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Global stability of rock anchoed wind turbine foundations

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Introduction

- Rock anchored foundations are cost-efficient way for windmill foundations
- This requires a pedant process to ensure smooth and cost-efficient design
- Rock anchored foundations feasible:
  - Rock found near surface
  - Rock quality is at least decent

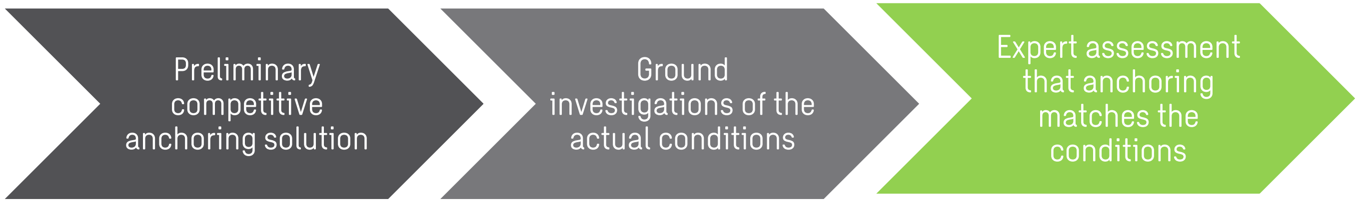
Three things will allow most cost effective solution:

Great products

Great rock (verified by great geologists)

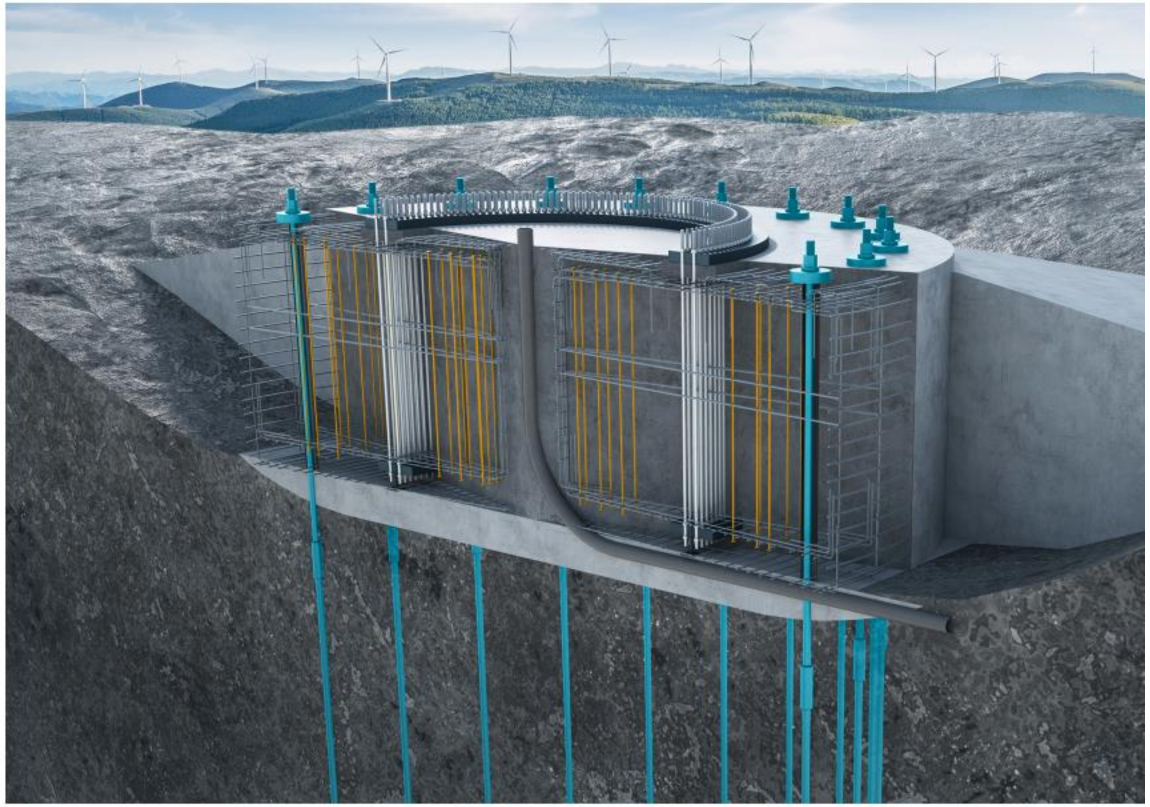
Great design

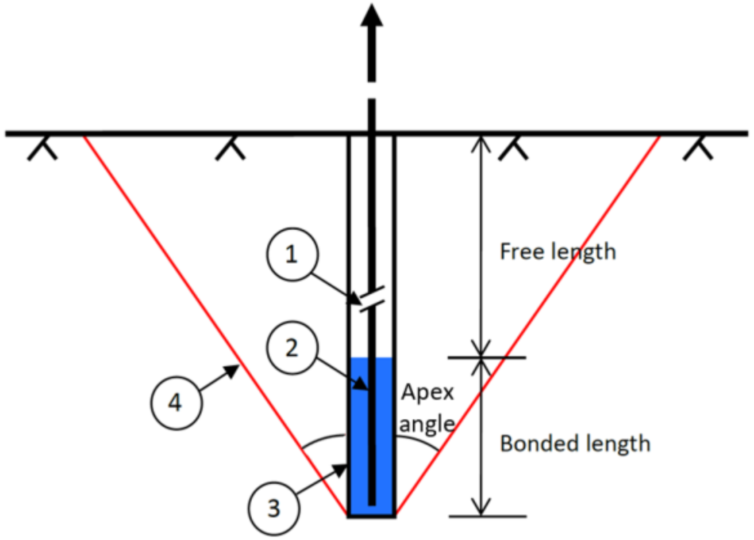
This master thesis will contribute to the cost-efficient design process

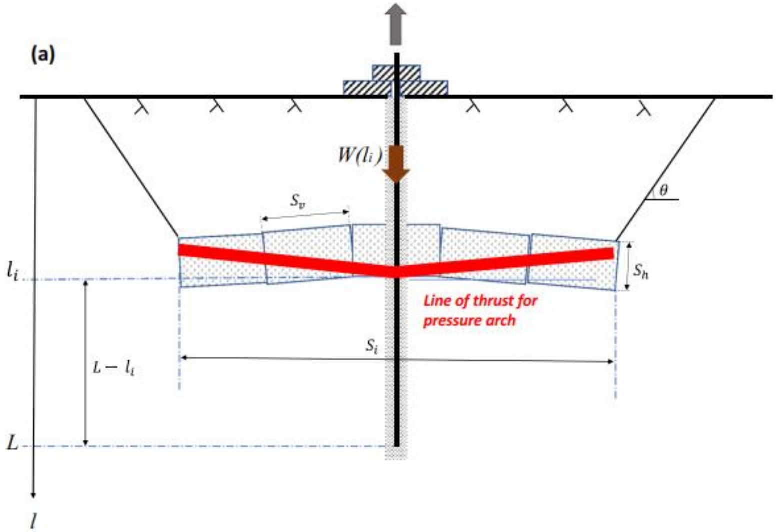


Literature review

- Rock anchored foundations require less concrete
- Most cost effective foundation type when feasible
- Rock block interlocking vs classic approach
  - Interlocking carries more load
  - Classic method conservative and made for single anchors

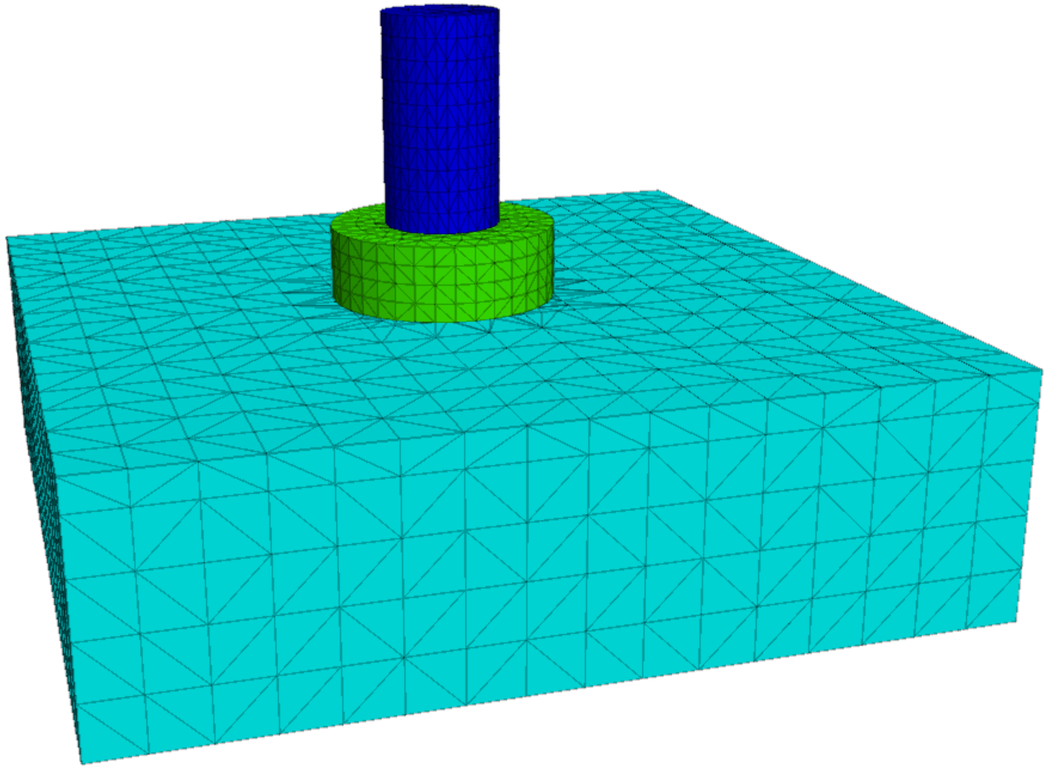






Modelling

- Modelling done by 3DEC 4.10
- Modelling in good quality blocky rock
- Goal:
  - Define the maximum capacity of the foundation by increasing the load until failure
  - Determine overturning point



Modelling assumptions

Rock

Density	Young's modulus	Poisson's ratio	Q'
2700 kg/m3	80 GPa	0.27	10 (Good)

Discontinuities

Normal stiffnes	Shear stiffnes	Friction angle
100 GPa	10 Gpa	30 deg

Concrete

Density	Poissons ratio	Young modulus
2350 kg/m3	0.2	30 GPa

Same modelling parameters used as in Peikko White Paper to produce comparable results.

Anchors were assumed to be Peikko 98mm FATBARs, Length 12 m with 0.5 m over the foundation. Groundwater bouancy is taken into account. Groundwater level at the rock surface.

5

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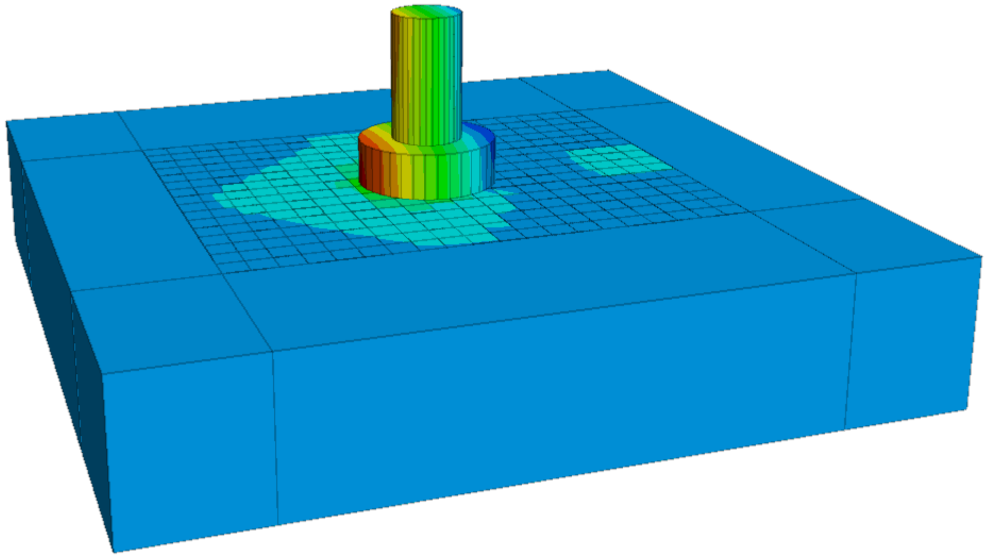
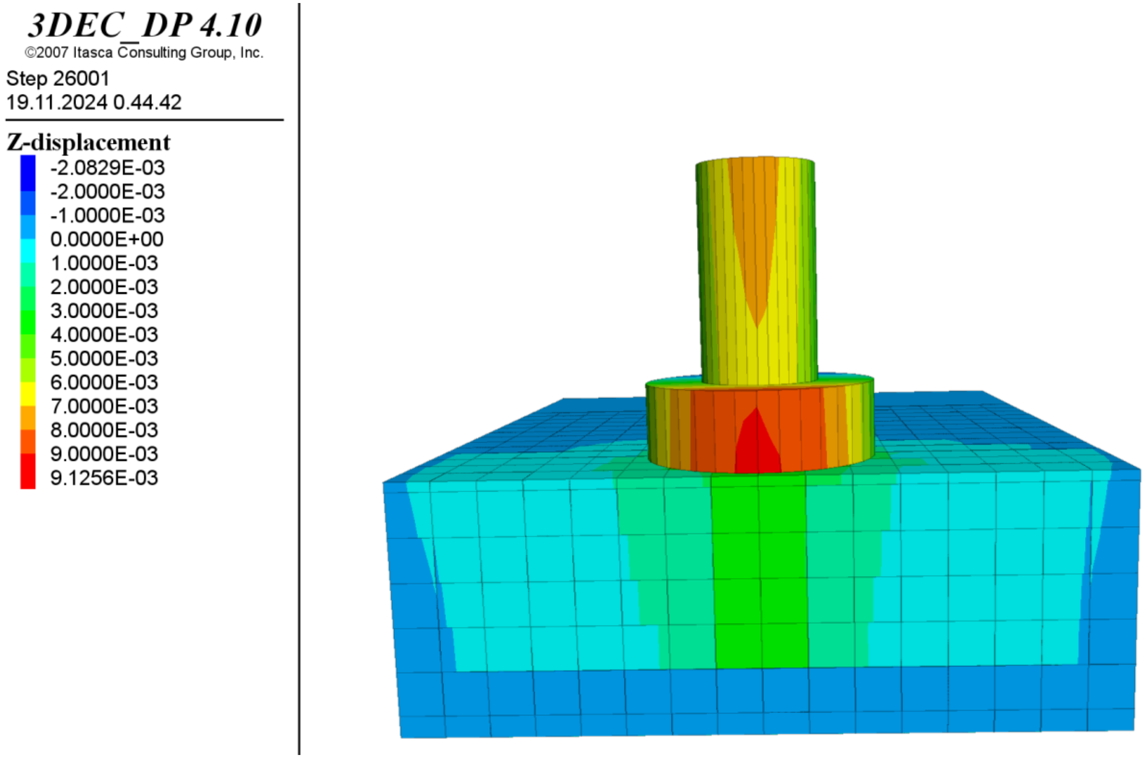
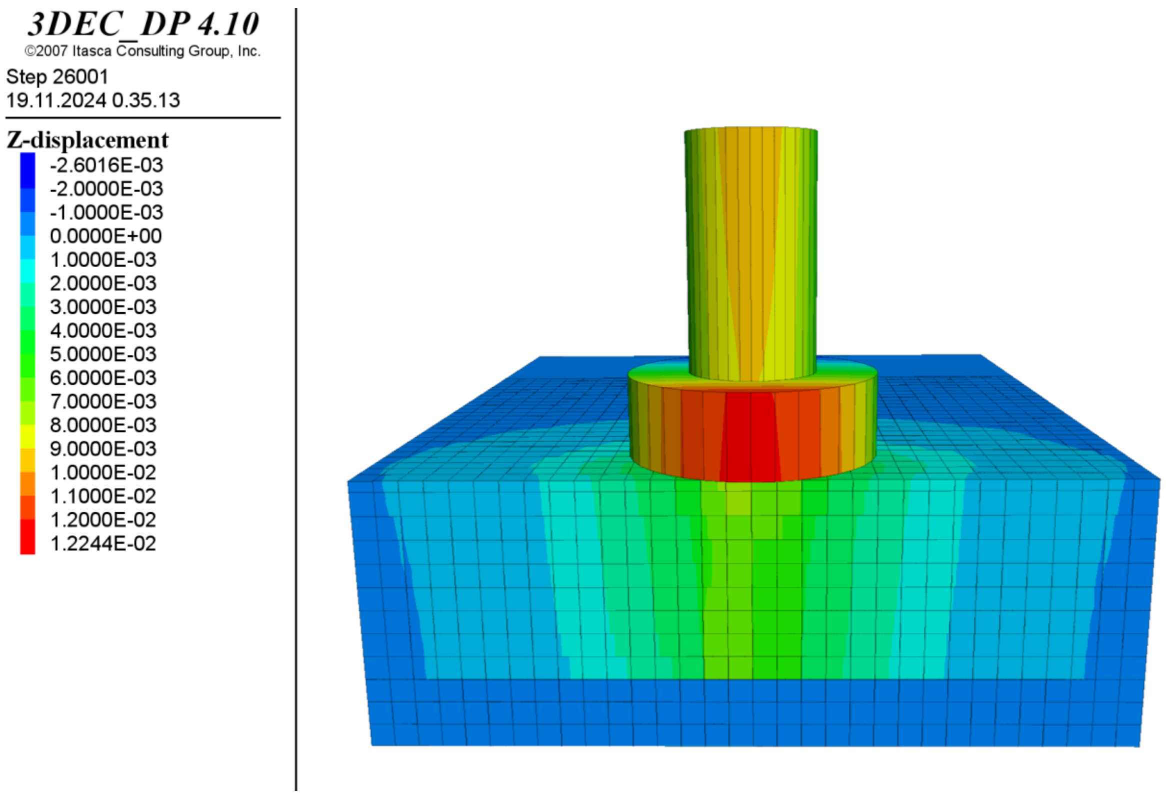
Modelling assumptions

- Orthogonal/cubic jointing of the rock
- Anchors assumed to me fixed to top of the concrete with infinite strength
- Free length assumed to be 4 m
- 20 anchors used
- Pretensioning 4.5 MN per anchor
- Overturning force is applied as horizontal force 40 MN at height of 10 m
- No soil on top of rock to simplify modelling



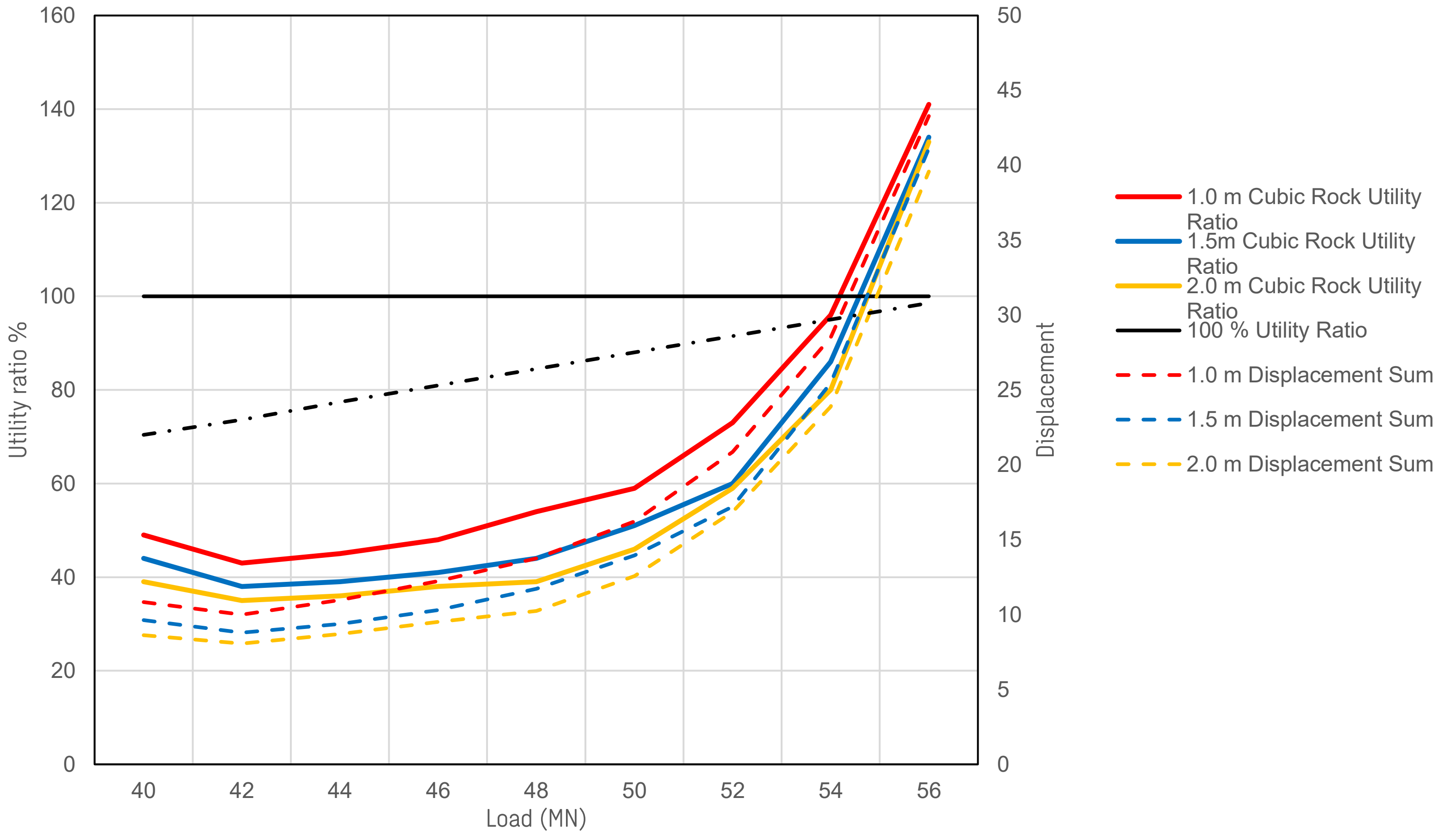
Master thesis – modelling results





Results: Utility ratio

- Depending on the block size the anchoring fails at 53-55 MN loads, 1.325 – 1.375 times the design load of 40 MN
- Calculated using Sweco template on rotational stiffness of foundation from deflections of the turbine shaft.
    - The required rotational stiffness of 100 GNm/rad. This requirement in itself is considered conservative.



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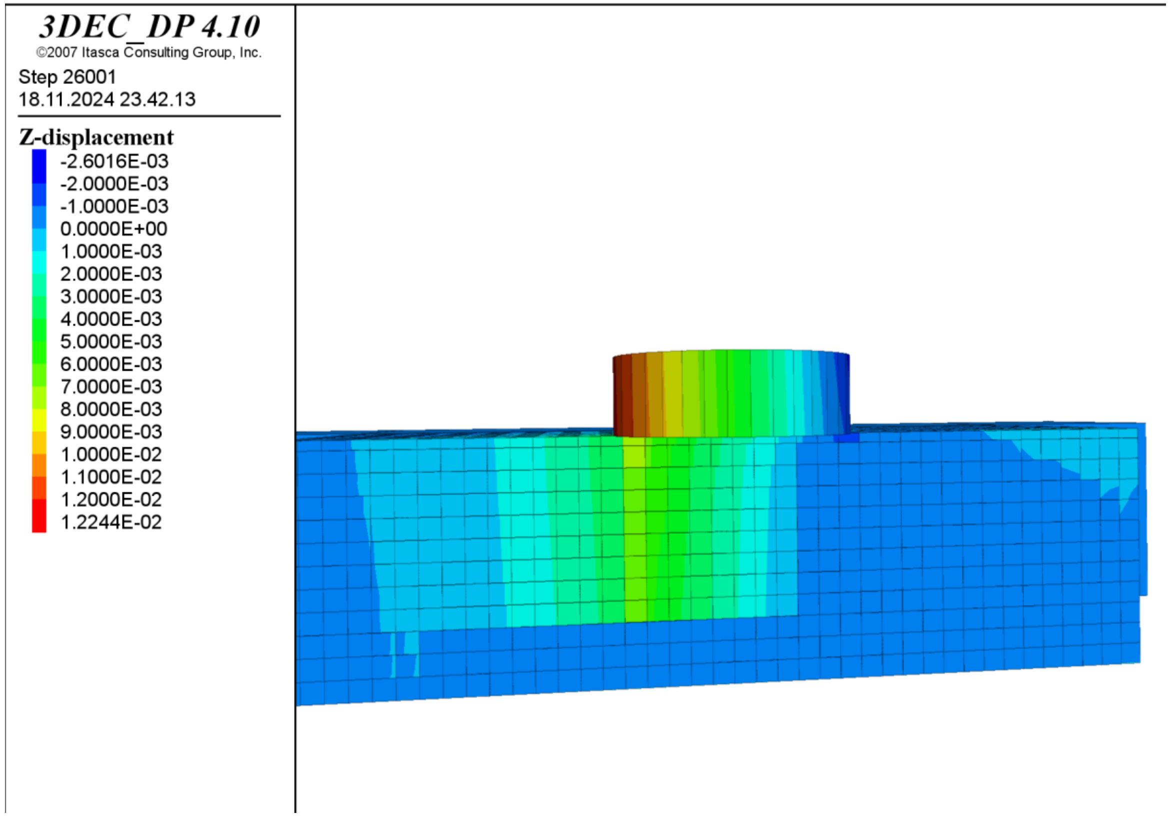
Results:
Utility ratio on different block sizes

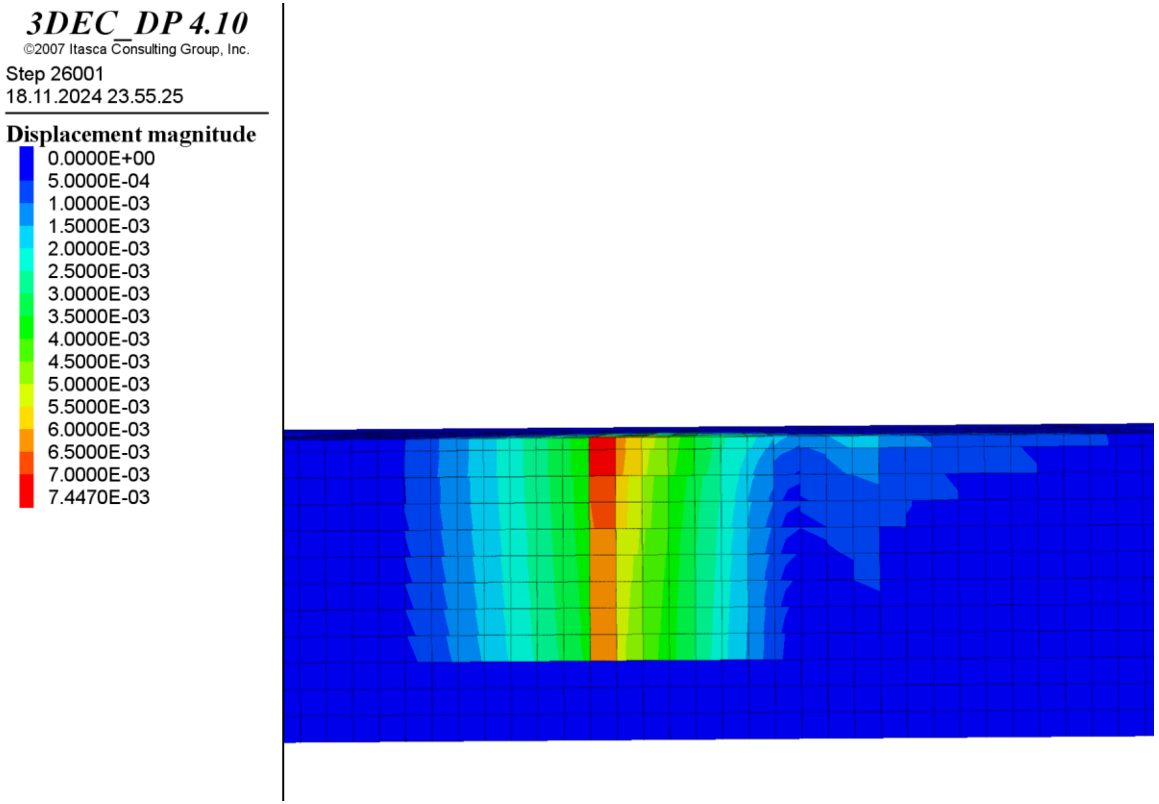
- Global stability was calculated with different block sizes:
- Better quality rock leads to lower utility ratio
  - Could lead to reduced anchoring lengths
- Smaller block sized could be modelled if seen necessary later

		Displacement			
Joint spacing (m)	Load (MN)	uz,max,sls (mm)	uz,min,sls (mm)	Δuz,sls (mm)	Λ, Utility ratio
0.75	40	13.58	-1.128	14.71	67
1	40	9.768	-1.074	10.84	49
1.5	40	8.578	-1.053	9.63	44
2	40	7.595	-1.024	8.62	39

Results:
Overturning point

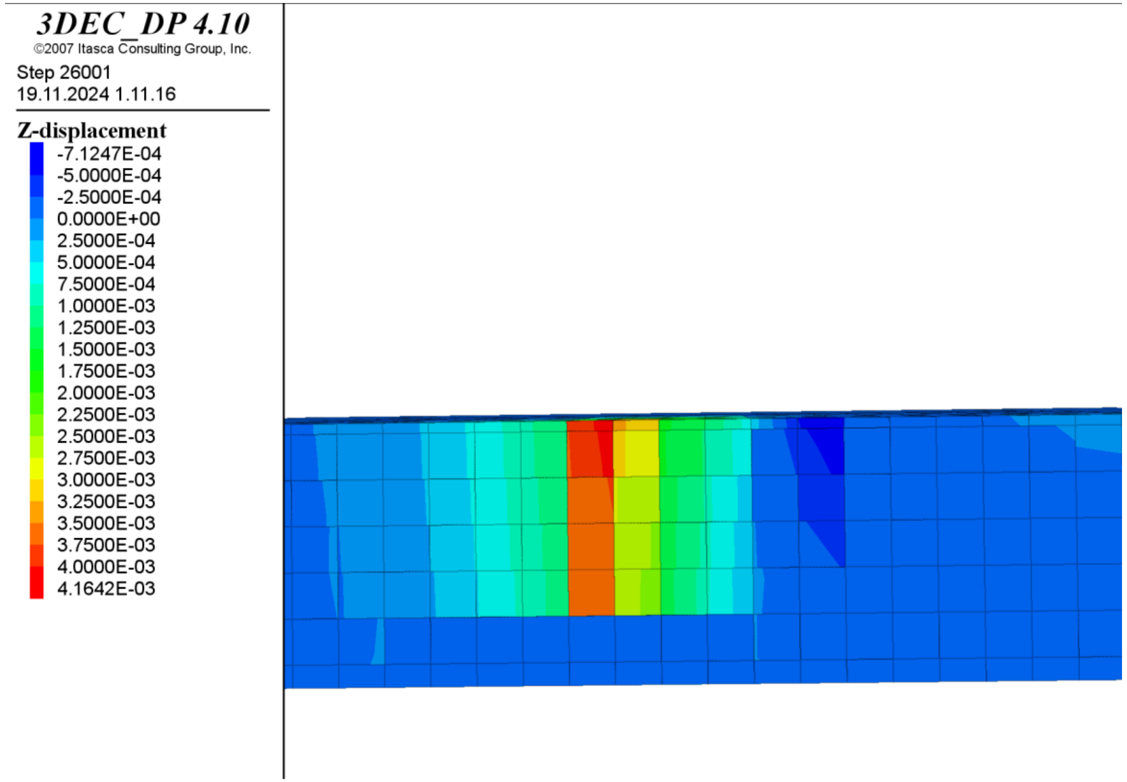


Overturing point 40MN load 1m jointing, about (3,0,-12)

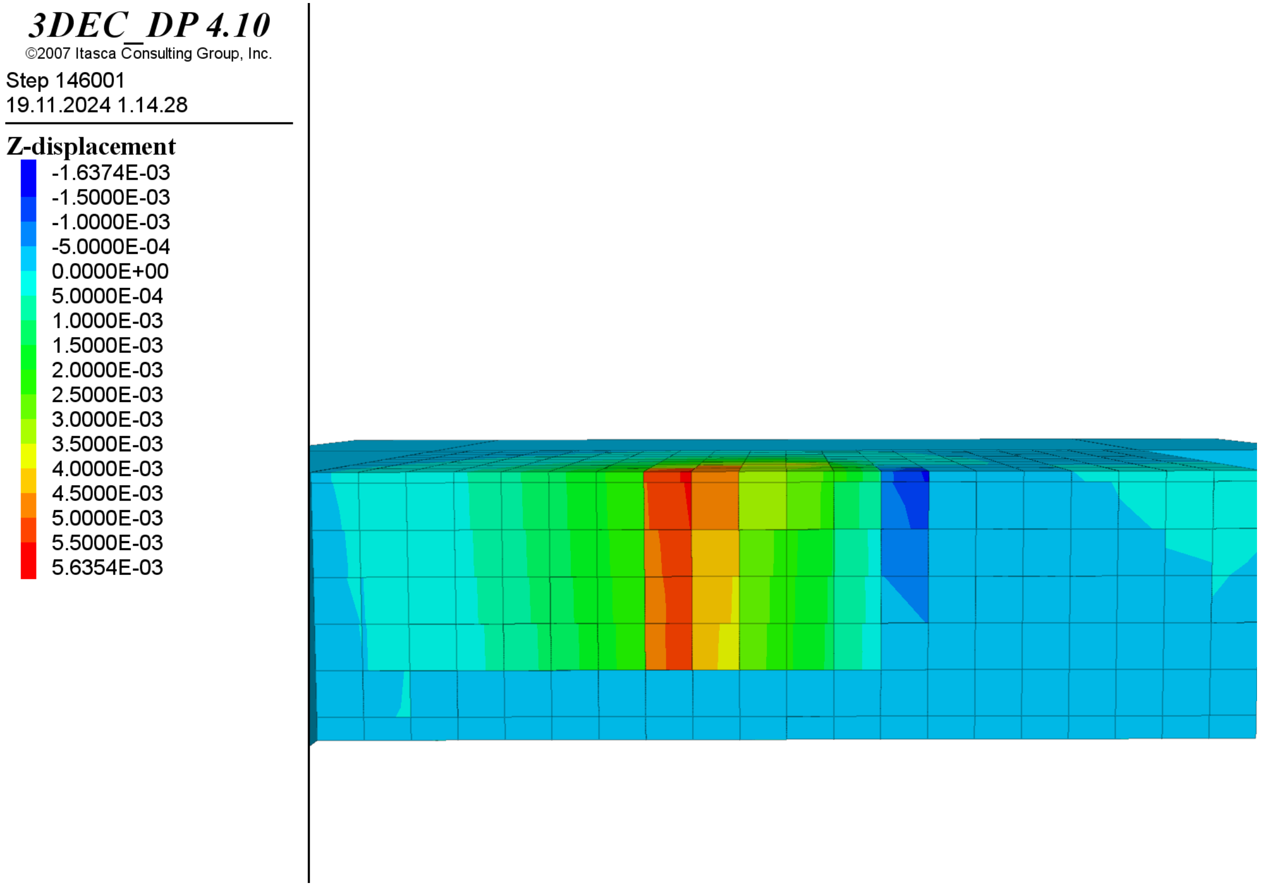


Overturing point 40MN load 1m jointing, about (3,0,-12)

Results:
Overturning Point



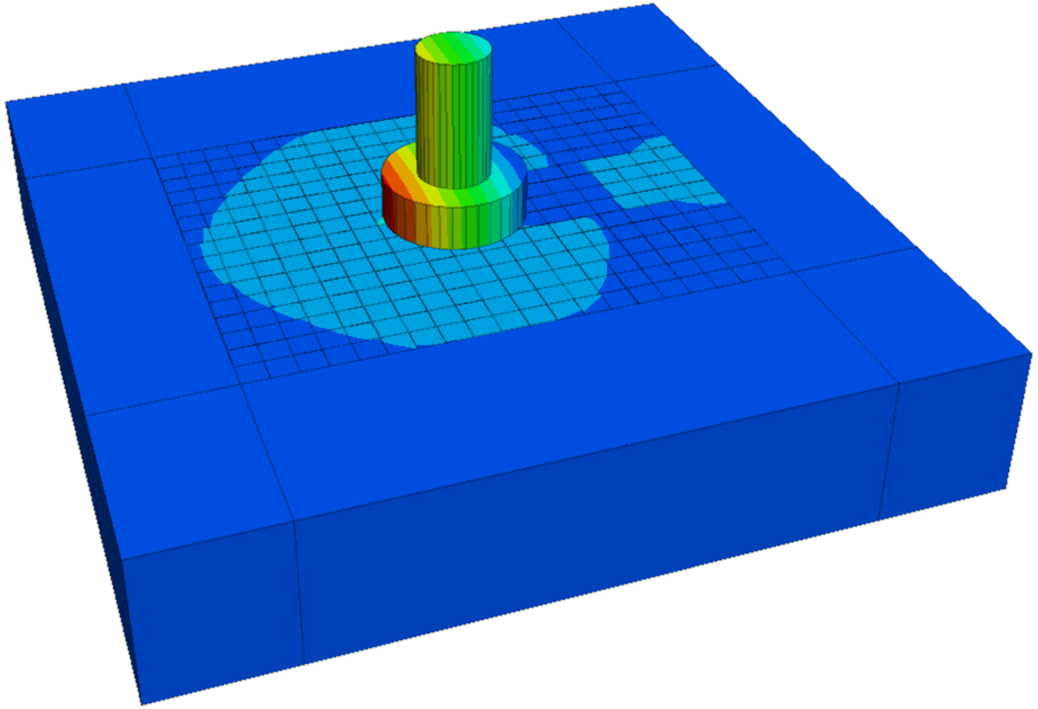
40 MN, 2.0m orthogonal jointing OTP: (2.0.-12)



56MN, 2.0m orthogonal jointing OTP: (4,0,-12)

Conclusions

- Overturning point changes depending on the load
  - In X-Y plane, it is inside the concrete foundation, z point difficult to interpret
- Rock Quality has significant impact on anchoring capacity
- Better quality leads to lower utility ratio
  - More research needed about shorter anchors, would they be enough
- There is oversafety in current design methods
  - Hypothesis was that they would have even higher FOS

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