Time and rate effects on the ultimate resistance of foundations on clays

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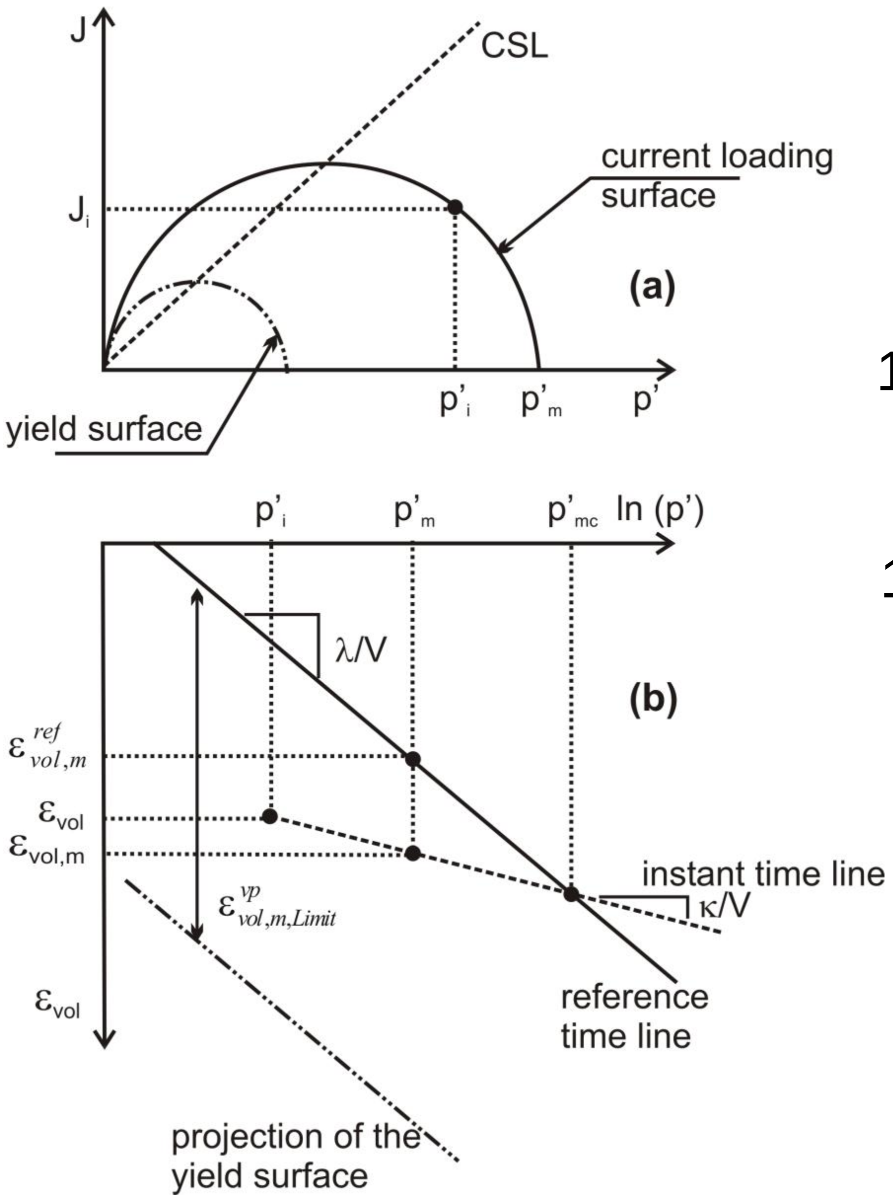
Layout of the presentation

- Implemented EVP model
- Analysis of vertically loaded footings
- Analysis of axially loaded piles
- Concluding remarks

Implemented EVP model

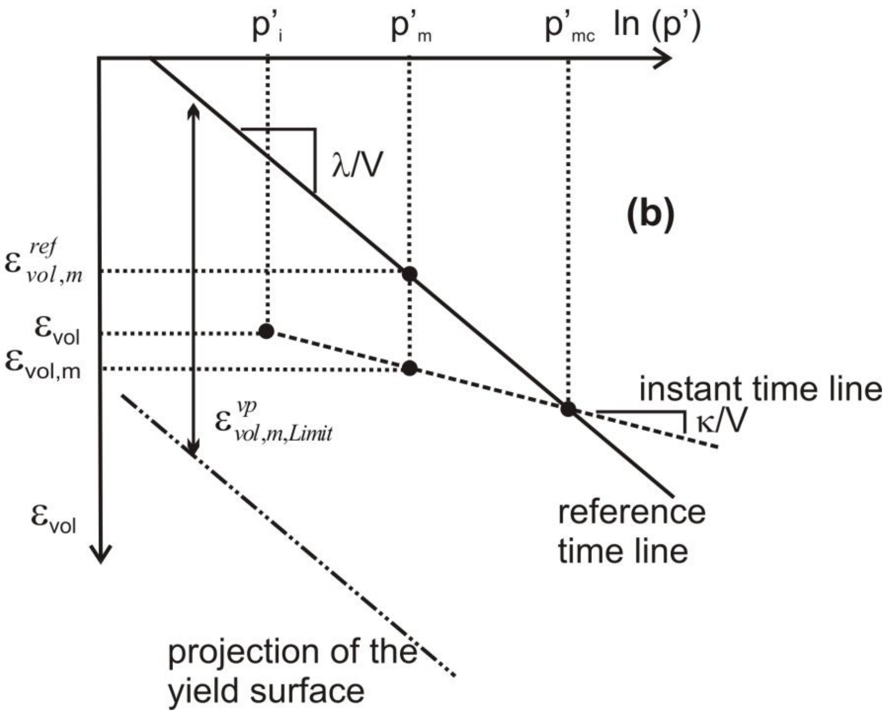


Elastic viscoplastic (EVP) model based on Perzyna´s overstress theory

$$1+\frac{\varepsilon^{ref}_{vol,m}-\varepsilon_{vol,m}}{\varepsilon^{vp}_{vol,m,Limit}} \geq 0 \qquad \left\{\Delta\varepsilon^{vp}_{ij}\right\}=\Phi\cdot\left\{\frac{\partial g}{\partial\sigma'_{ij}}\right\}\cdot\Delta t$$

$$1+\frac{\varepsilon^{ref}_{vol,m}-\varepsilon_{vol,m}}{\varepsilon^{vp}_{vol,m,Limit}} < 0 \qquad \left\{\Delta\varepsilon^{vp}_{ij}\right\}=0$$

Implemented EVP model



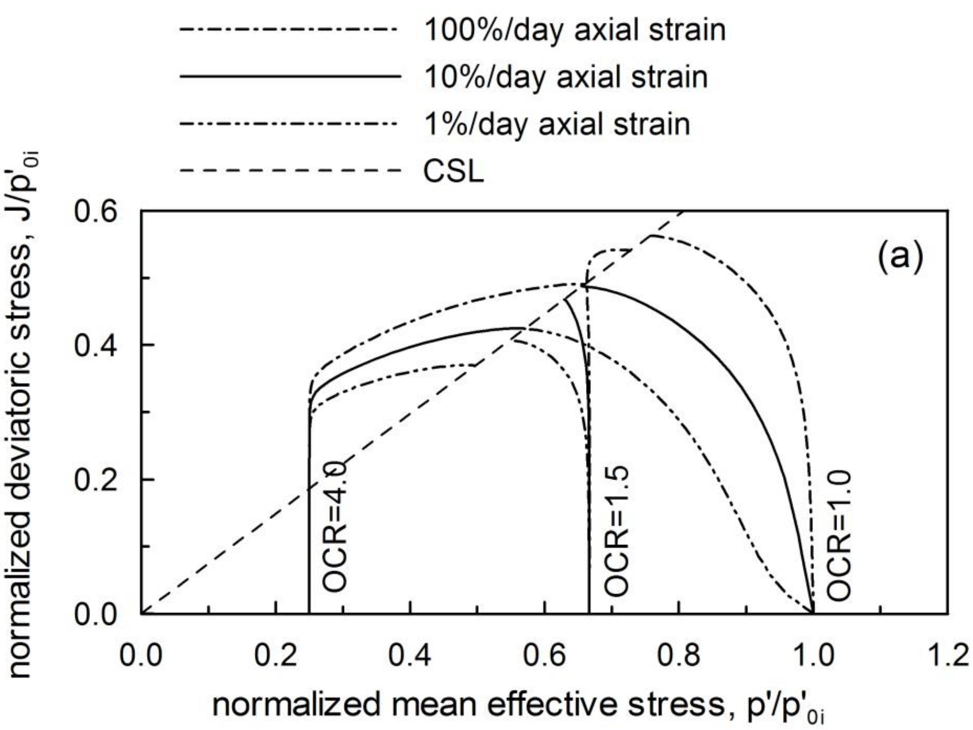
Model parameters

M, α and μ	controls the shape of the loading surface
κ/V and G or ν	elastic response
λ/V	large scale compressibility
ψ_0/V, t_0, $\varepsilon_{vm,limit}$	time related parameters

$$\Phi = \frac{\psi_0}{V \cdot t_0} \cdot \left(1 + \frac{\varepsilon^{ref}_{vol,m} - \varepsilon_{vol,m}}{\varepsilon^{vp}_{vol,m,Limit}}\right)^2 \cdot \exp\left[\frac{V}{\psi_0} \frac{\varepsilon^{ref}_{vol,m} - \varepsilon_{vol,m}}{\left(1 + \frac{\varepsilon^{ref}_{vol,m} - \varepsilon_{vol,m}}{\varepsilon^{vp}_{vol,m,Limit}}\right)}\right] \cdot \frac{1}{\left|\frac{\partial g}{\partial p'}\right|_{\substack{p'=p'_m \\ J=0}}}$$

Implemented EVP model

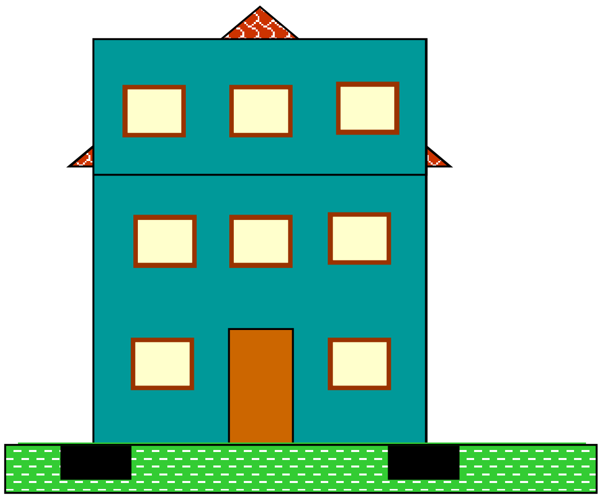
Undrained triaxial compression

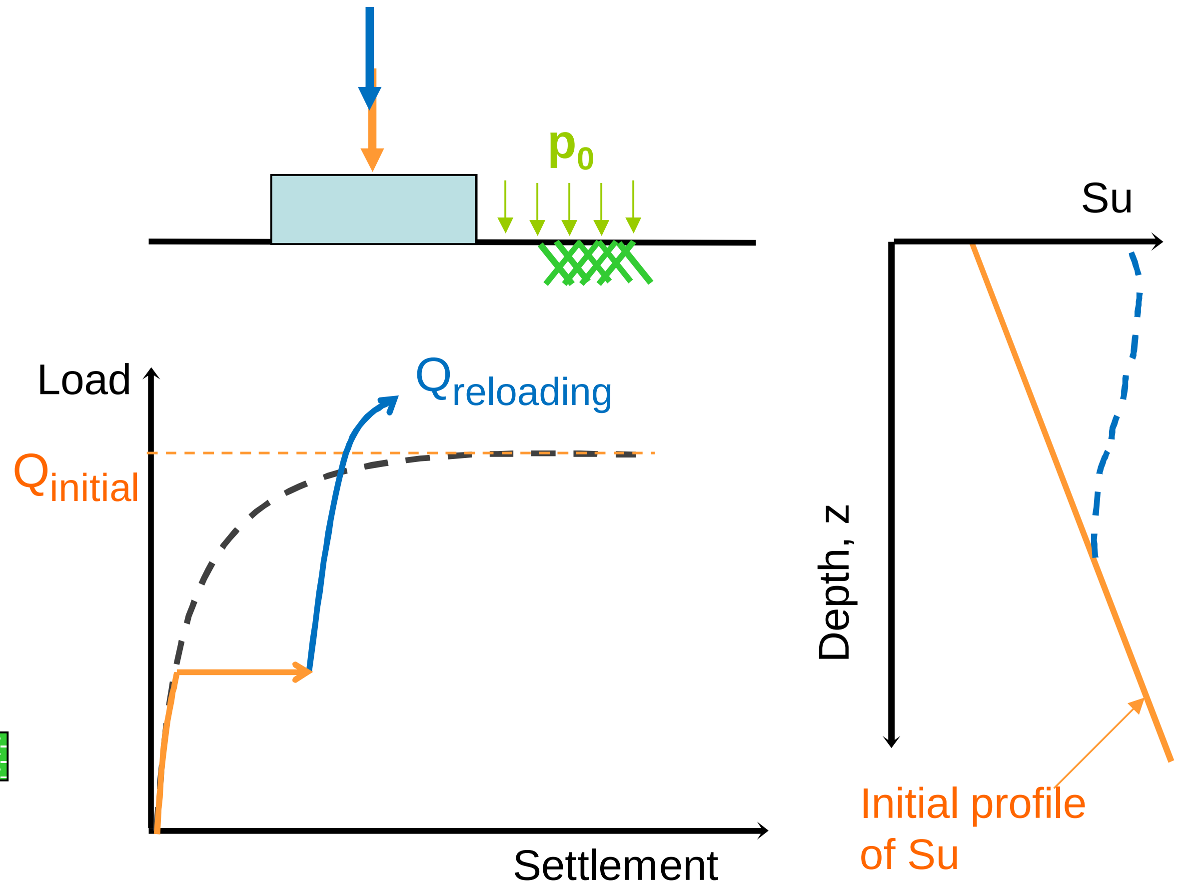


Other features

- Secondary compression;
- Stress relaxation;
- Permanent strain rate effects on the stress strain response (1D compression and shearing);
- Increase of the soils yield stress with strain rate;
- Increase in the soil yield stress and undrained strength following a creep period.

Analysis of vertically loaded footings

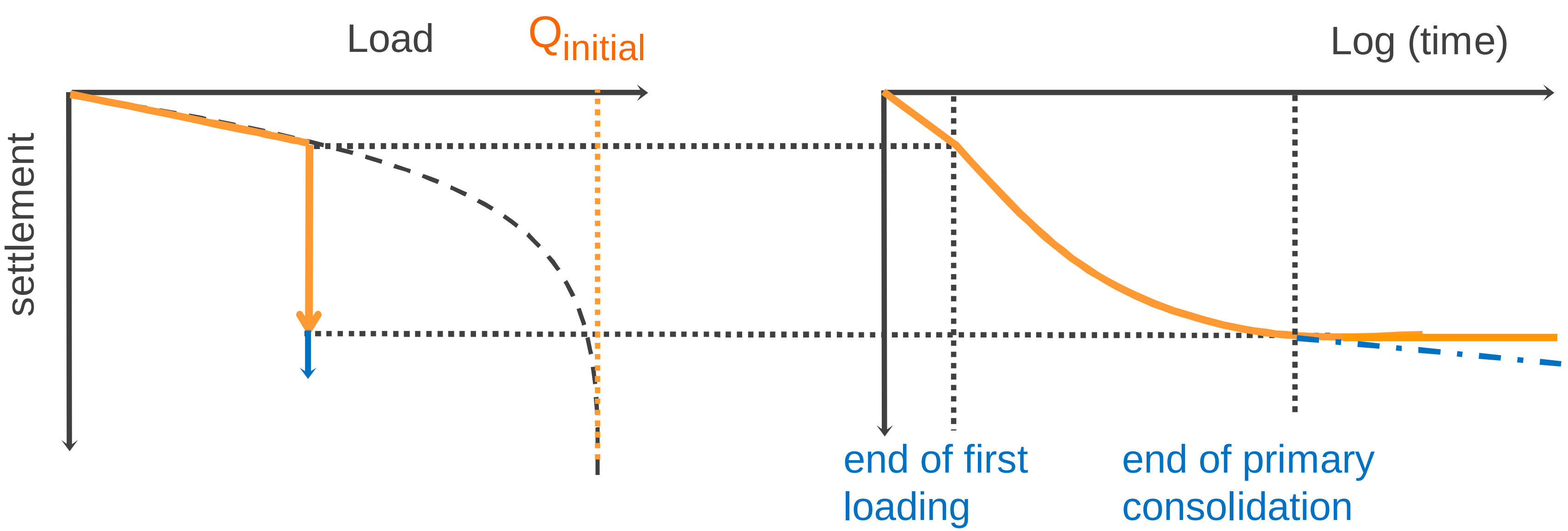


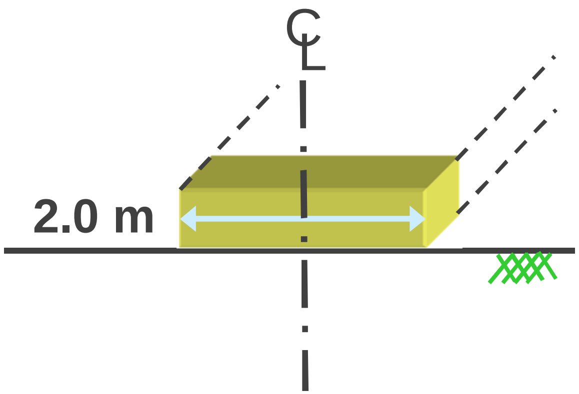


- extra load to be added to an existing foundation
- reuse of old foundations for a new building

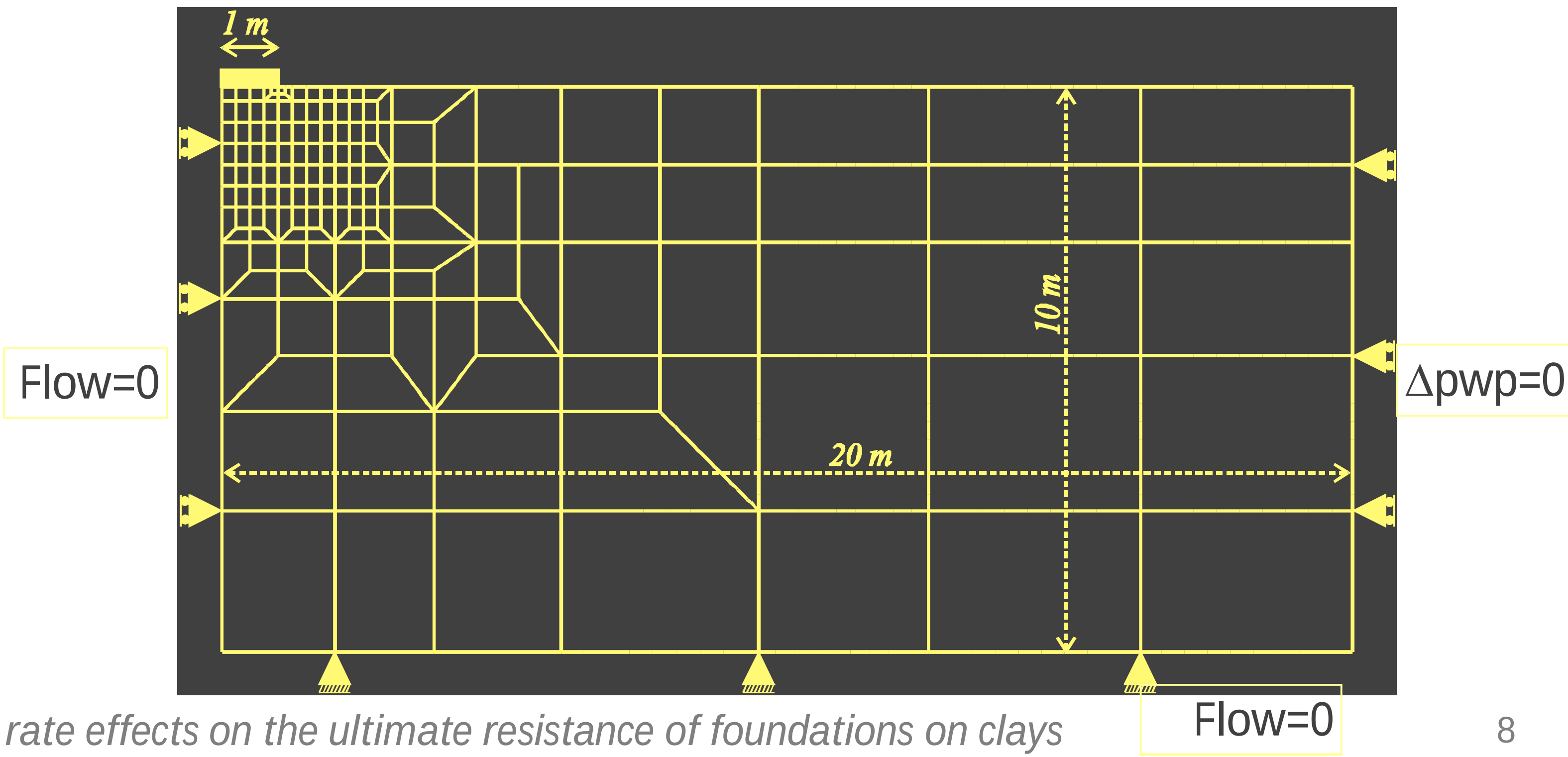
Analysis of vertically loaded footings

- Using the MCC model Zdravkovic et al (2003) computed $Q_{reloading}/Q_{initial}$ for strip footings for several values of pre-load and different soil profiles;
- In this case once the excess of pwp generated during 1st loading has dissipated no further increase in Su is predicted;
- In reality soils are known to undergo ageing associated with either the development of structure or creep strains.



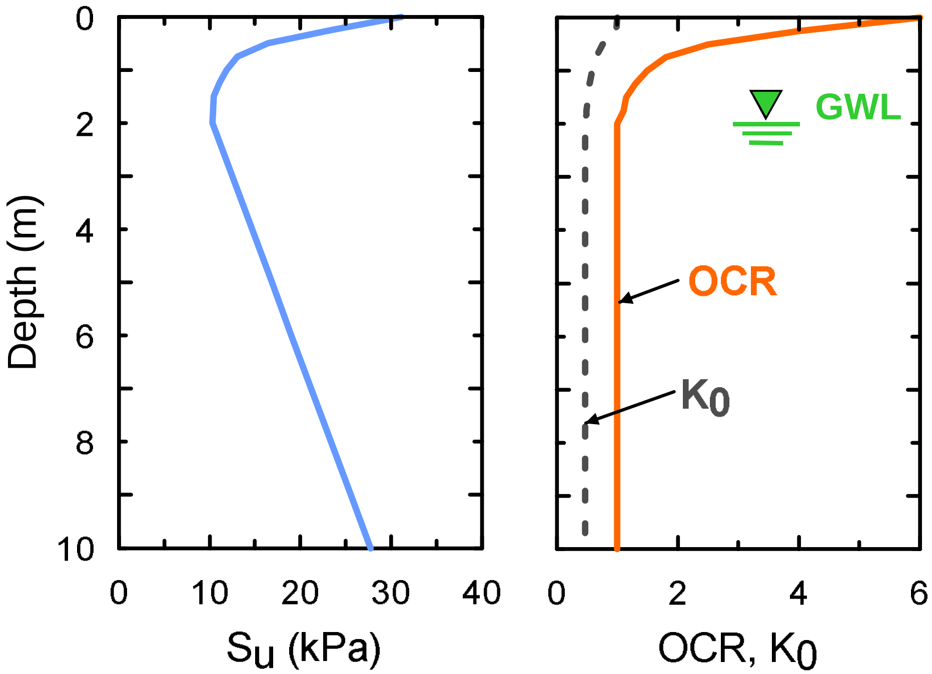


- 2 m wide rough strip footing;
- Appropriate displacement and pwp boundary conditions;
- Displacement controlled analyses;



Ground profile

- Soft clay case described by Zdravkovic et al, 2003;
- The material parameters mostly based on site investigation and laboratory data;



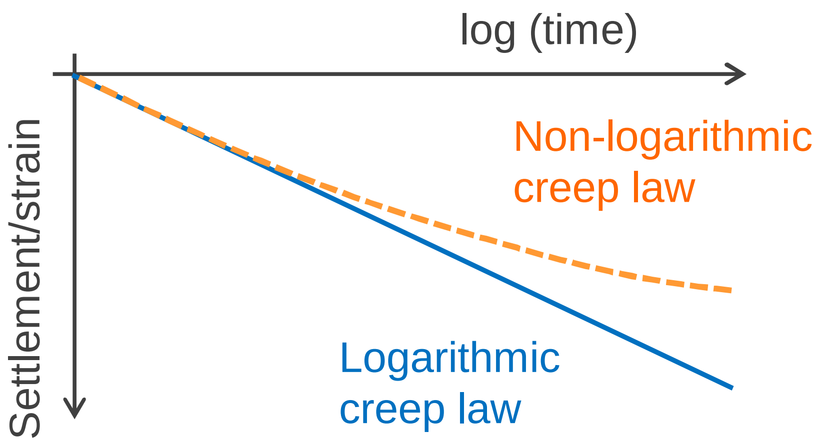
MCC model parameters (Zdravkovic el al., 2003)

ϕ'	κ	λ	G	γ	k	e
32°	0.022	0.22	1700 kPa	17kN/m^3	5x10^{-10} m/s	1.5

EVP model parameters

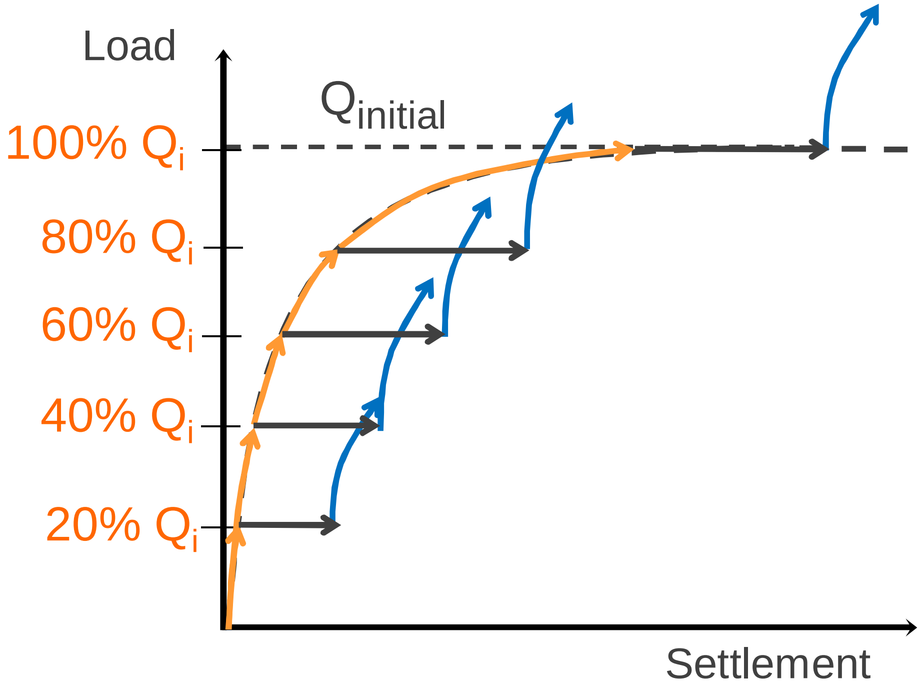
M	κ/V	λ/V	ψ_0/V	t_0	$\varepsilon_{vm,limit}$	G	γ	k	e
-	-	-	-	days	-	kPa	kN/m^3	m/s	-
1.287	0.0088	0.088	0.00521 0.00174	1.0	0.6 0.06	1700	17.0	5×10^{-10}	1.5

α=0.4
μ=0.9

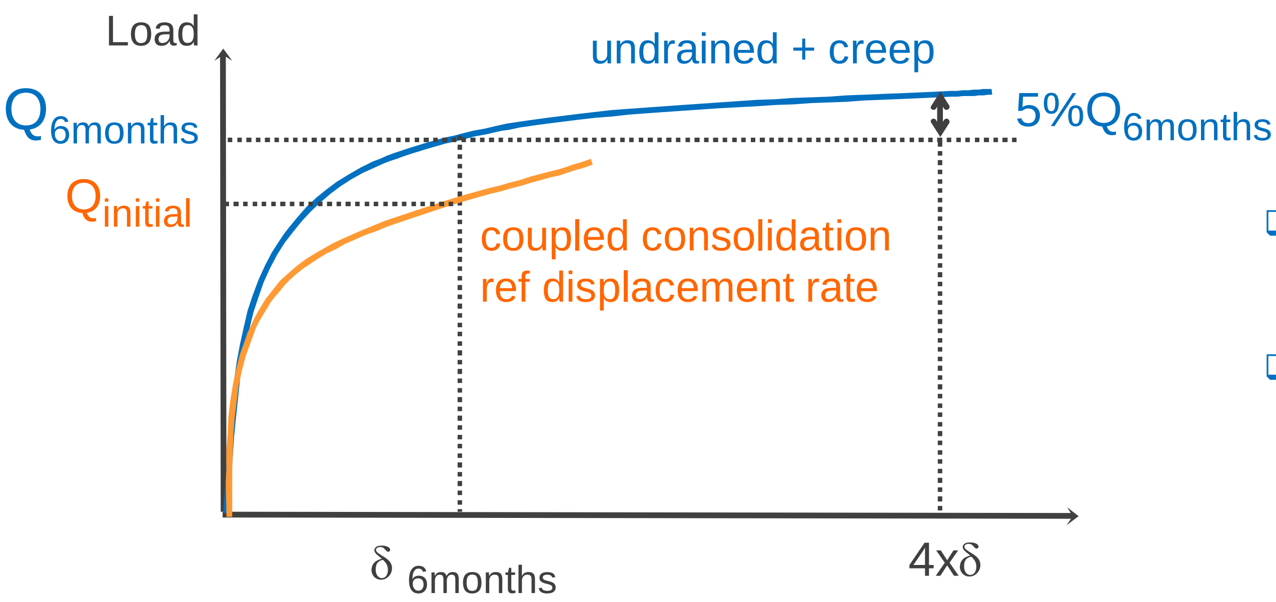


	ψ_0/V	$\varepsilon_{vm,limit}$	
Set A	0.00521	0.6	C_α=0.03; log law
Set B	0.00174	0.6	C_α=0.01; log law
Set C	0.00521	0.06	C_α=0.03; non-log

Description of the analyses



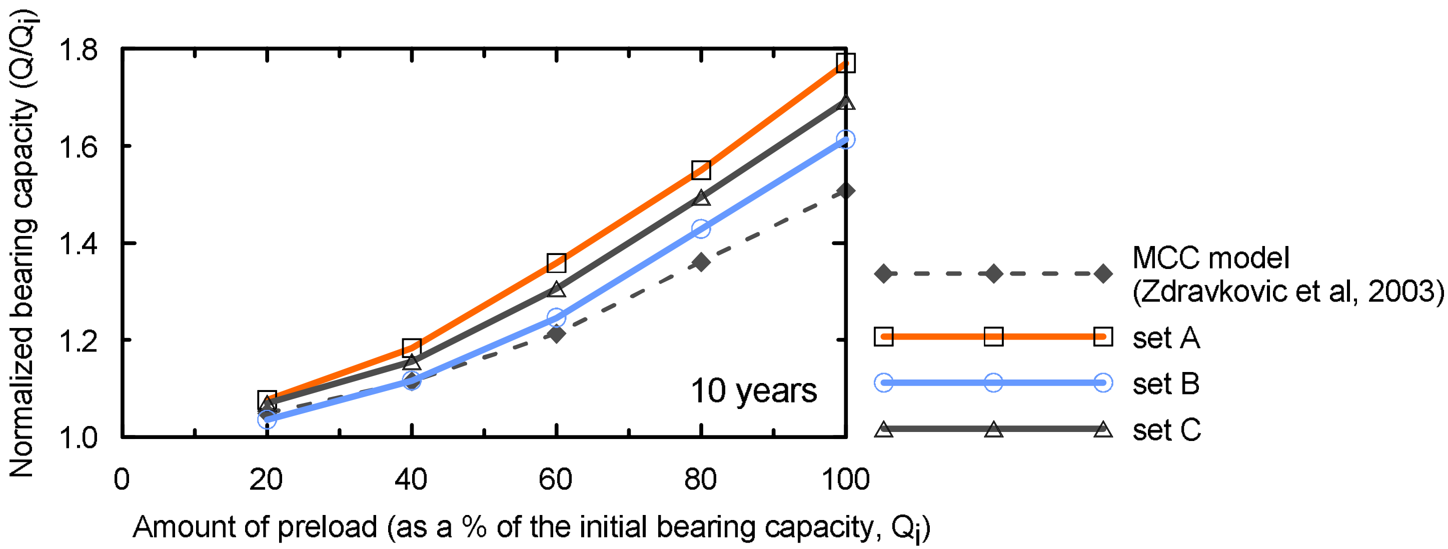
- Definition of the initial load displacement curve
- Preload to a % of $Q_{initial}$
- Maintain the load for a period of time (1yr, 10yr, 100yr or to end of primary consolidation)
- Load to failure at the same loading rate

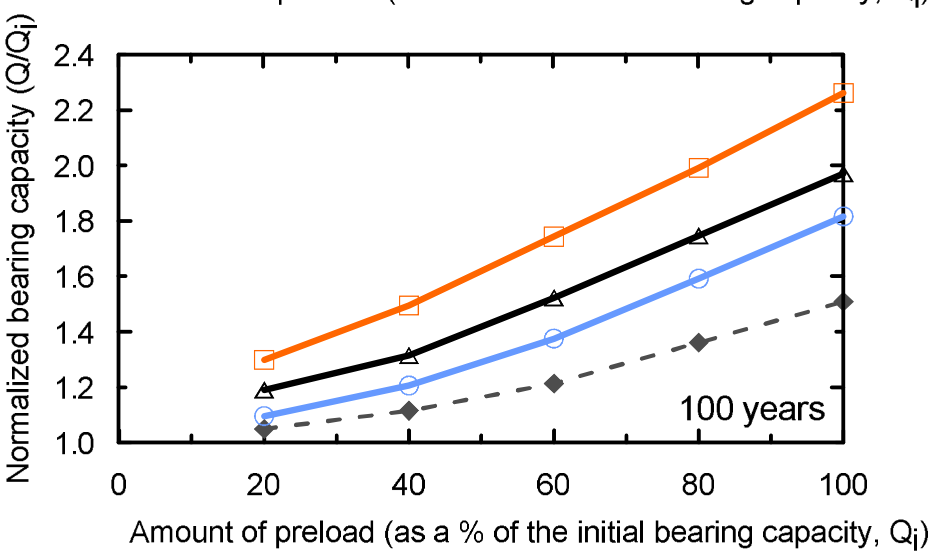


- Initial load displacement curve
- Definition of $Q_{initial}$ and the loading rate for each analysis set

- $Q_{reloading}$ - failure on reloading is defined as the onset of incremental negative pwp immediately below the footing

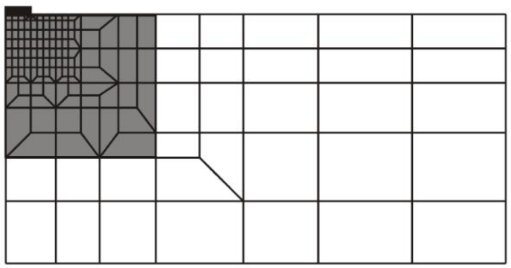
Results – bearing capacity

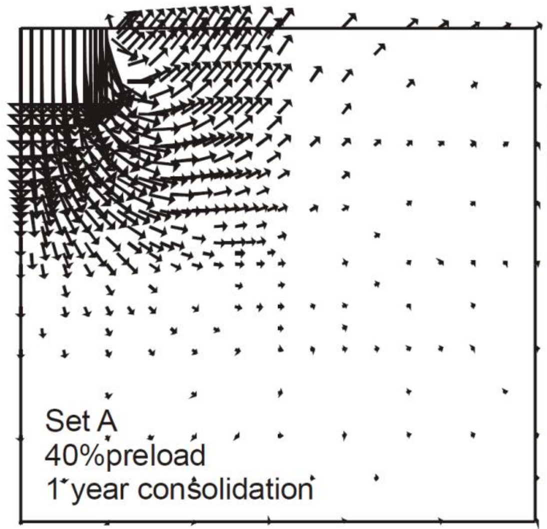


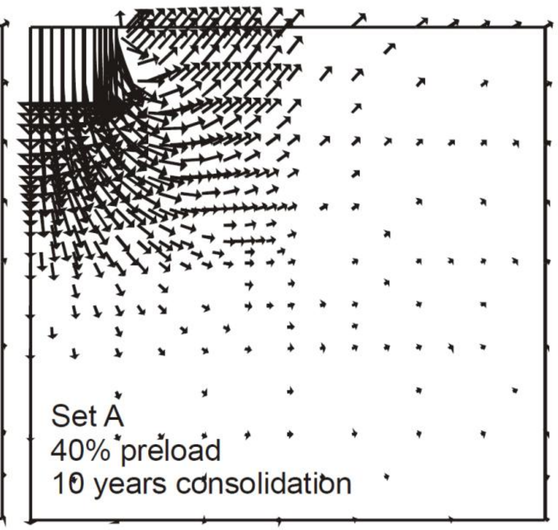


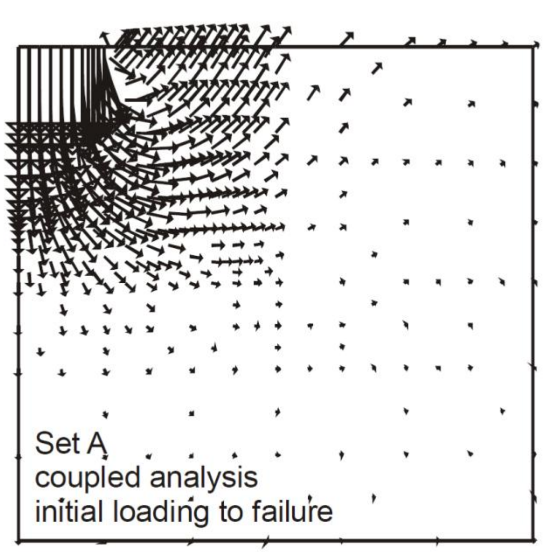
- the MCC model under predicts the bearing capacity.
- The effect of creep is more significant at large preload values;

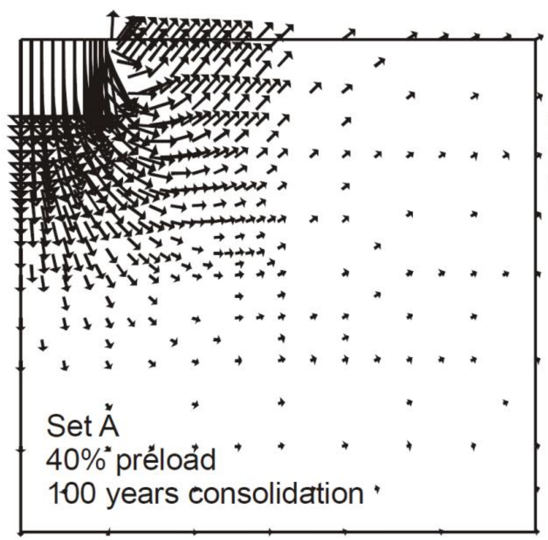
Results – failure mechanism

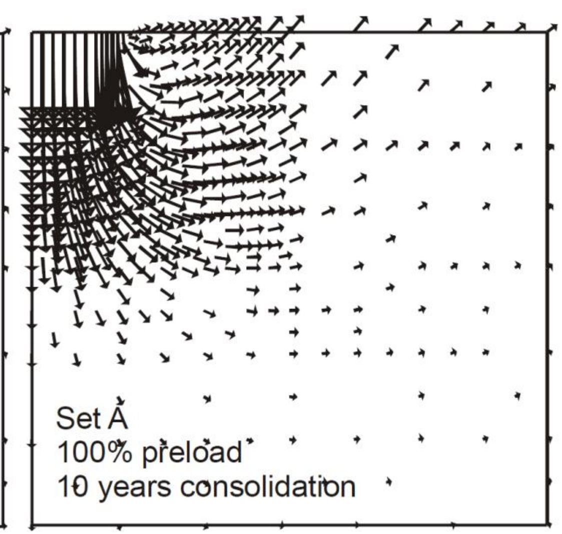




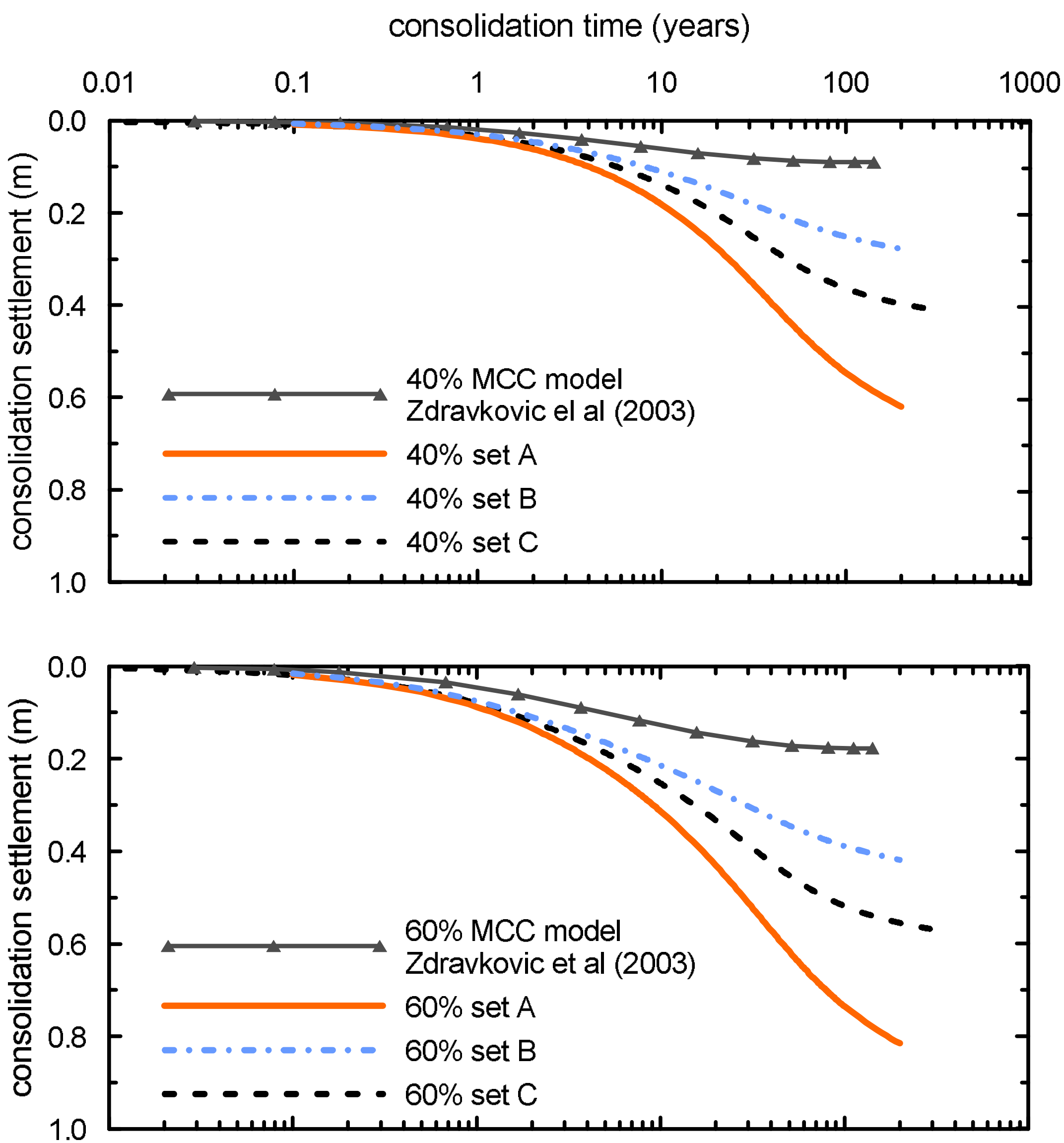








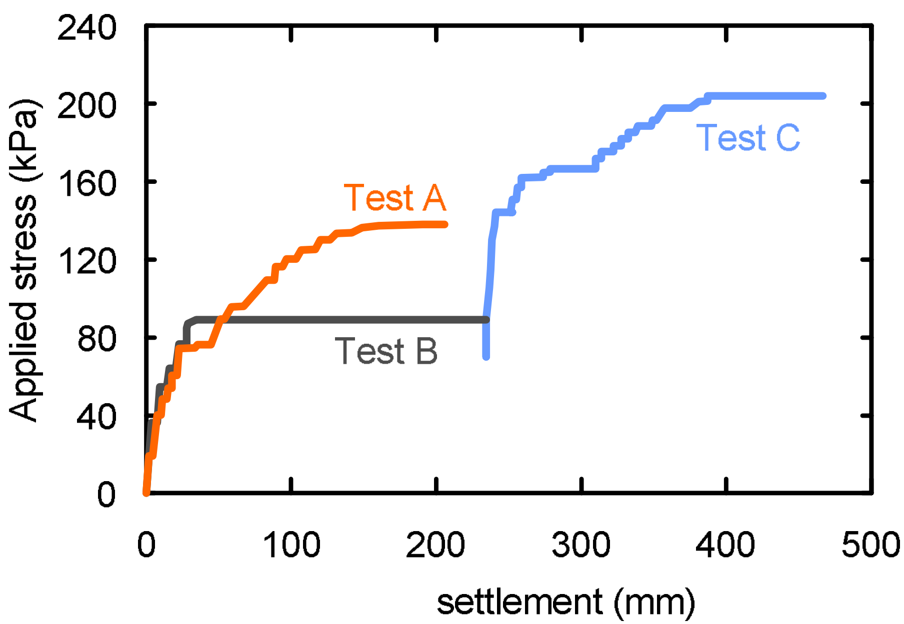
Results – settlements

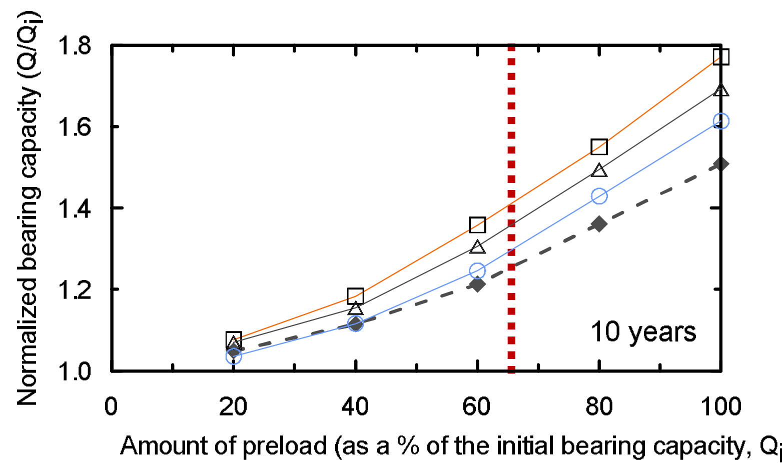


Results – summary

- Parametric study on the increase of bearing capacity of a 2m wide strip preloaded footing, on soft clay ground profile;
- Quantifies the increase in the soil S_U due to consolidation and soil hardening due to creep;
- But does not considered soil structuration (true ageing), anisotropy;
- Factors considered: level of preloading, soil creep properties but also loading rate and footing shape (though not shown here);
- Other aspects to consider – size of the footing, other ground conditions, validation.

Loading tests on two footings at the Bothkennar research site





- Footing A (2.2 x 2.2 m^2), taken to failure in 3 days; q_{ult}=138kPa
- Footing B (2.4 x 2.4 m^2), q_{ult}=205kPa after 11 years under q=89kPa.

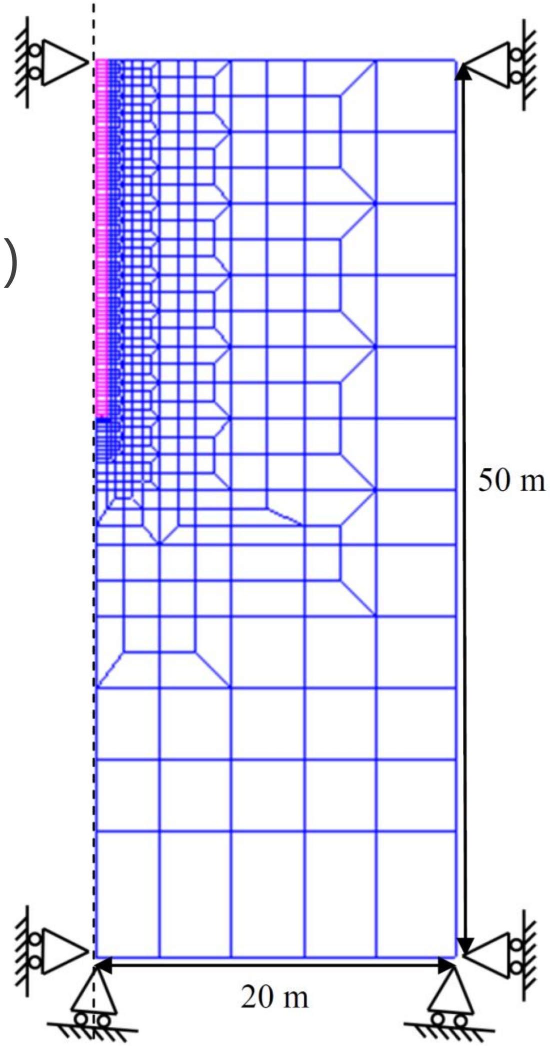
Preload= 0.64

Q/Qi=1.48

Analysis of axially loaded piles

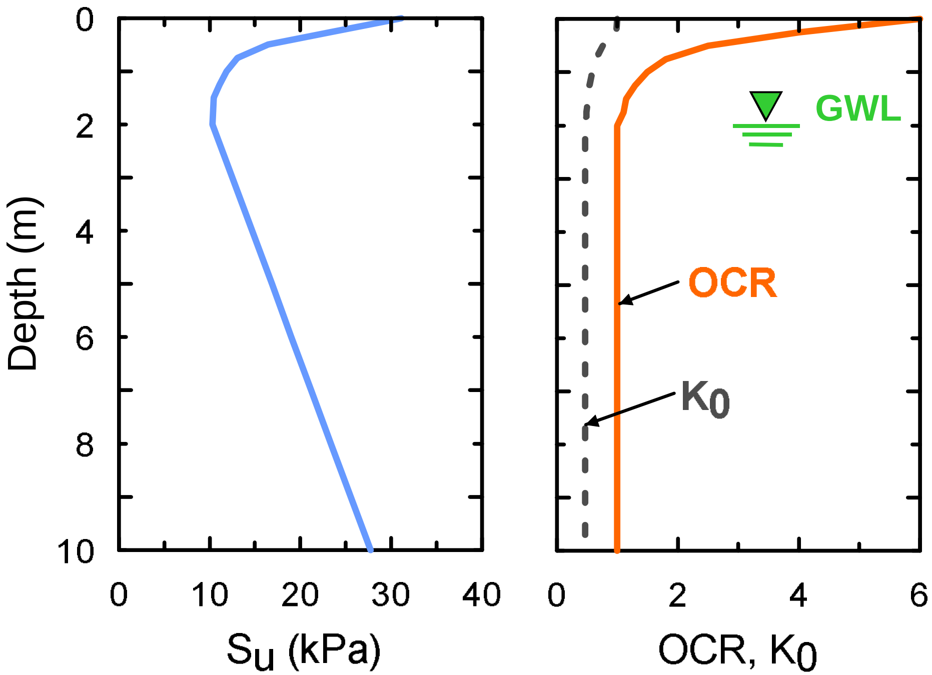
- Influence of axial preload on the axial pile capacity.
- Effect of consolidation only (analysis with MMC model)
- Consolidation + soil hardening due to creep (EVP model)
- Both a soft soil and a stiff soil profile are considered.

  - 1 m diameter 20m long pile.
  - Appropriate displacement and pwp boundary conditions.
  - Displacement controlled analyses.
  - Pile as a linear elastic material.



Soft clay profile

- Identical to the soft clay ground profile adopted for the footings analysis;
- For NC states OCR=1.05 was adopted to simulate soil ageing;
- Adopted time related parameters correspond to a linear logarithmic creep law with C_α equal to 0.01.



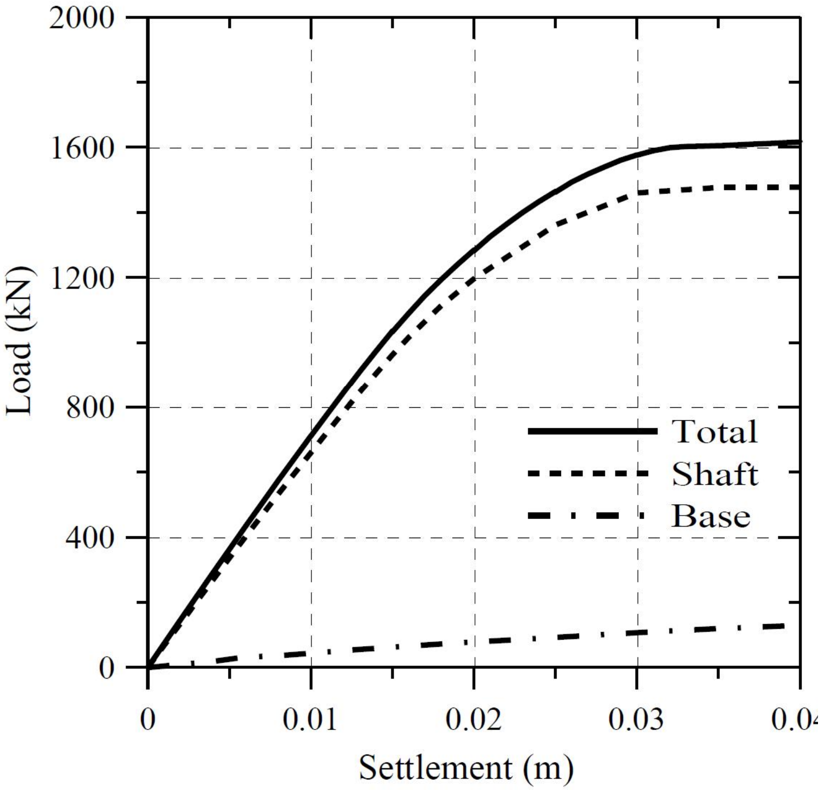
Stiff clay profile

- Model parameters correspond to London Clay;
- OCR=4.0 and K_0=1.0 constant with depth;
- Ground water table at 2.5m meters below ground level;
- Adopted time related parameters correspond to a linear logarithmic creep law with a C_α equal to 0.016.

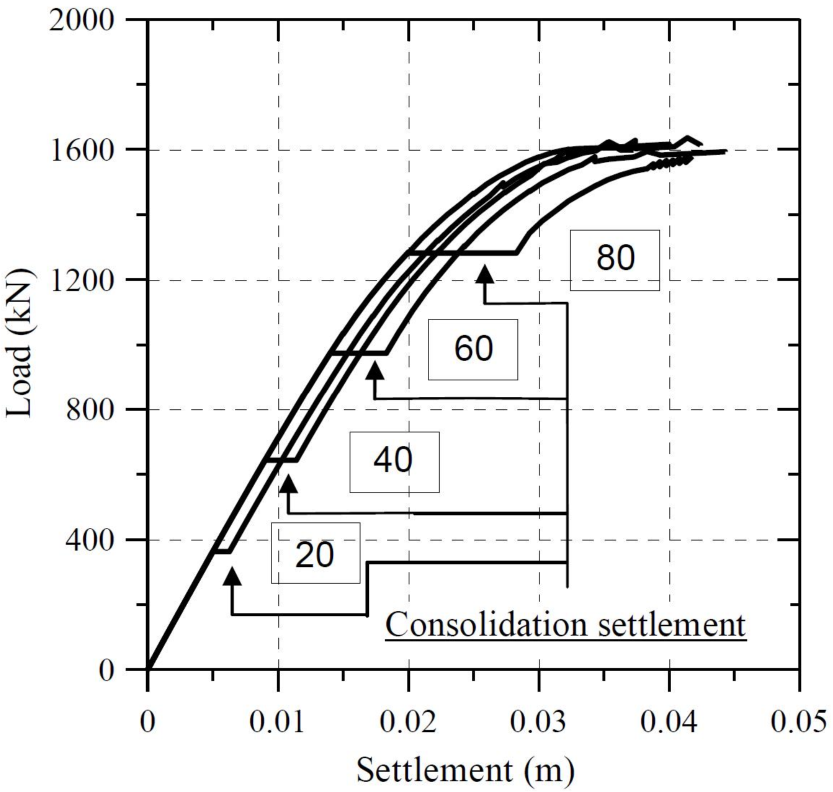
EVP model parameters

ϕ'	κ/V	λ/V	ψ_0/V	t_0	$\varepsilon_{vm,limit}$	G	γ	k	e
°	-	-	-	days	-	kPa	kN/m^3	m/s	-
23	0.03	0.06	0.00695	1.0	0.412	70000	21.0	5×10^{-10}	0.7

Soft clay profile - Modified Cam – Clay model

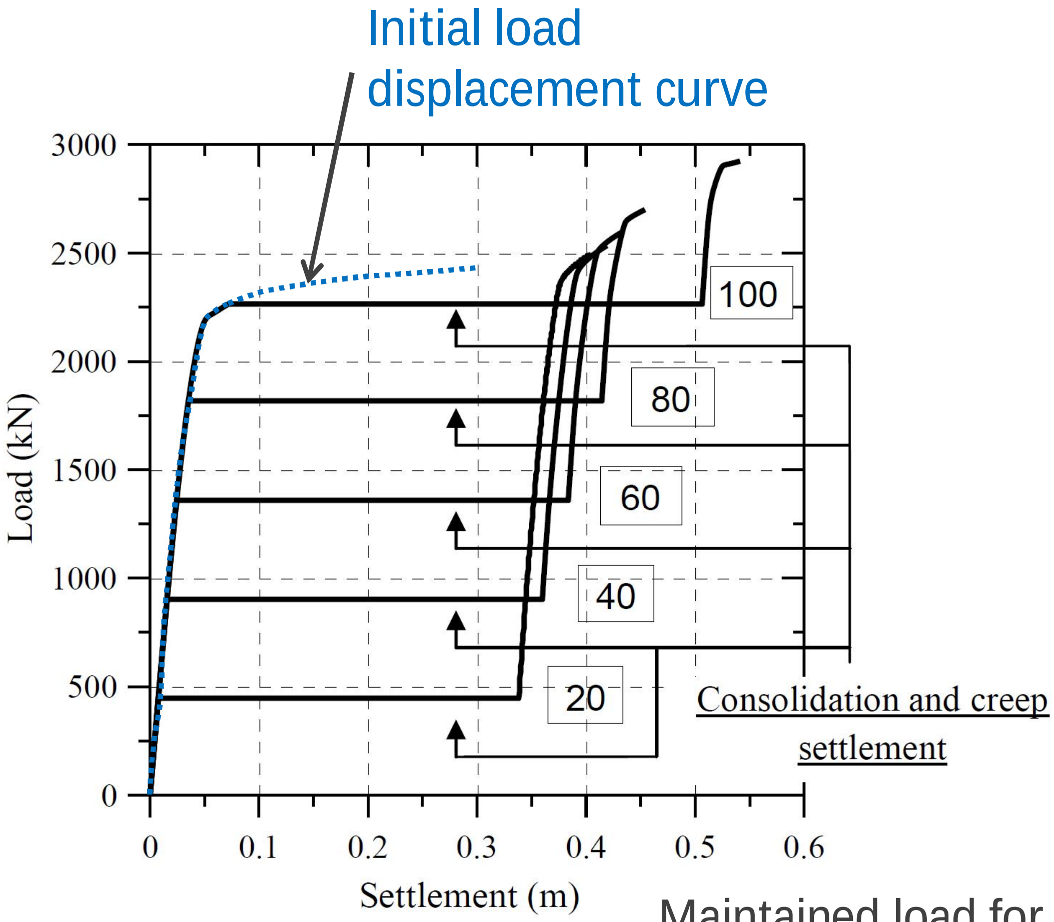


Undrained loading



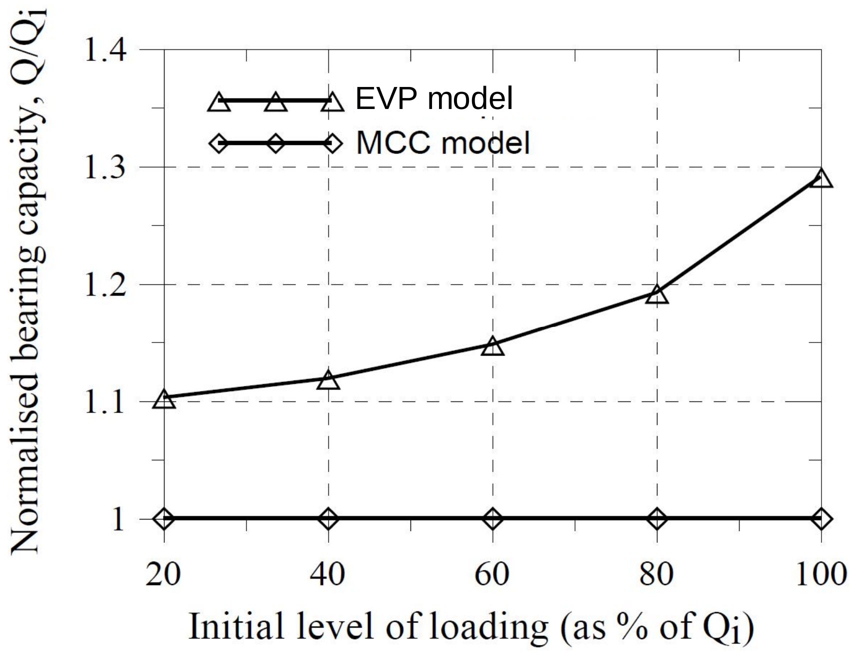
Maintained load for 50 years

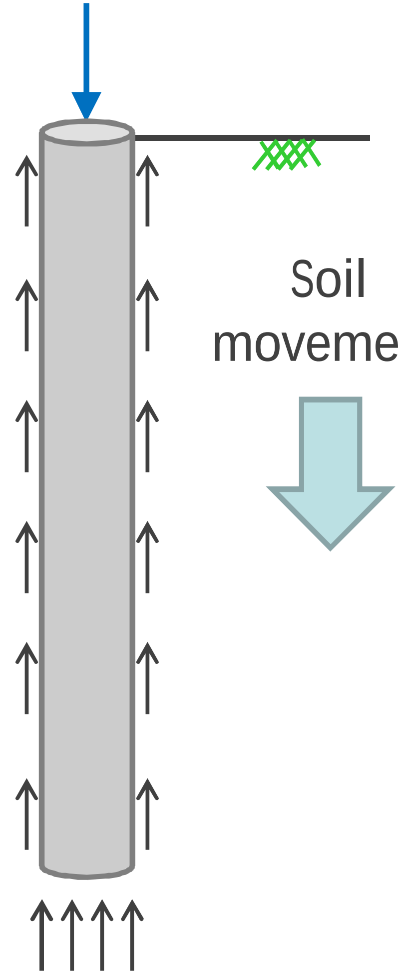
Soft clay profile - EVP model



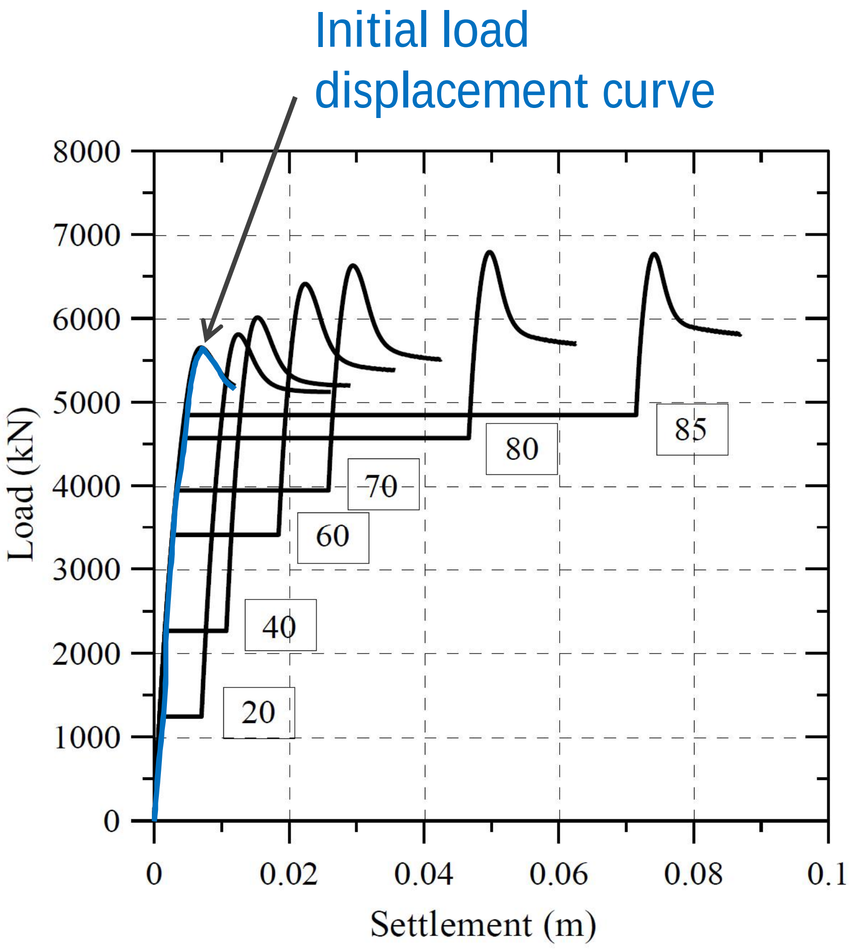
Maintained load for 50 years

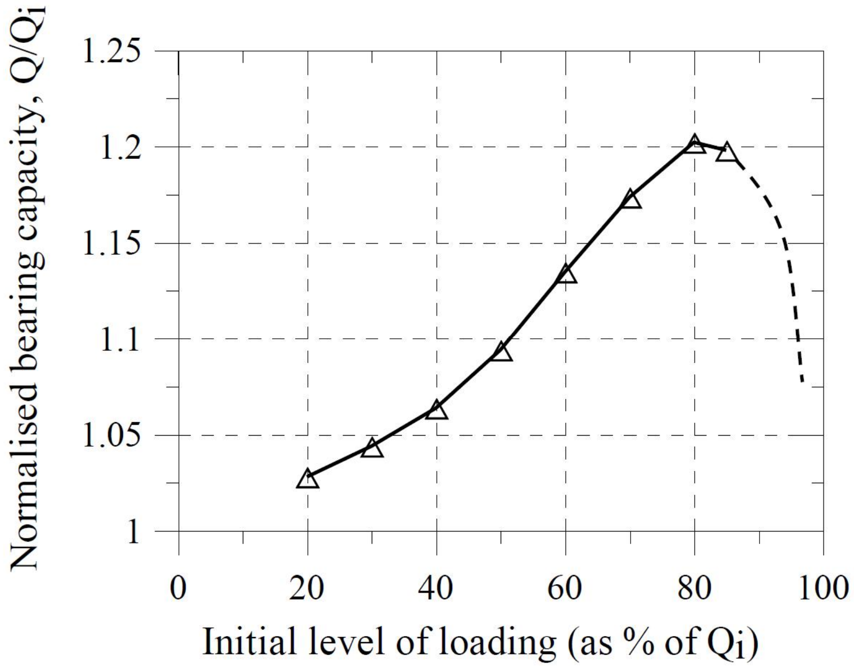
Soft clay profile - EVP model



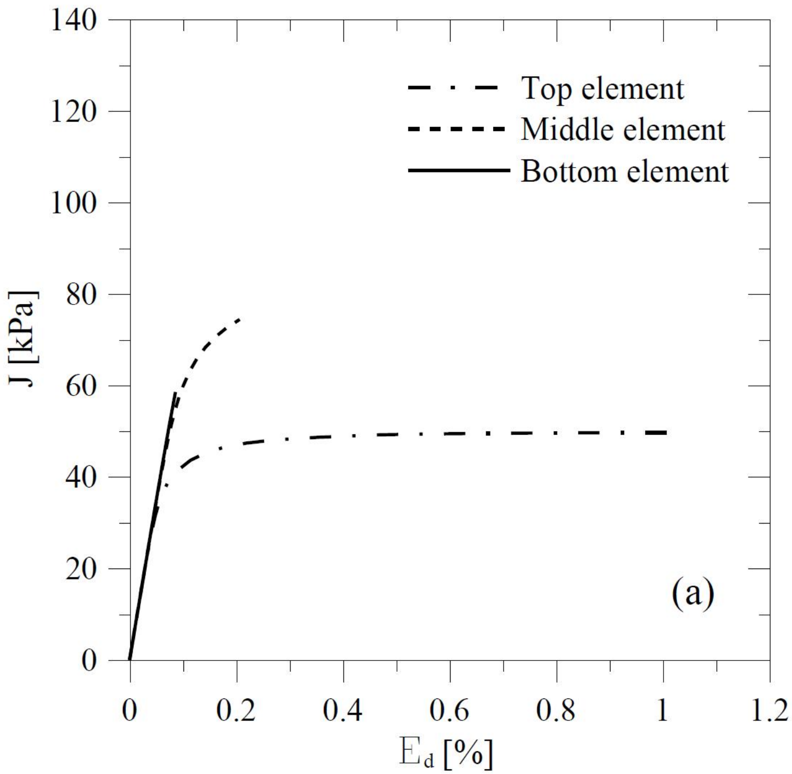


Stiff clay profile - EVP model

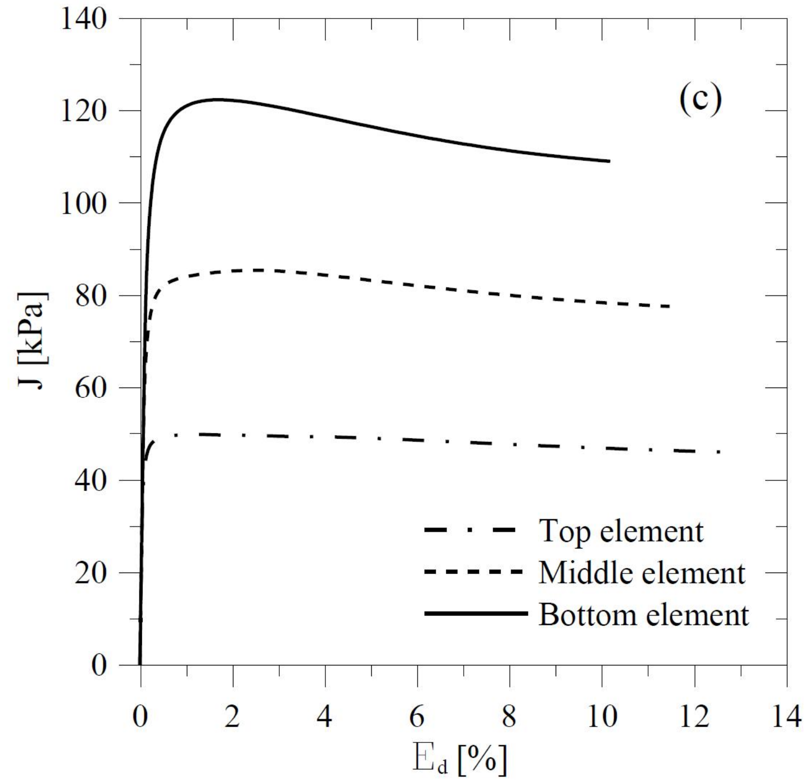




Stiff clay profile - EVP model



60% Q_i



After failure

Conclusions

- There are various models published in the literature to mimic permanent strain rate effects on the soil response. Often these are validated through the simulation of laboratory tests and comparison with experimental data.
- Here it was presented a first attempt to apply these models to the analysis of preloaded footings and piles is presented.
- When applied to the analysis of footings the model implemented by the authors seems to produce reasonable trends for the increase of bearing capacity with time.
- The analysis of piles need to be further detailed to understand the mechanisms responsible for the observed increase in pile axial capacity.
- Fields of work to be explored are i) the application of EVP models to other boundary value problems and loading conditions and ii) experimental and numerical characterization of the interaction between rate effect and structuration.