A novel oedometer capable of full stress-path recording to aid in pile design in chalk

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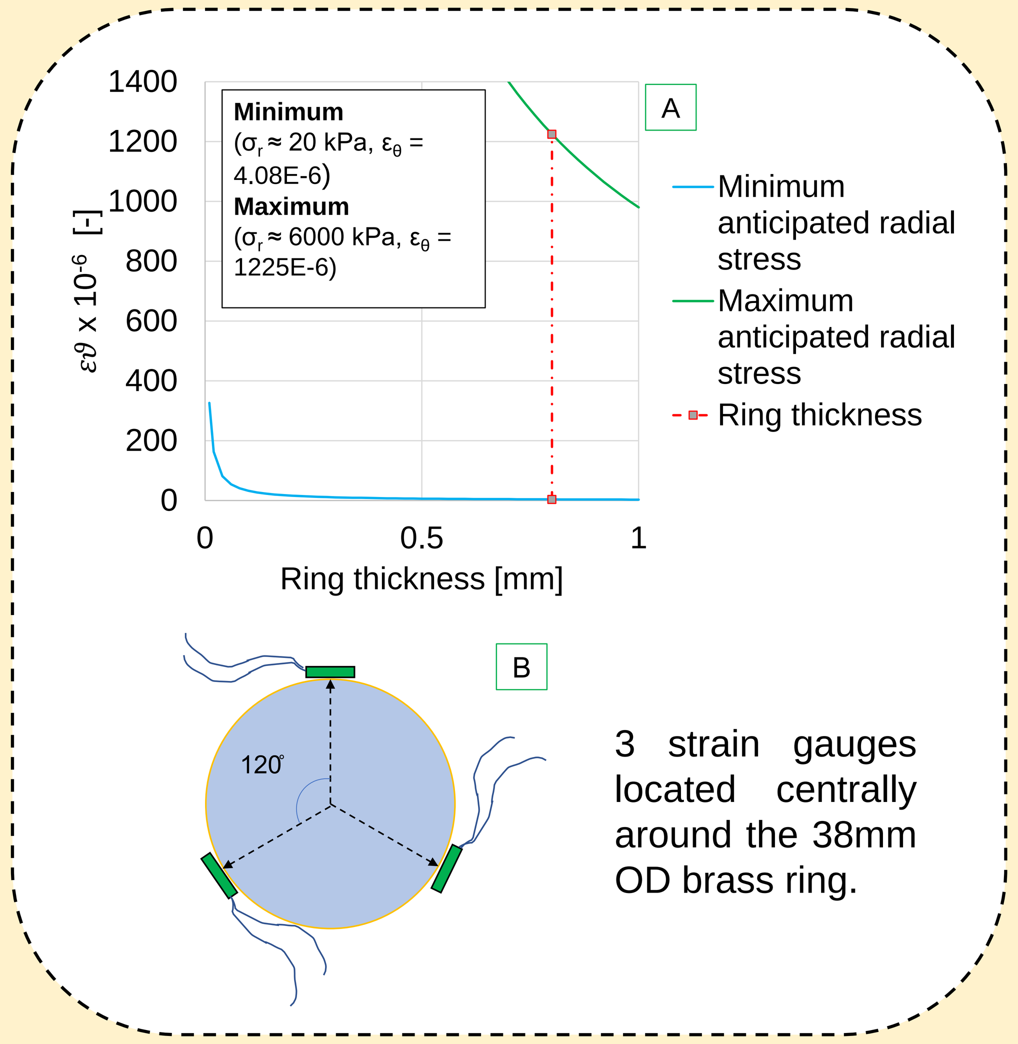
An alternative tool to the traditional oedometer is presented coined the "soft oedometer" which can perform $1D - k_0$ consolidation tests. Design, calibration and preliminary data on soft chalk are shown. After, a note on its application and finally a brief discussion on the challenges associated with $k_0 = \sigma_r/\sigma_a$ derivation for pile design in weak/soft rock.

Design of soft oedometer ①

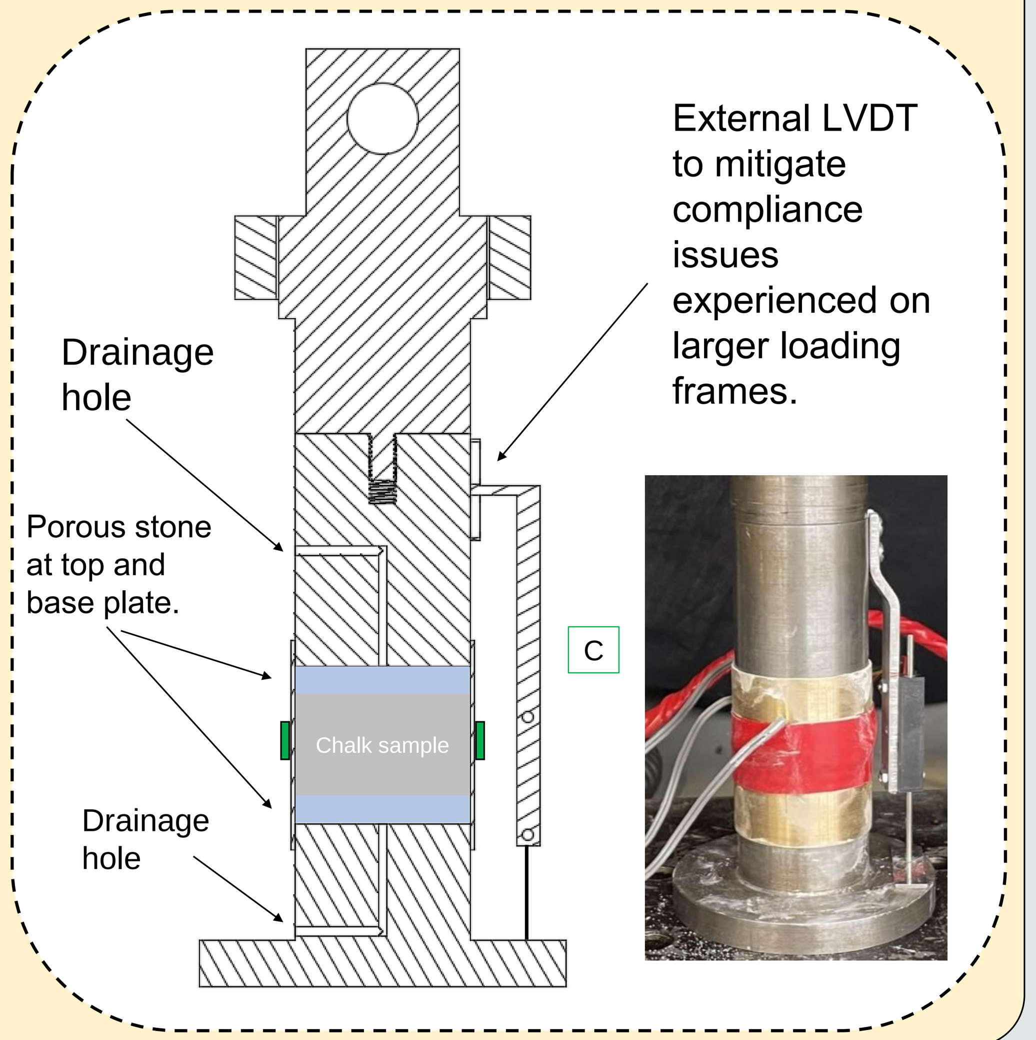


Specimen ring

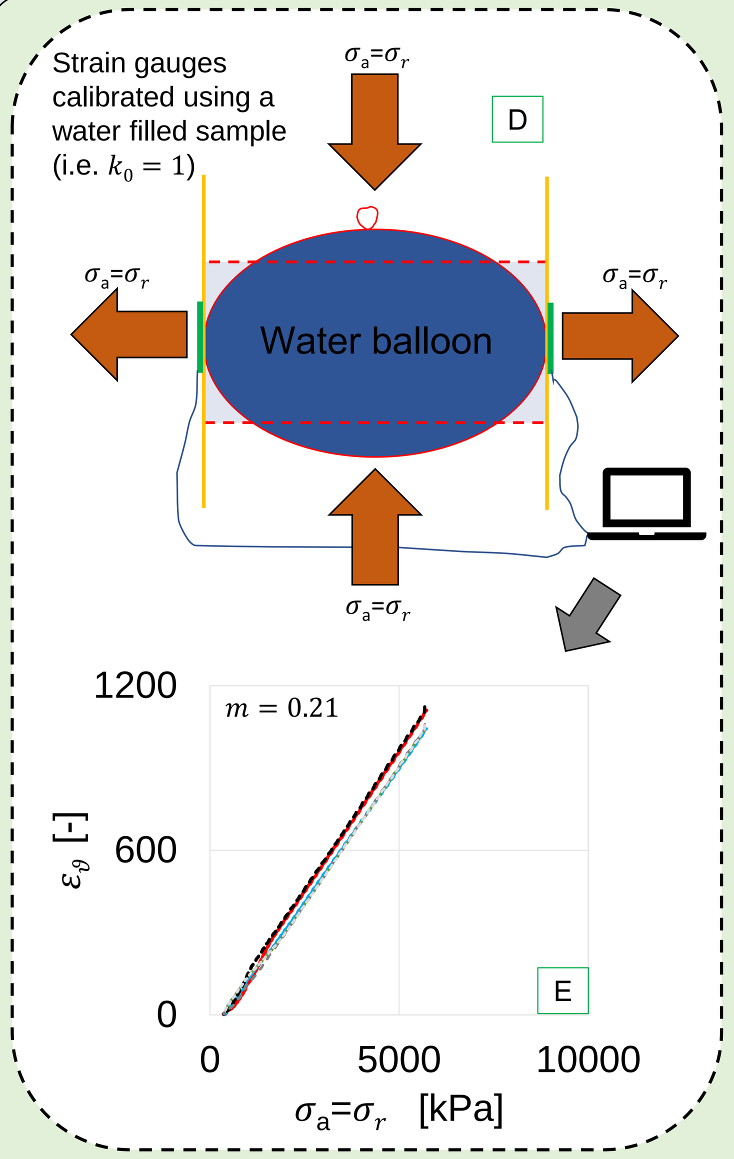
- Ensuring quasi-oedometric (but "flexible") conditions, a brass ring (38mm OD) was chosen (B).
- A parametric study (A) found that a ring thickness of 0.8mm would capture strain resolution from approximately 20-6000kPa whilst maintaining quasi-oedometric conditions (i.e not exceeding $\varepsilon_\theta = 5\text{x}10^{-5}$ as suggested by Okochi and Tatsuaoka (1984) for triaxial tests.
- A brass ring was chosen over other metals due to its ease of fabrication, elasticity and high yield.

Operation and loading actuation

- Loading and installation of samples was performed using an Instron © loading frame.
- Intact samples require cutting and are pushed through a sharp cutter to ensure good, clean confinement in the ring.
- To reduce friction the ring is design to float between a base plate and upper piston (C).
- Tests are displacement controlled ($0.05mm/min$) ensuring drained conditions can be assumed.



② Initial Calibration



1. Linearity between σ_a and ε_θ from a water tested sample (D) can be used to infer σ_r for materials where $k_0 \neq 1$ using Mariotte theory for hollow cylinders.

$$\sigma_r = \frac{1}{m}(\varepsilon_\theta)$$

Where m is the average gradient of the loading phase and ε_θ is the recorded circumferential strain from each strain gauge and σ_r is radial stress (E).

2. Calibration allows hysteresis and strain gauge drift to be monitored. From several load/unload cycles drift was negligible (E), indicating continued elasticity of the ring.

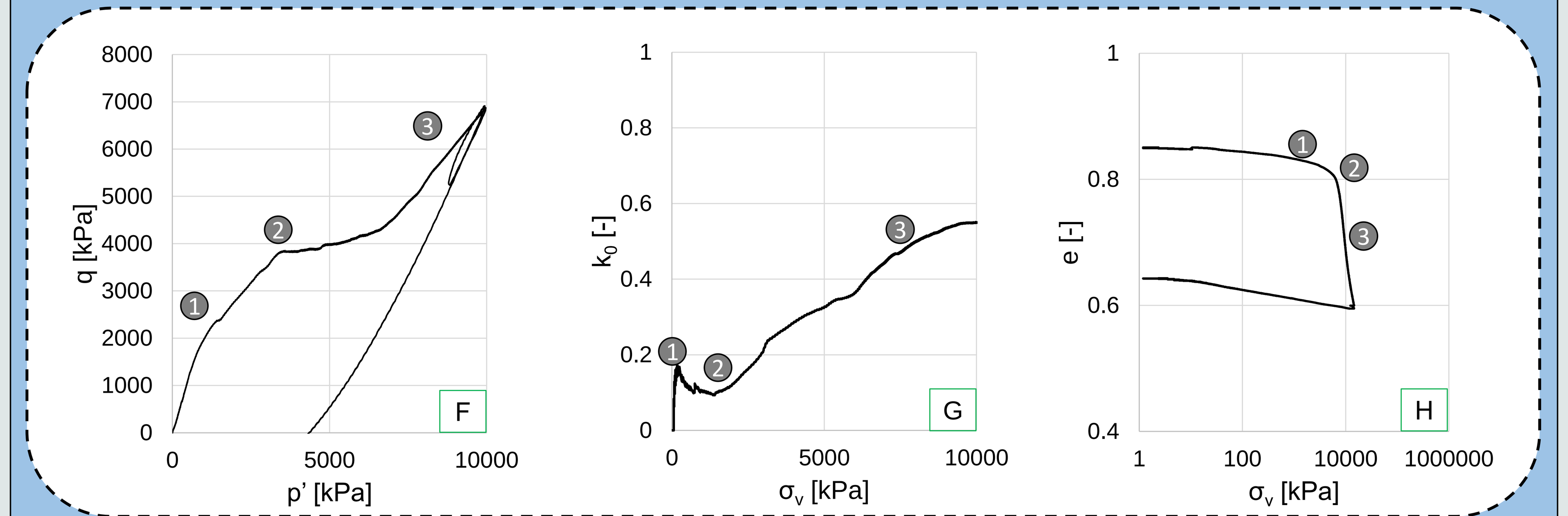
3. Calibration to $\sigma_r = 6000kPa$ is shown (E). In principle, a material with $k_0 = 0.5$ can be consolidated to $\sigma_a = 12000kPa$ whilst remaining within the calibrated elastic window.

Preliminary testing ③

Intact testing

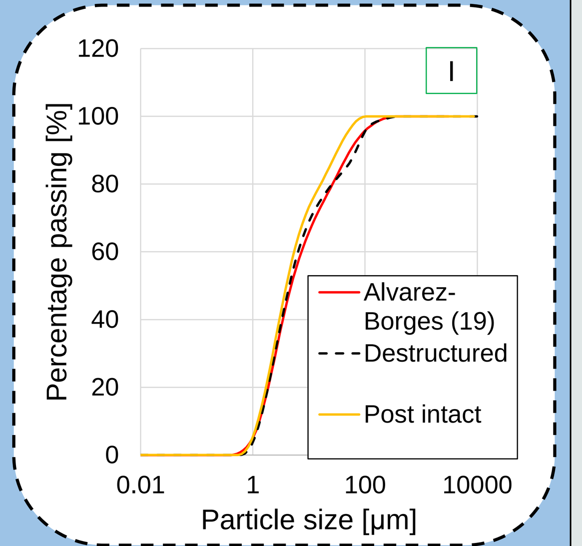
- In chalk, $1D - k_0$ triaxial tests are limited due to the challenges of performing such test (often they rapidly collapse upon yield).
- The soft oedometer shows the full k_0 evolution from intact to a fully de-structured state (G), exhibiting similar behaviour to other limited $1D - k_0$ tests. (Addis & Jones, 1990).

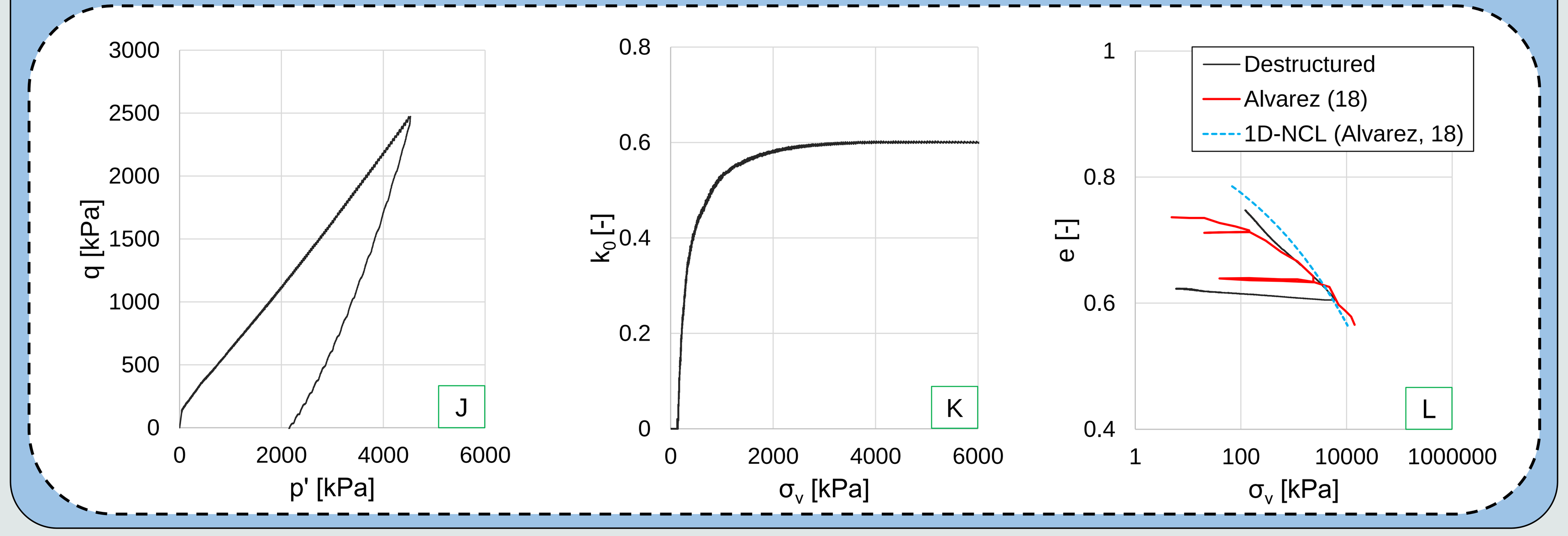
① Initial yield
② Pore collapse
③ Work hardening



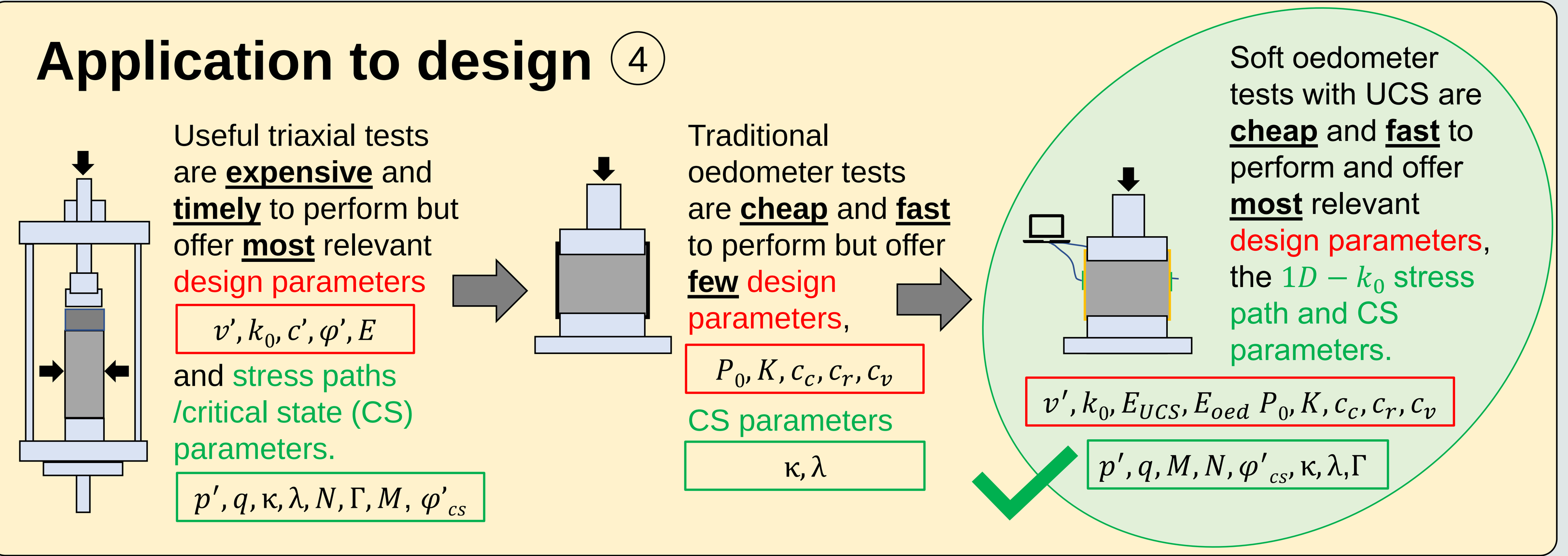
De-structured testing

- Estimated voids ratio shows analogous behaviour seen in traditional oedometric tests on the same de-structured material (I). Tendency to the same 1D-NCL line described in Alvarez (2018) is clear (L).
- Intact stress paths broadly converge with those on initially de-structured samples indicating that gross yield and complete de-structure in oedometric conditions are possible for intact tests (G,K,H,L). Convergence to the $1D - k_0$ path denoted for de-structured tests may require greater stress levels due to the strict organisation of particles upon yield.



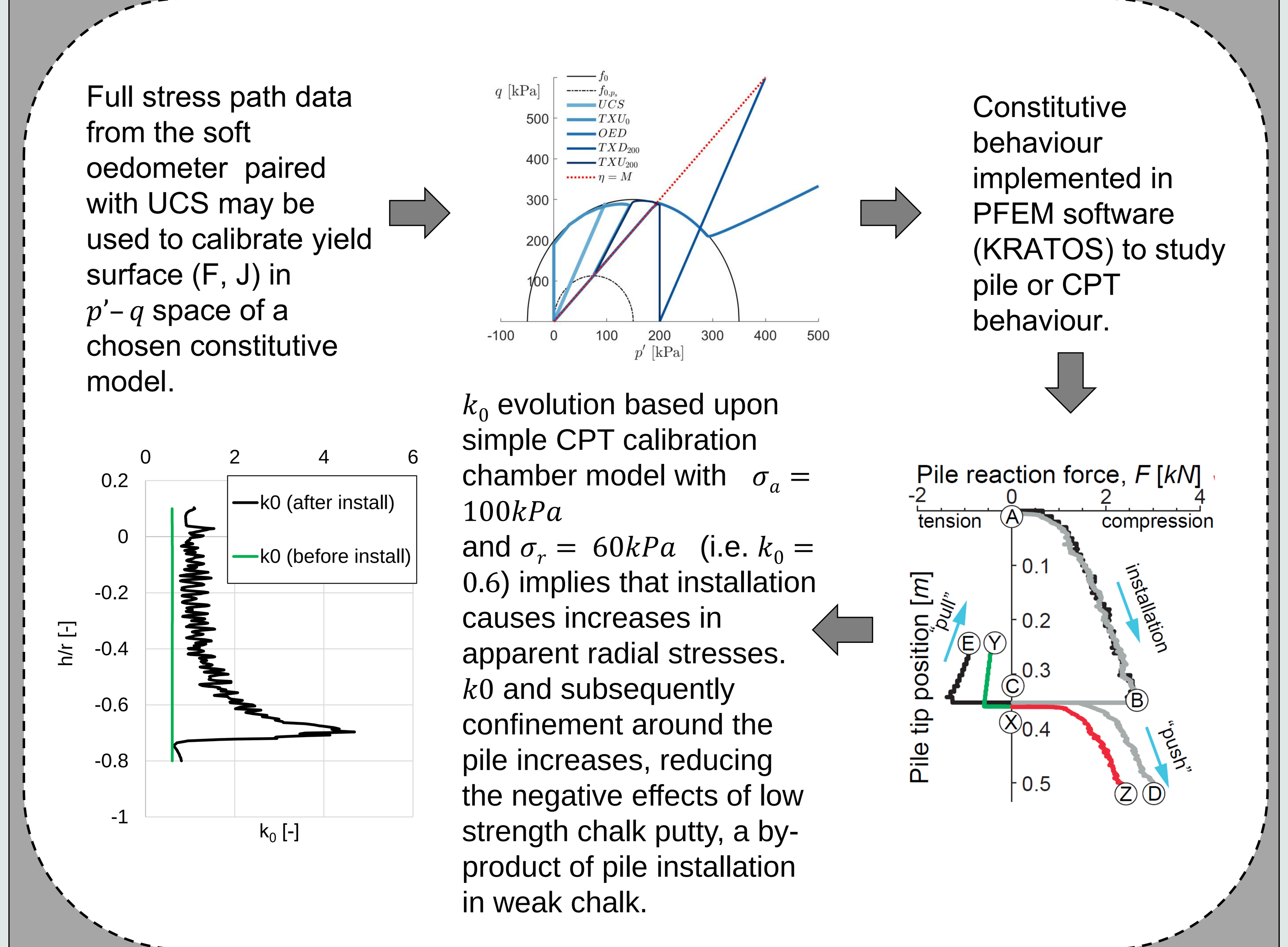


Application to design ④



⑤ The true k_0 for effective stress design approaches?

Installation of piles in chalk will have significant effect on horizontal stresses, along with mechanical changes to the initially intact chalk and so the capacity. A study using PFEM Ciantia (2022) shows the effect of pile instal in chalk, indicating that driving may release "locked" in horizontal stresses ignored by standard effective stress design methods which generally predict shaft capacity using $k_0 = 0.8$ irrespective of depth or installation processes (API, 2014).



- Measuring in-situ k_0 from element tests may lead to underestimation of confinement behaviour around a pile, leading to conservative design. Pressuremeter tests may give more representative results (Terente et al., 2017) but vertical fissures in a rock mass may hinder results (Vinck, 2022)
- In absence of expensive pressuremeter data, soft oedometer results may be used to calibrate a bonded-material constitutive model (Ciantia 2022, Nova et al., 2003) which can then be used to study installation effects and pile capacity based on element behaviour and rock mass understanding.
- Field, centrifuge or 1g scale data may then be used to validate numerical results.

Conclusion

- A new soft oedometer has been developed. Shown to fully describe the $1D - k_0$ behaviour of chalk in intact and de-structured states, it may be used to study other geomaterials (Ciantia, 2013; Castellanza, 2002)
- The full stress-path approximates close-ended/plugged pile behaviour below the pile tip and can be used to calibrate constitutive models.
- Numerical studies performed earlier indicate that k_0 may increase as a result of pile installation in weak chalk, often ignored by other effective stress methods (Ciantia, 2022).

References