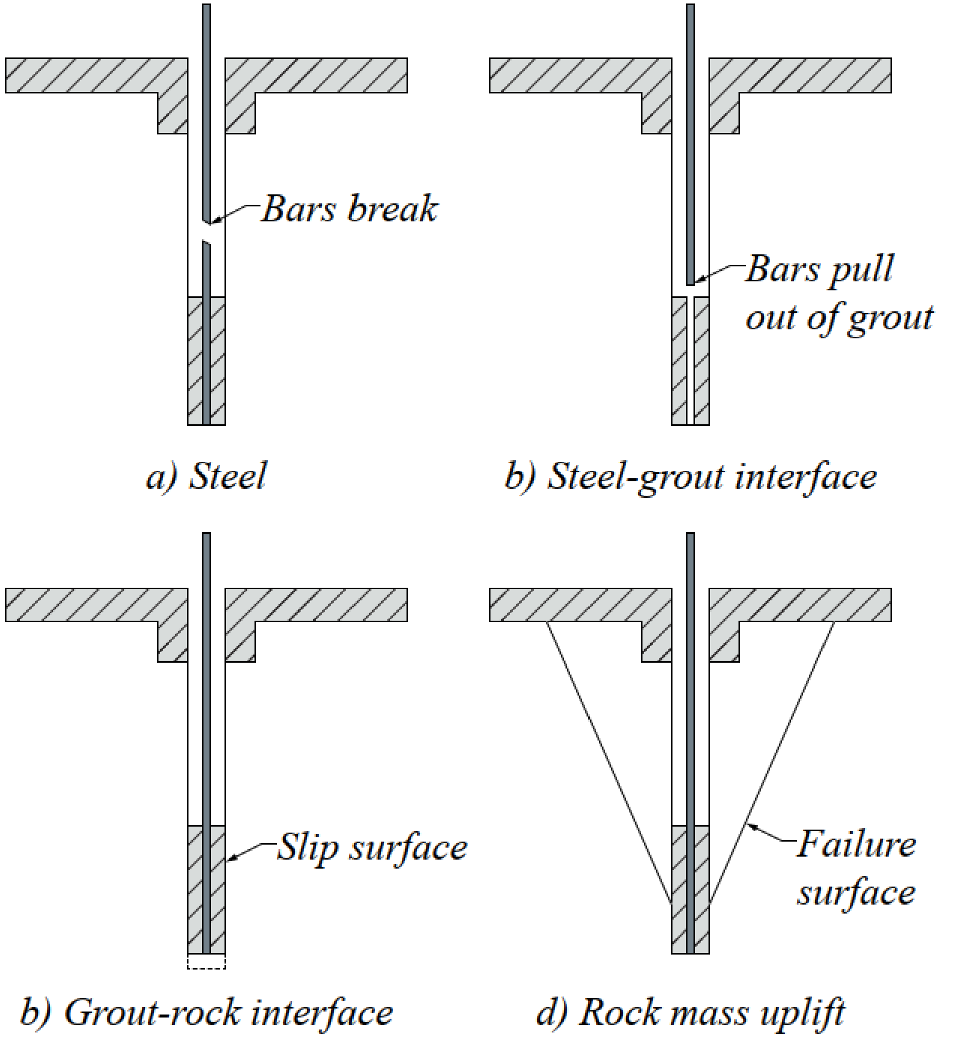
Modes of rock anchoring failure



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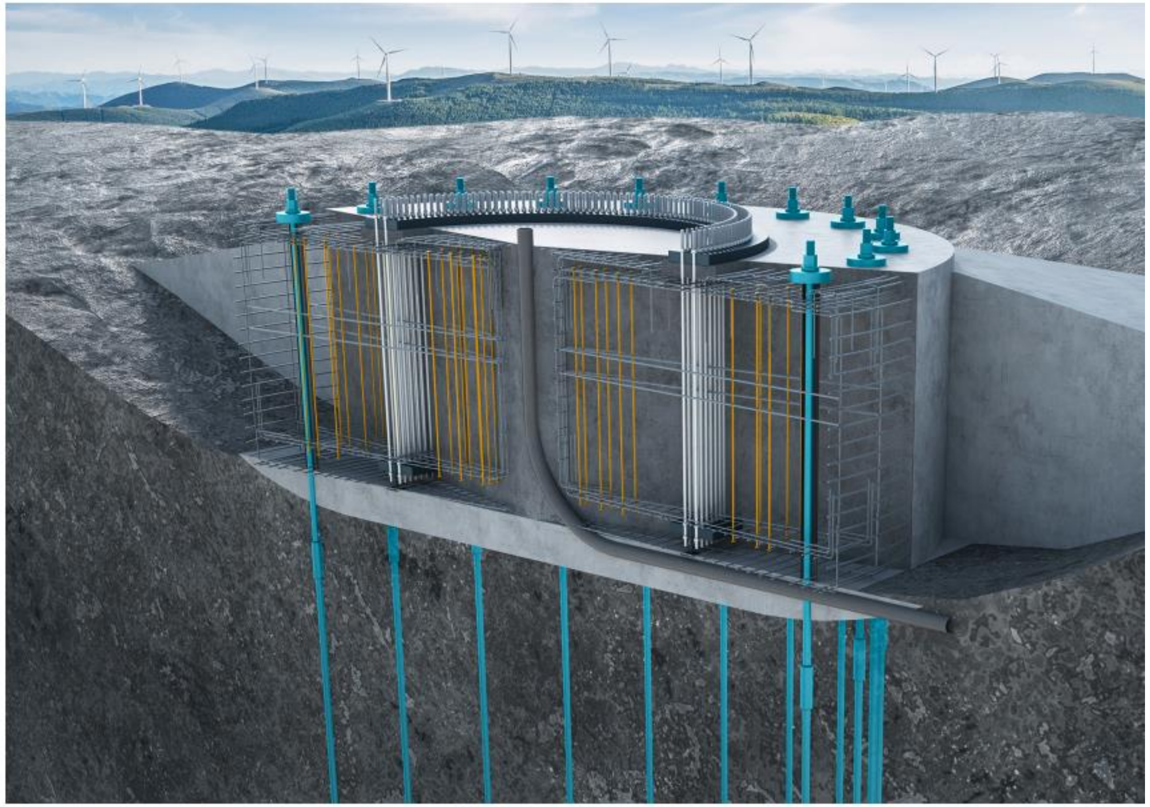
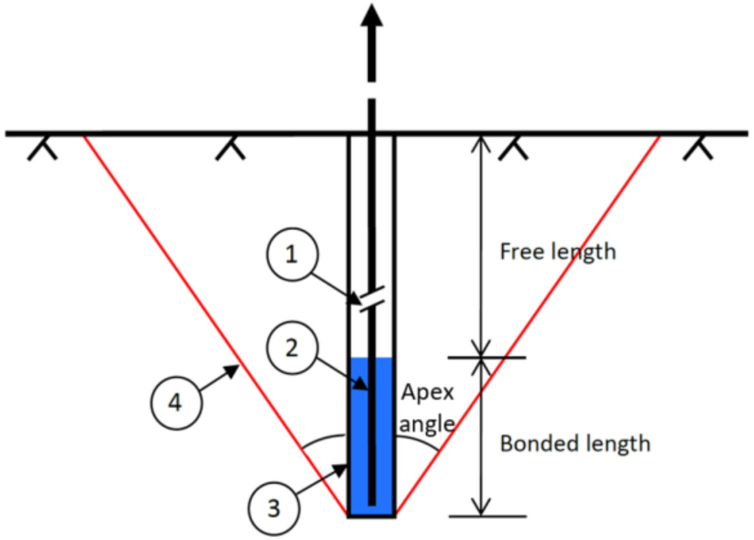
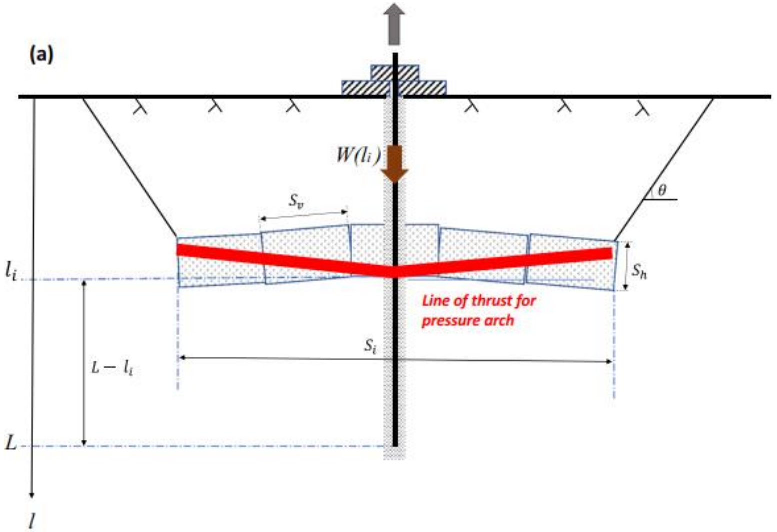
Rock anchoring



- Rock anchored foundations require less concrete
- Most cost effective foundation type when feasible
- Rock block interlocking vs classic approach
  - Interlocking carries more load
  - Classic cone method is very conservative





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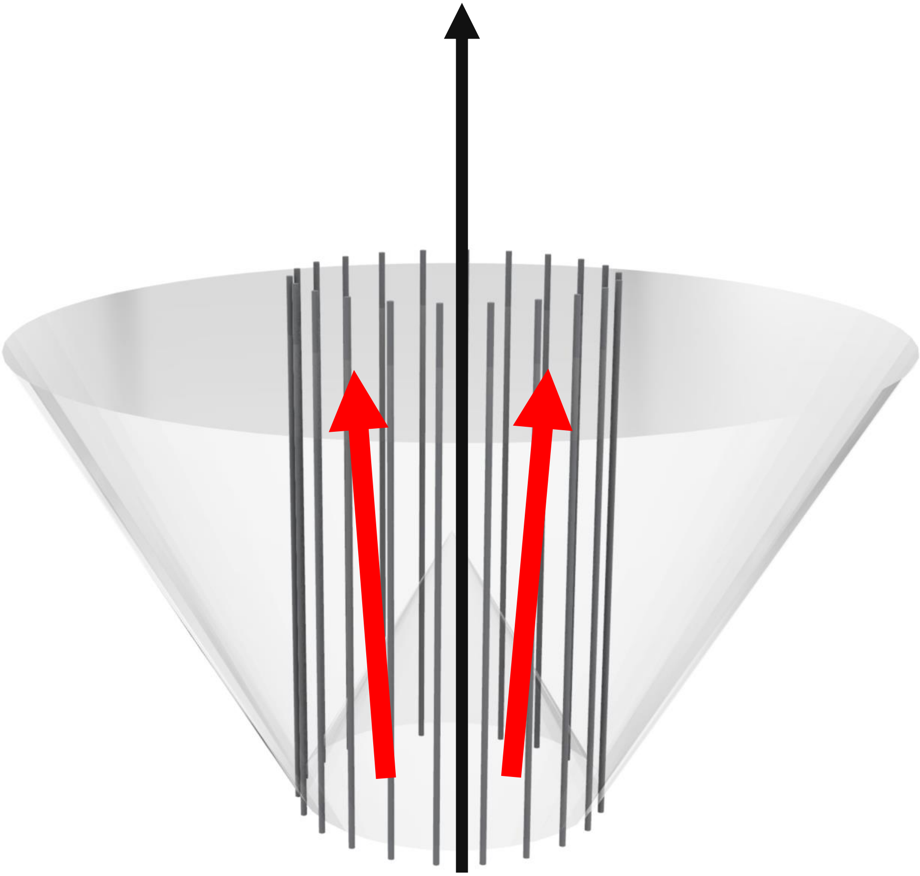
Traditional cone model

- Traditional cone model assumes that the foundation behaves just like it would be embeded in soil
- This is the current design approach

- Not taking account the shear strength of the rock, dilatation nor the high *in situ* stresses in rock mass



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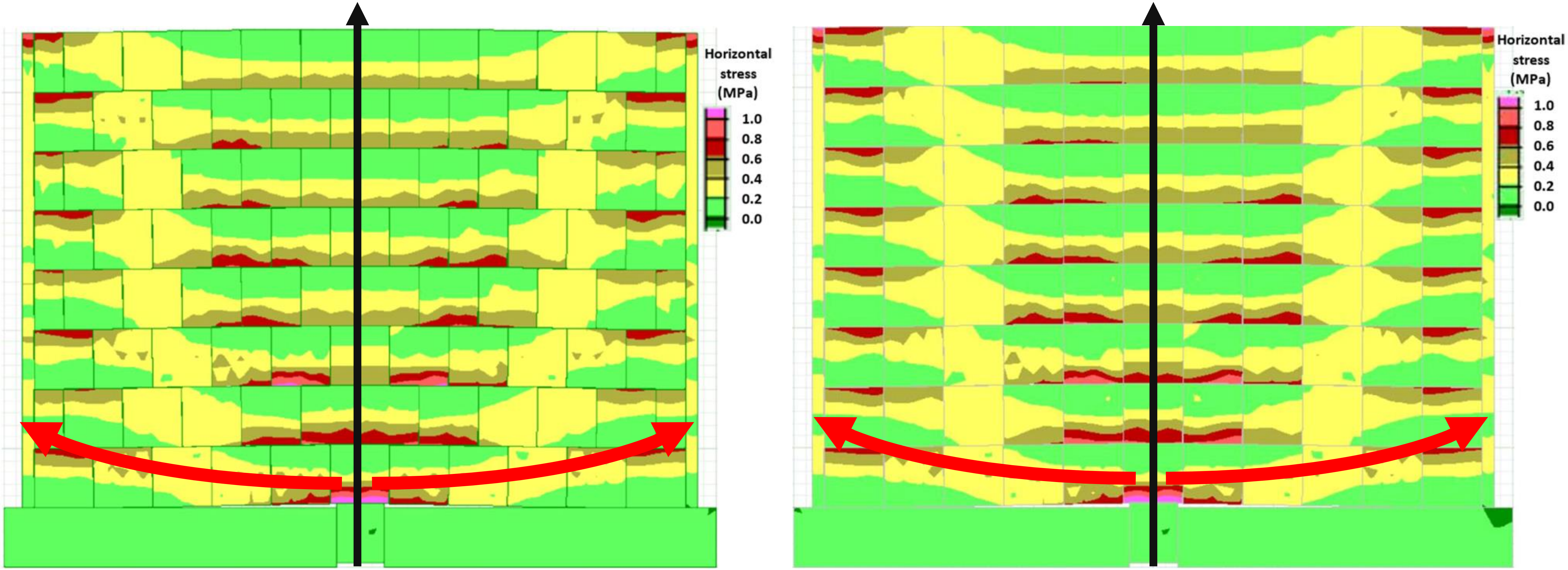
Pressure arch design approach



a) staggered block pattern

b) non-staggered block pattern

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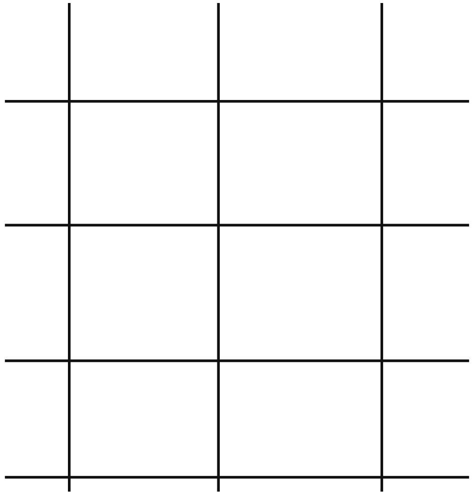
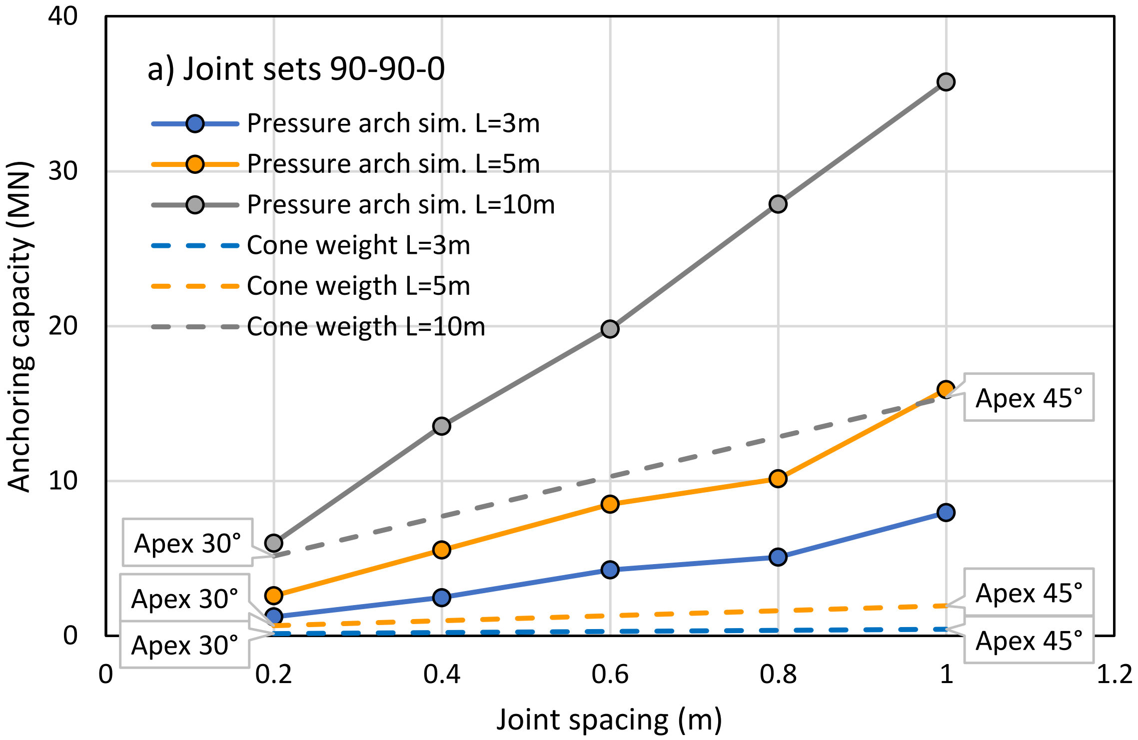
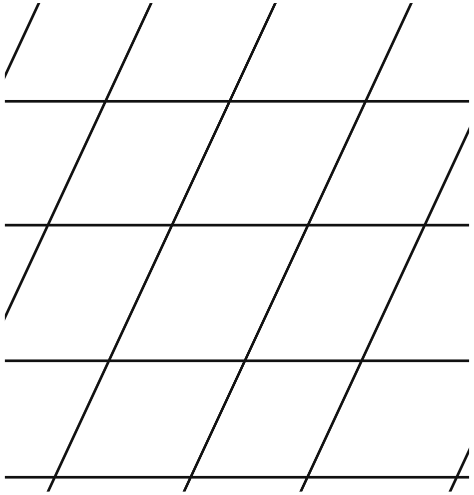
Grindheim, B., Aasbø, K.S., Høien, A.H. *et al.* Small Block Model Tests for the Behaviour of a Blocky Rock Mass Under a Concentrated Rock Anchor Load. *Geotech Geol Eng* 40, 5813–5830 (2022). https://doi.org/10.1007/s10706-022-02251-1

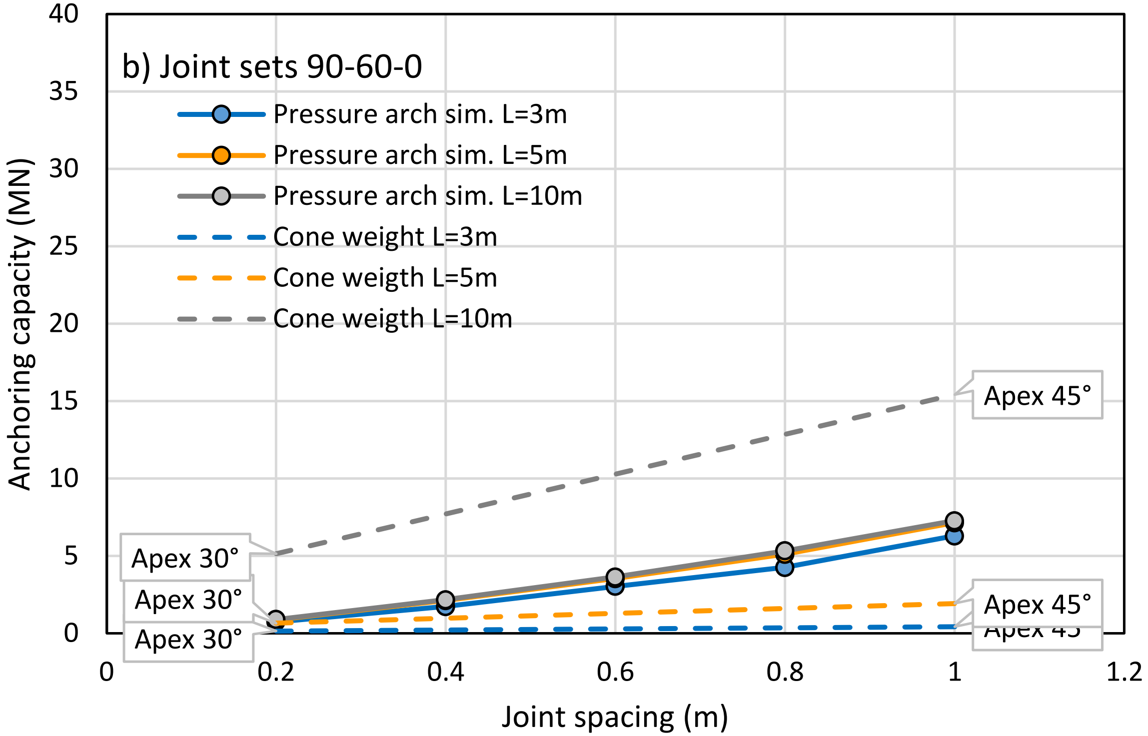
90-90-0 geology





90-60-0 geology





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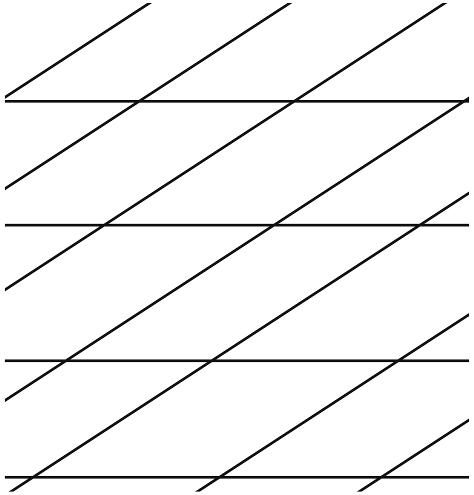
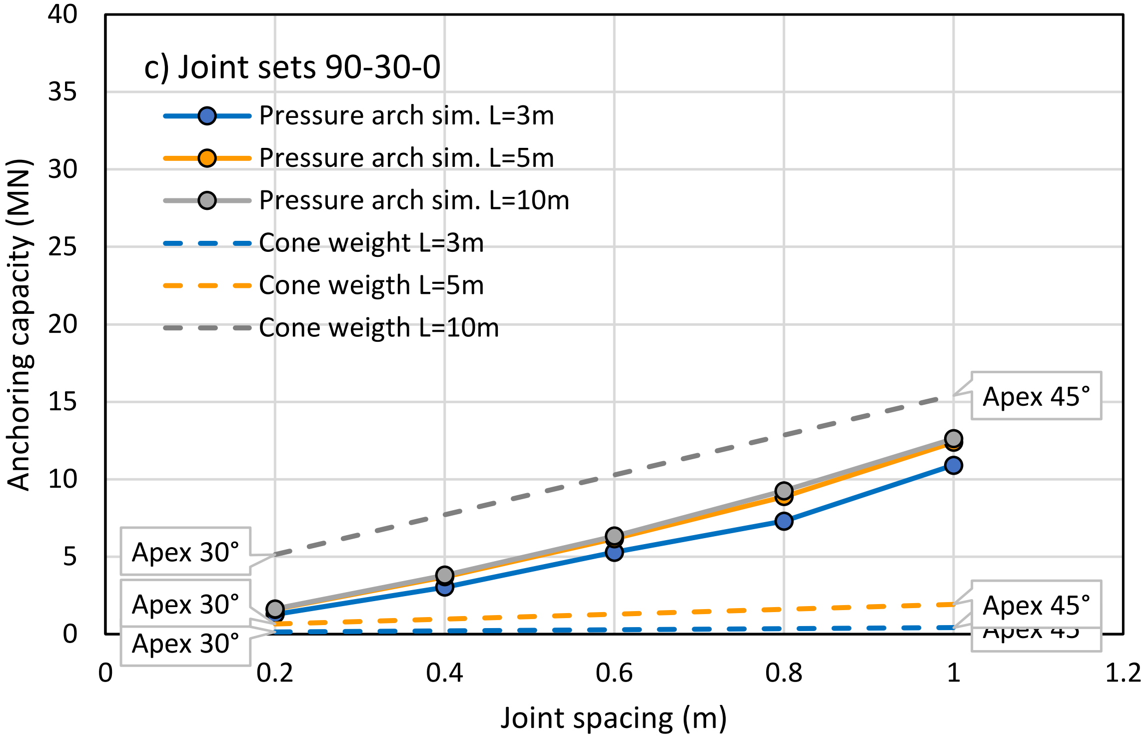
90-30-0 geology





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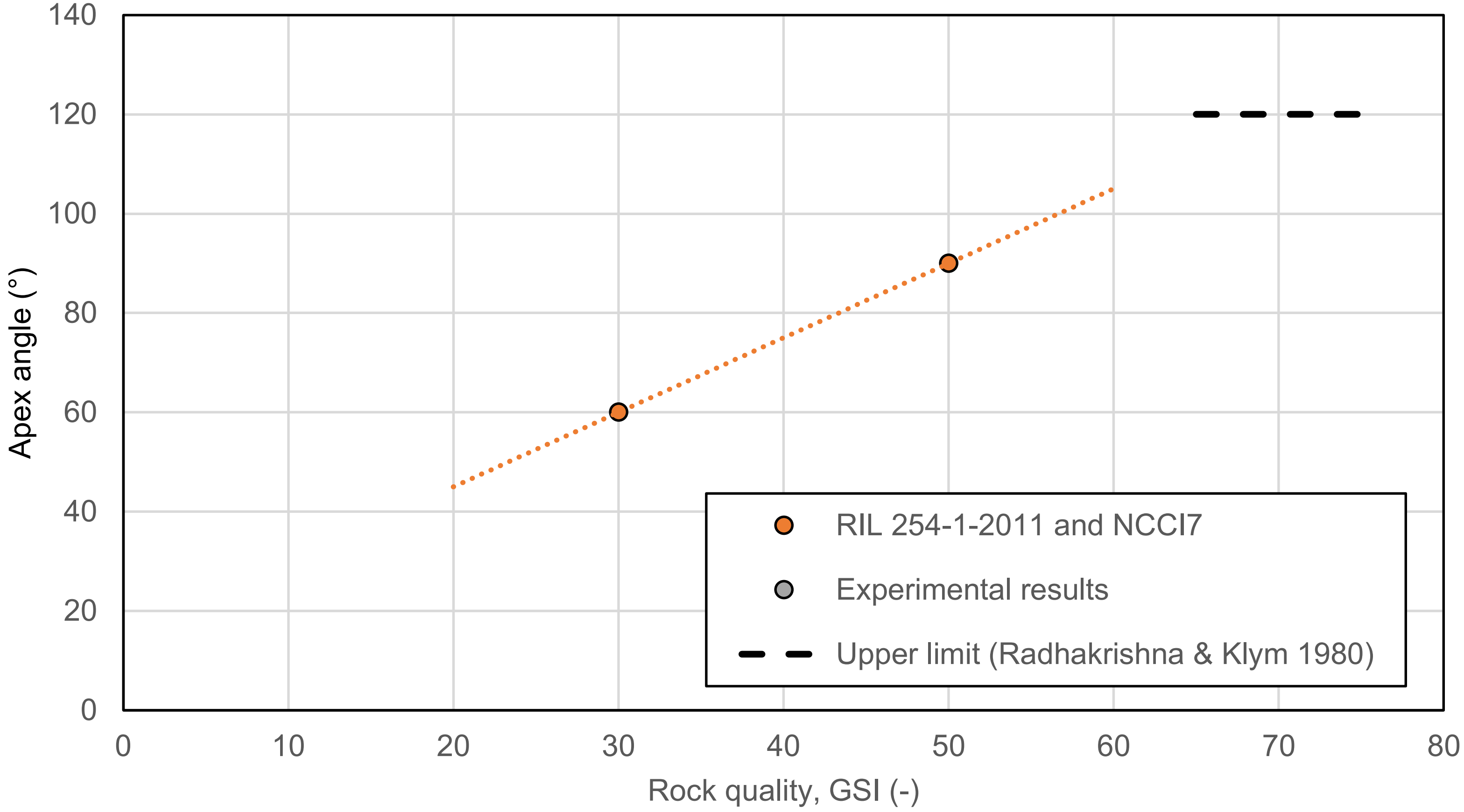
Relationship between Apex angle and rock quality



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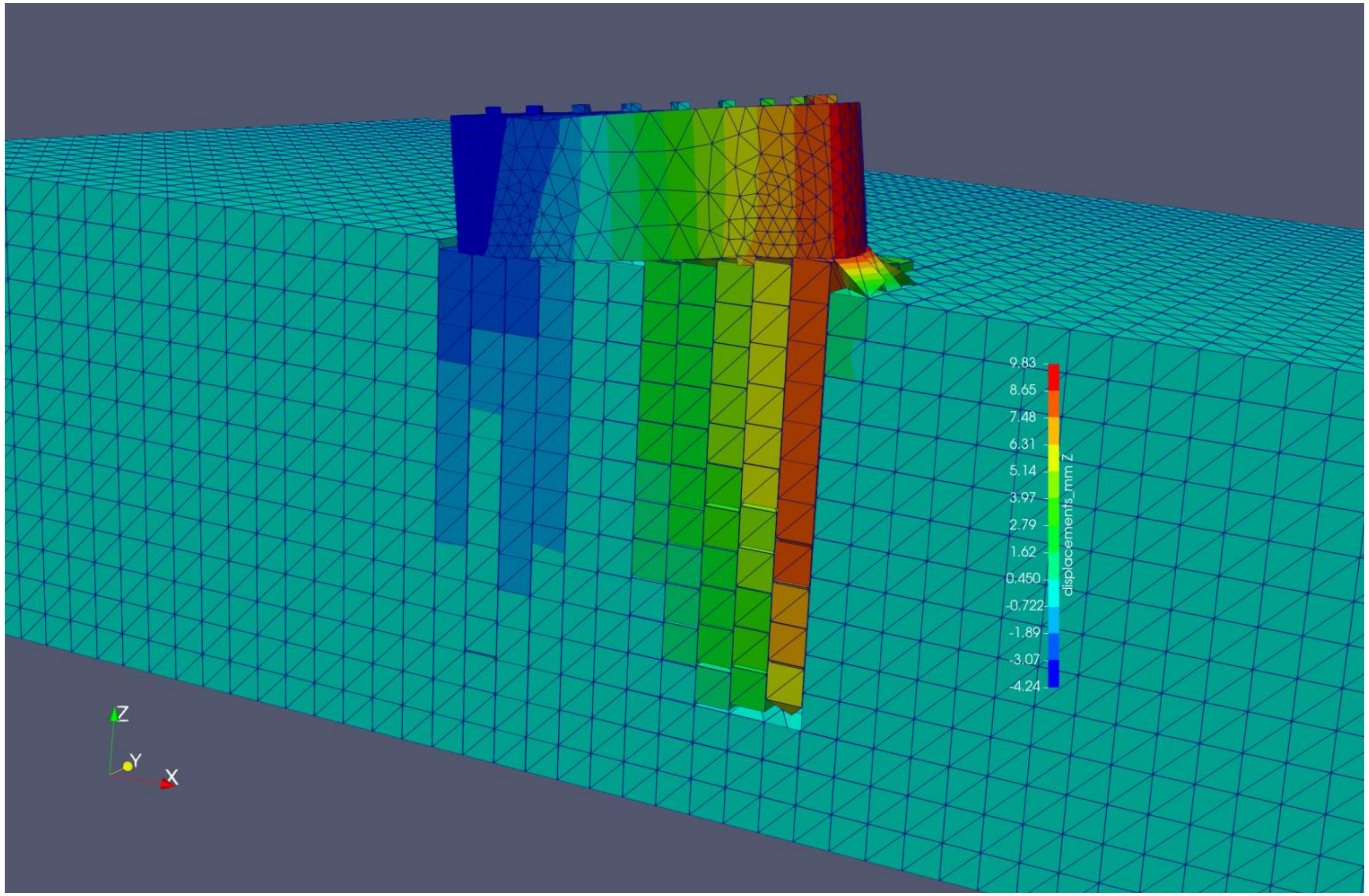
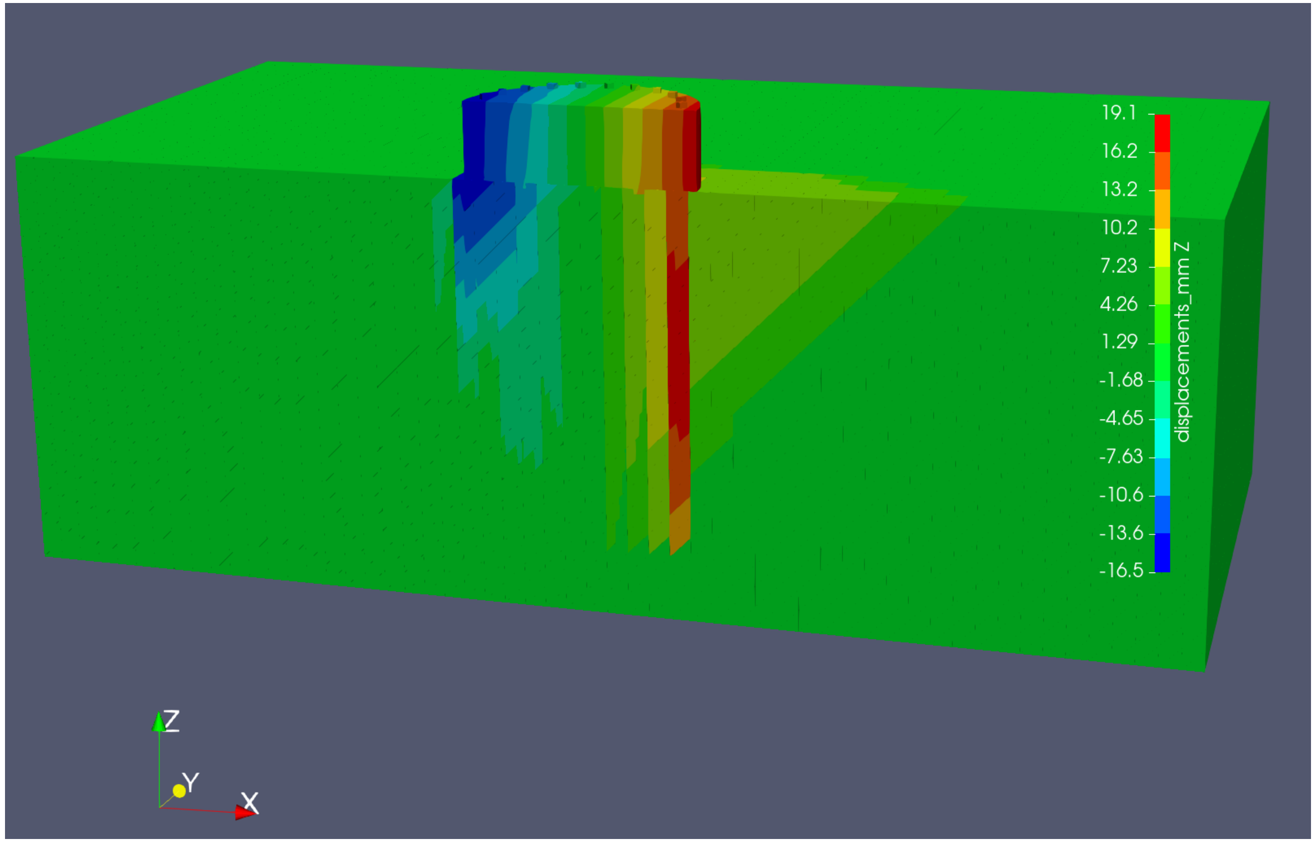
Peikko's in-house solver NL_SMS results



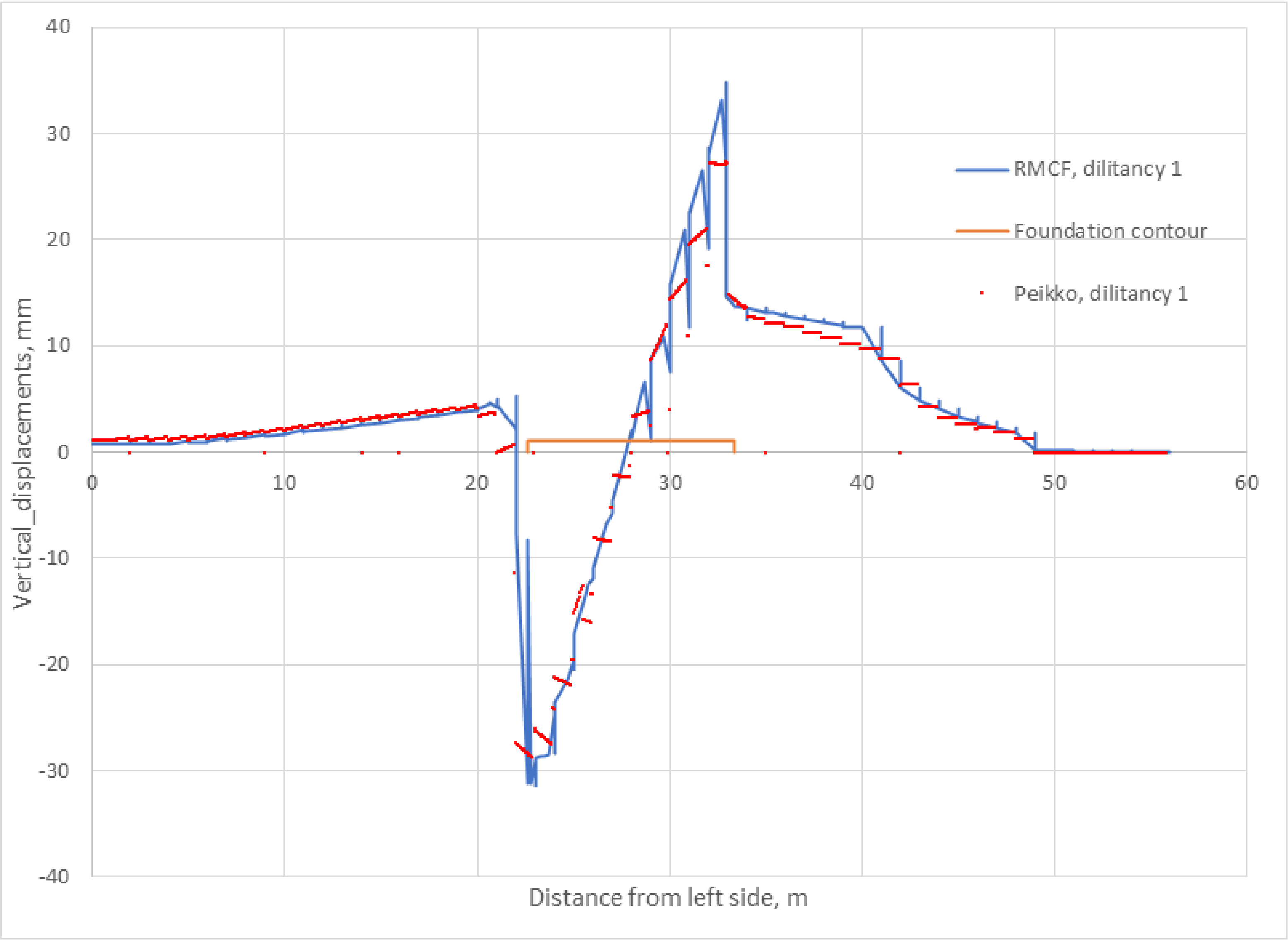
Fully applied deformation loads x100

RMCF 3DEC verification

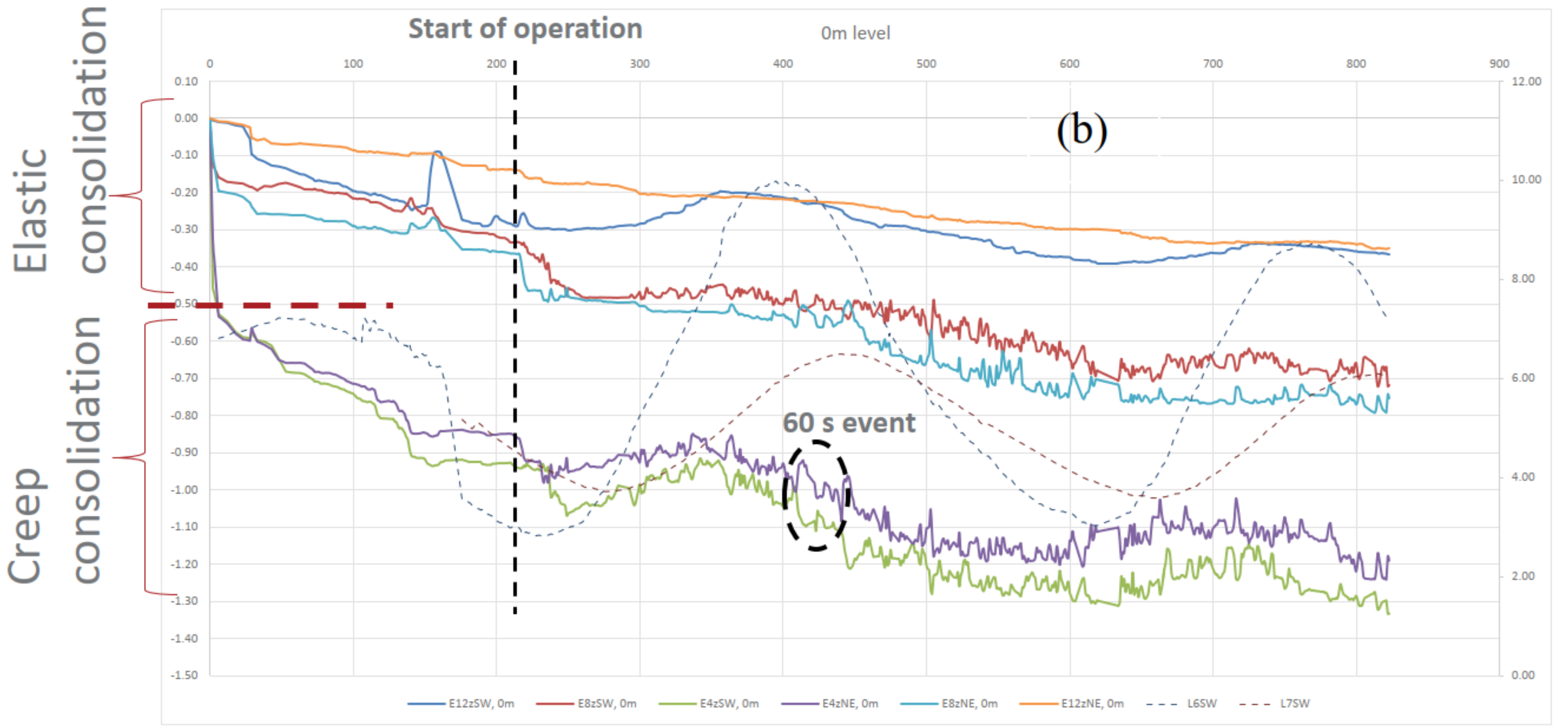


Fully applied deformation loads

Verification



Saarenkylä project extensometer measurements



Conclusions

- Rock Quality has significant impact on anchoring capacity
- The traditional analytical calculation method using a cone is not up to date. A more modern, realistic, and optimized approach involves numerical modelling, which captures the mechanism of action and can predict deformations.
- NL_SMS solver has been used to do numerical modelling also verified by 3DEC by RMCF
- Thorough analysis and modern engineering approaches ensure the sustainable and cost-effective solutions for wind turbine foundations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