Laboratory block model tests simulating rock anchoring in rock mass

EUROCK 2022

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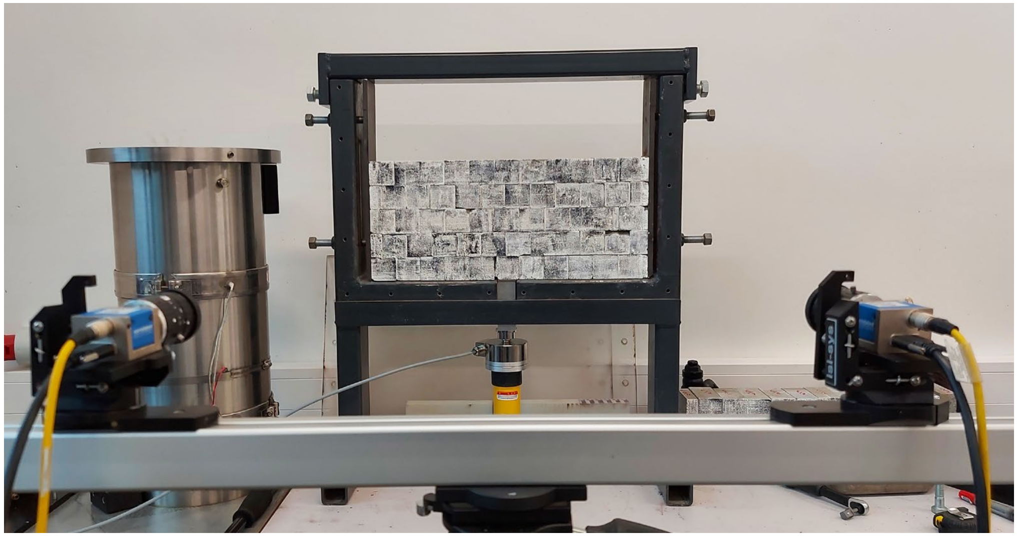
Contents



Background

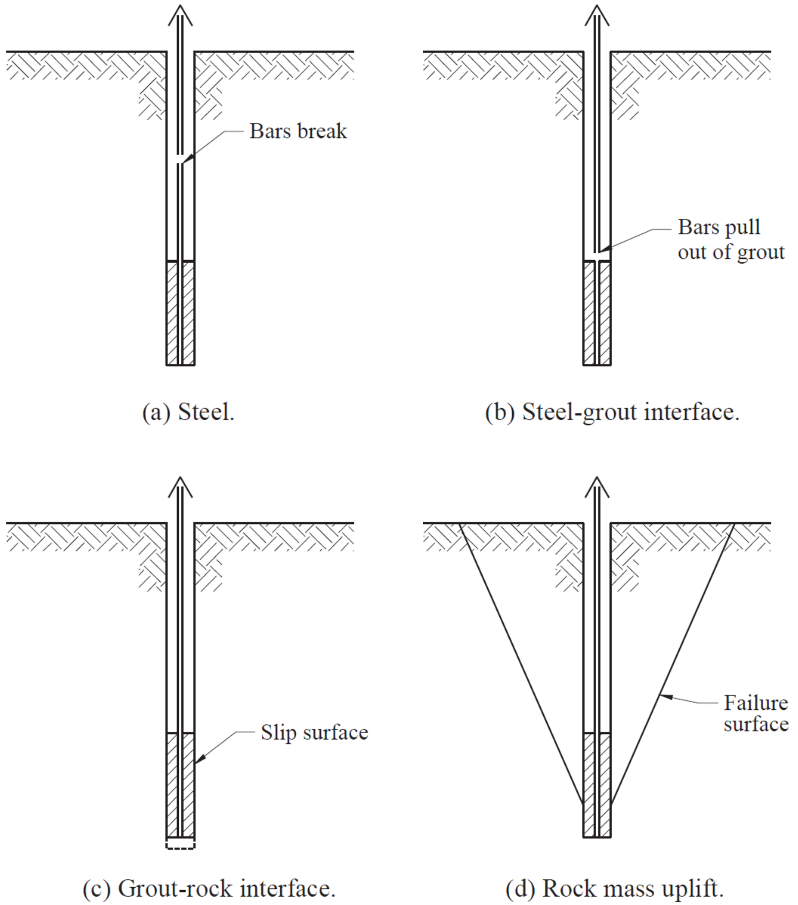
- Rock anchors are used as load carrying elements for large scale infrastructures.
- A review of rock anchors by Brown (2015) concluded that the design is based upon simplified assumptions of the stress distribution and it is excessively conservative.

(Li, 2020)

(Li, 2020)

Failure Modes of Rock Anchors

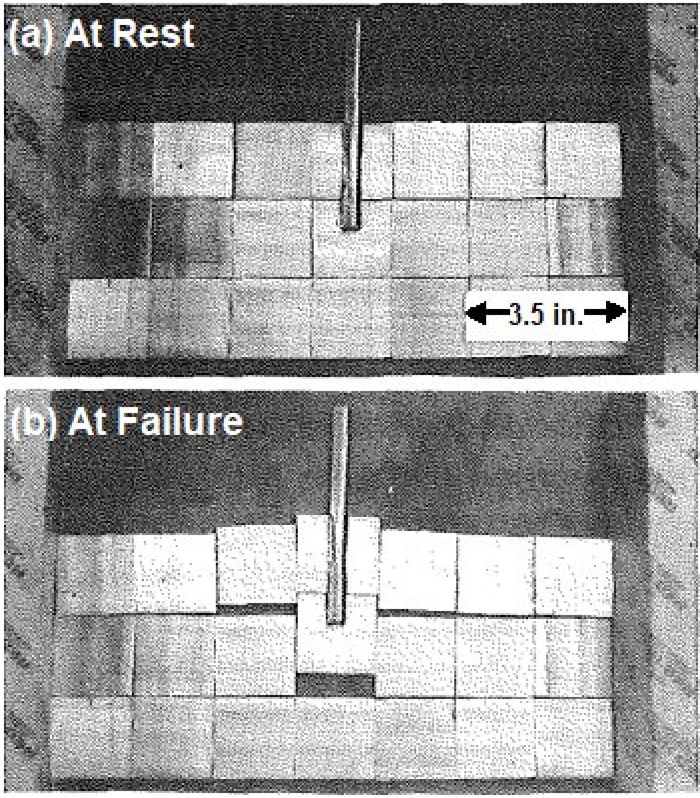
- 4 principal failure modes described in literature.
  a) Steel tendon tensile failure.
  b) Tendon-grout bond or interface failure.
  c) Grout-rock bond or interface failure.
  d) Rock mass uplift failure.



(Brown, 2015)

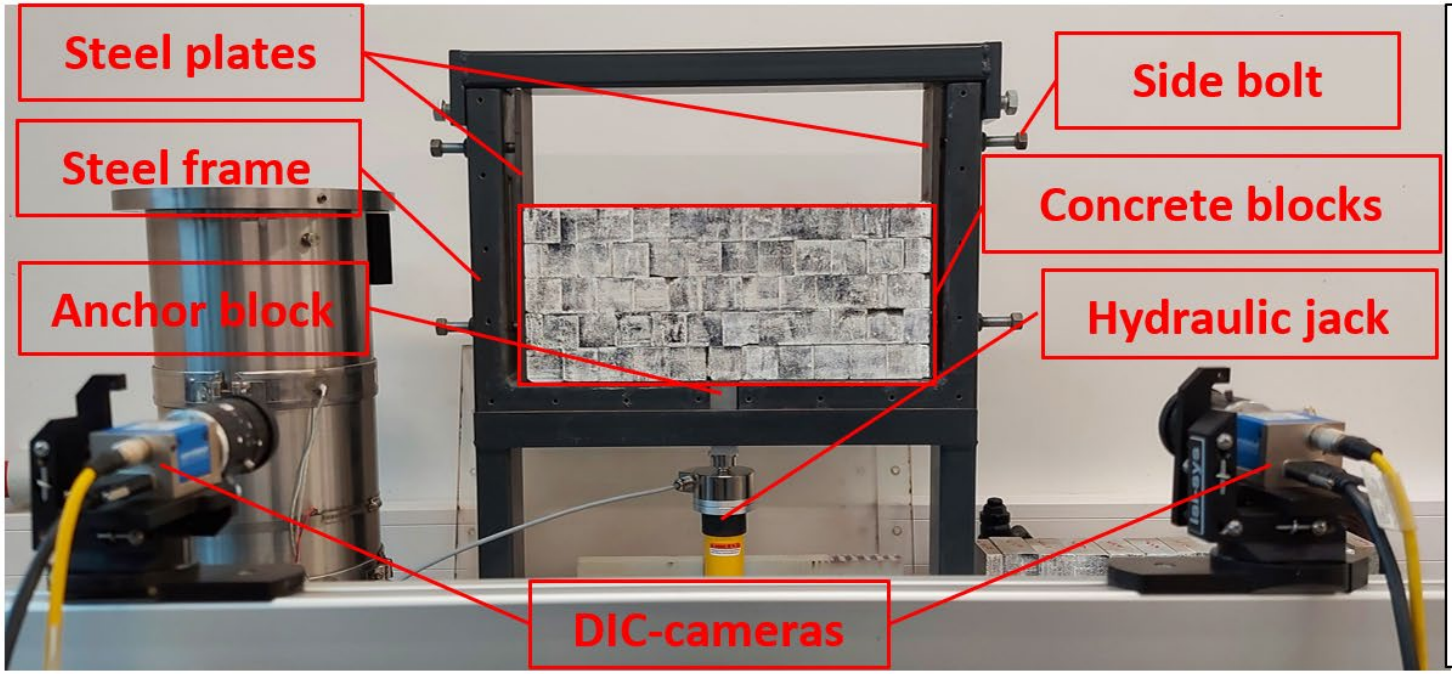
Laboratory Tests from Literature

- Most laboratory tests have been pullout test, which have tested failure modes b) tendon-grout bond failure and c) grout-rock bond failure.
- The most similar test to our was run by Dados (1984). Dados did pullout of an anchor in a small block model consisting of aluminium cubes.
    - The tests showed that the blocks starts to bulge upwards, and that tensional cracks develop between the horizontal layers.



(Dados, 1984)

Laboratory Setup



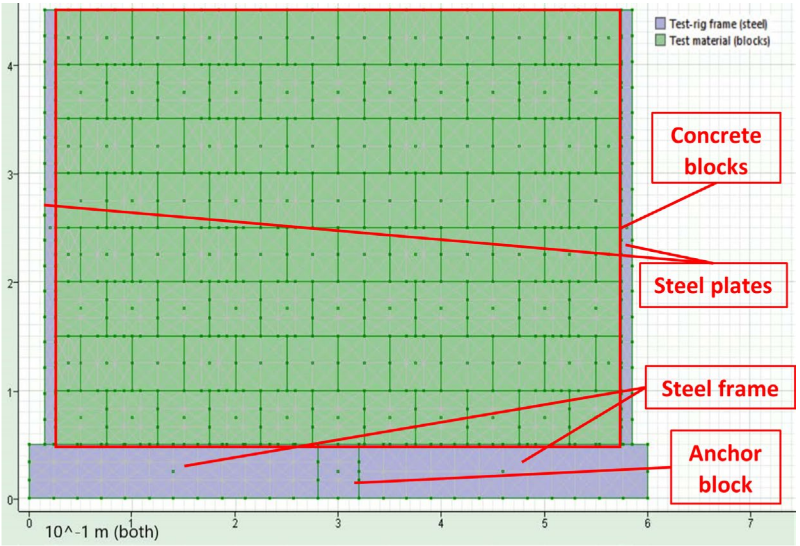
Test procedure:

1. Placement of blocks.
2. Apply confinement by tightening side bolts.
3. Start DIC capturing.
4. Apply load with hydraulic jack.
5. Stop loading when a desired load was reached or failure.
6. Stop DIC capturing.

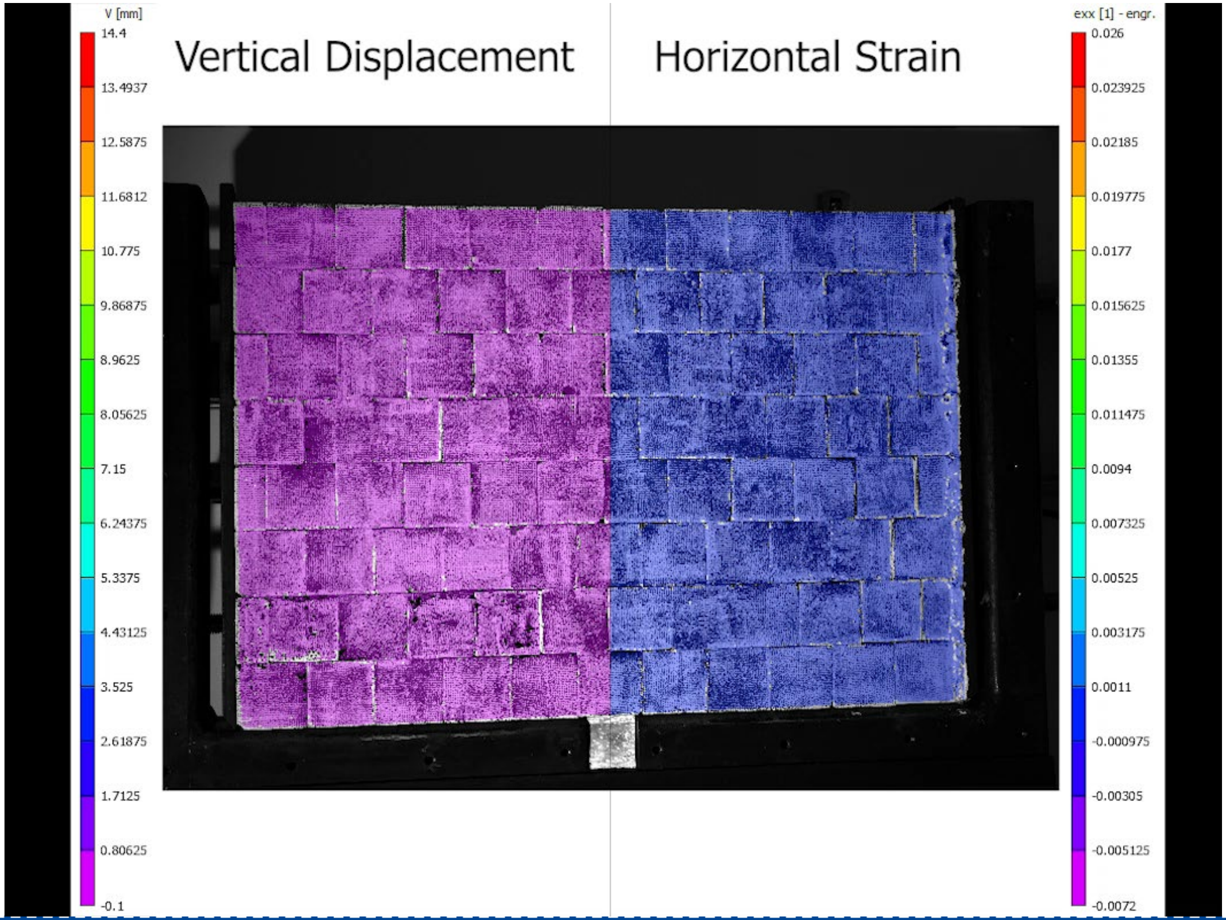
Numerical Model

- Same dimensions as the physical block model.
- Material parameters found from testing of the concrete material and in literature for the steel materials.
- The joint stiffness was found through trial and error by calibrating the model against the test results of the tests with 8 layers.

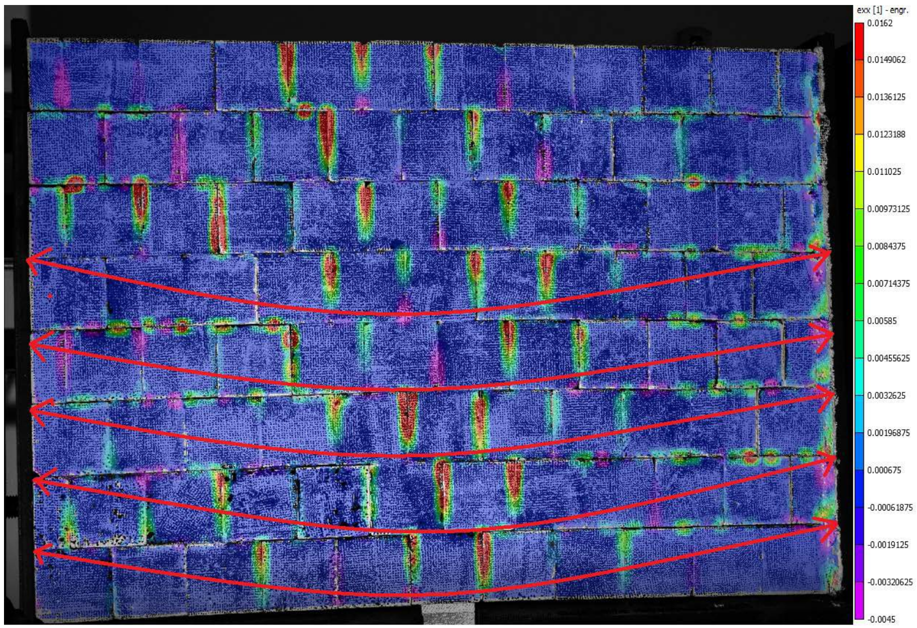
Material	Parameter	Value	Unit
Concrete block material (Mohr-Coulomb)	Density	2300	kg/m^3
	Young's modulus	27.7	GPa
	Poisson's ratio	0.25	
	Friction angle	34	Degrees
	Cohesion	11.2	MPa
Steel frame and anchor block (elastic)	Density	7930	kg/m^3
	Young's modulus	190	GPa
	Poisson's ratio	0.303	

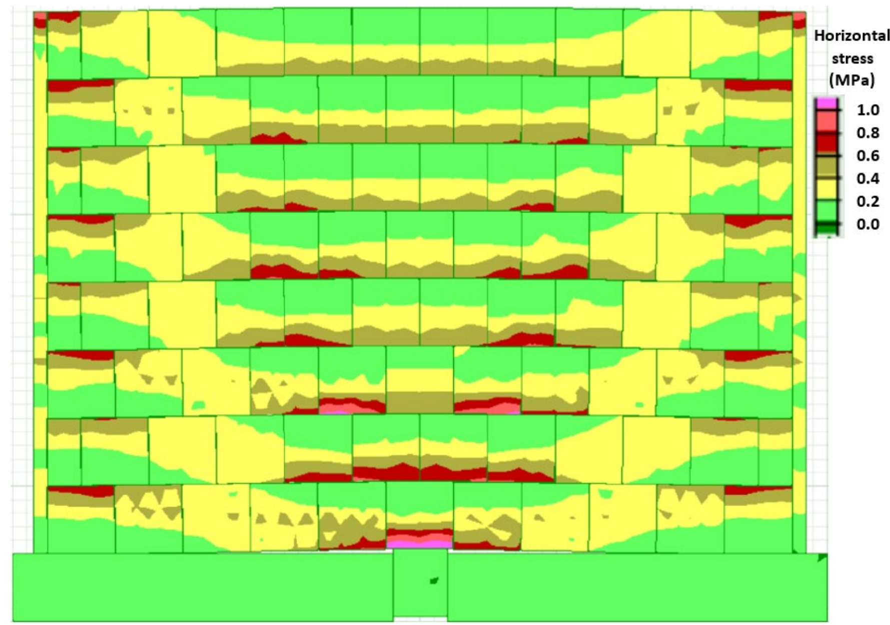


Video from the DIC Software from a Test Loading the Small Block Model



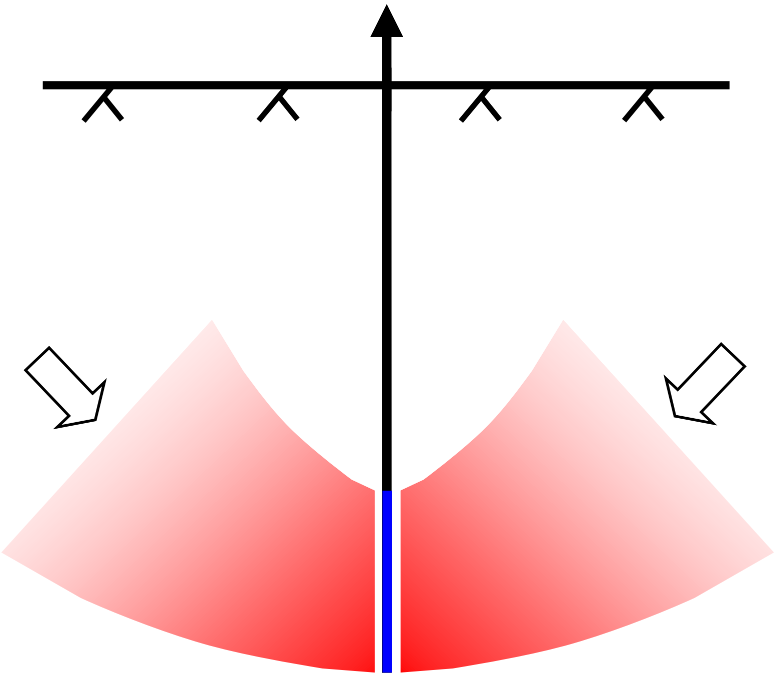
Load Bearing Arch





Load Bearing Arch

- When a rock anchor pulls on the rock mass, it changes both the deformation and stresses in the rock mass.
- The axial displacement leads to rotations of the blocks in the rock mass and a so called load bearing arch is formed in the surrounding rock mass.



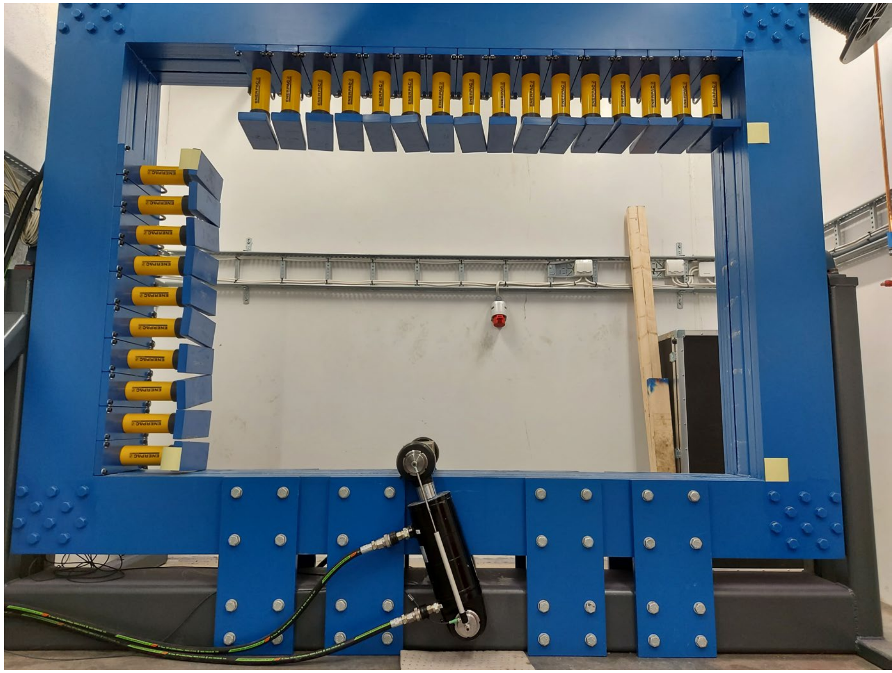
Load arch surrounding the anchor

Failure of Block Model

- Shape of an inverted cone.
- Applied confinement of 2.5 Nm to each bolt on the test frame.
- Highest load 9.71 kN at 14.1 mm displacement.
- Failed abruptly at 38.2 mm displacement.
- Estimated capacity based upon weight of overlying rock was 0.094 kN.
  - 100 times less than the test.

Further Research

- More research is needed to evaluate the load arch capacity and how the arch develops in other joint patterns.
- The confinement should be more controlled and the horizontal stresses should be measured to evaluate the capacity of the load arch.
- These results will be used in the development of a larger test rig.



Conclusions

- The current design against rock mass uplift failure around rock anchors is conservative.
- The load capacity of a small scale block model was over a 100 times higher than what was calculated with the weight of overlying rock design principle.
- Load arches were formed in each block layer which transferred the load to the boundaries of the model and increased the capacity.
- These tests have increased the knowledge on how load is transferred from a rock anchor to a blocky mass.

References

- Brown ET (2015) Rock engineering design of post-tensioned anchors for dams – a review. Journal of Rock Mechanics and Geotechnical Engineering 7(1):1-13, DOI https://doi.org/10.1016/j.jrmge.2014.08.001.
- Dados AT (1984) Design of anchors in horizontally jointed rocks. Journal of Geotechnical Engineering 110(11):1637-1647, DOI https://doi.org/10.1061/(ASCE)0733-9410(1984)110:11(1637).
- Li CC (2020) Rocarc - rock anchoring for stabilization of infrastructures. NTNU [Online], URL https://www.ntnu.edu/igp/rocarc.

Thank you, it was a pleasure to hold this presentation!