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Back calculation of embankments with OCR determined from prediction of initial strain rate rather than from OCR determined from disturbed samples in oedometer tests under unknown (different than the in-situ) stress condition, with a simple creep model

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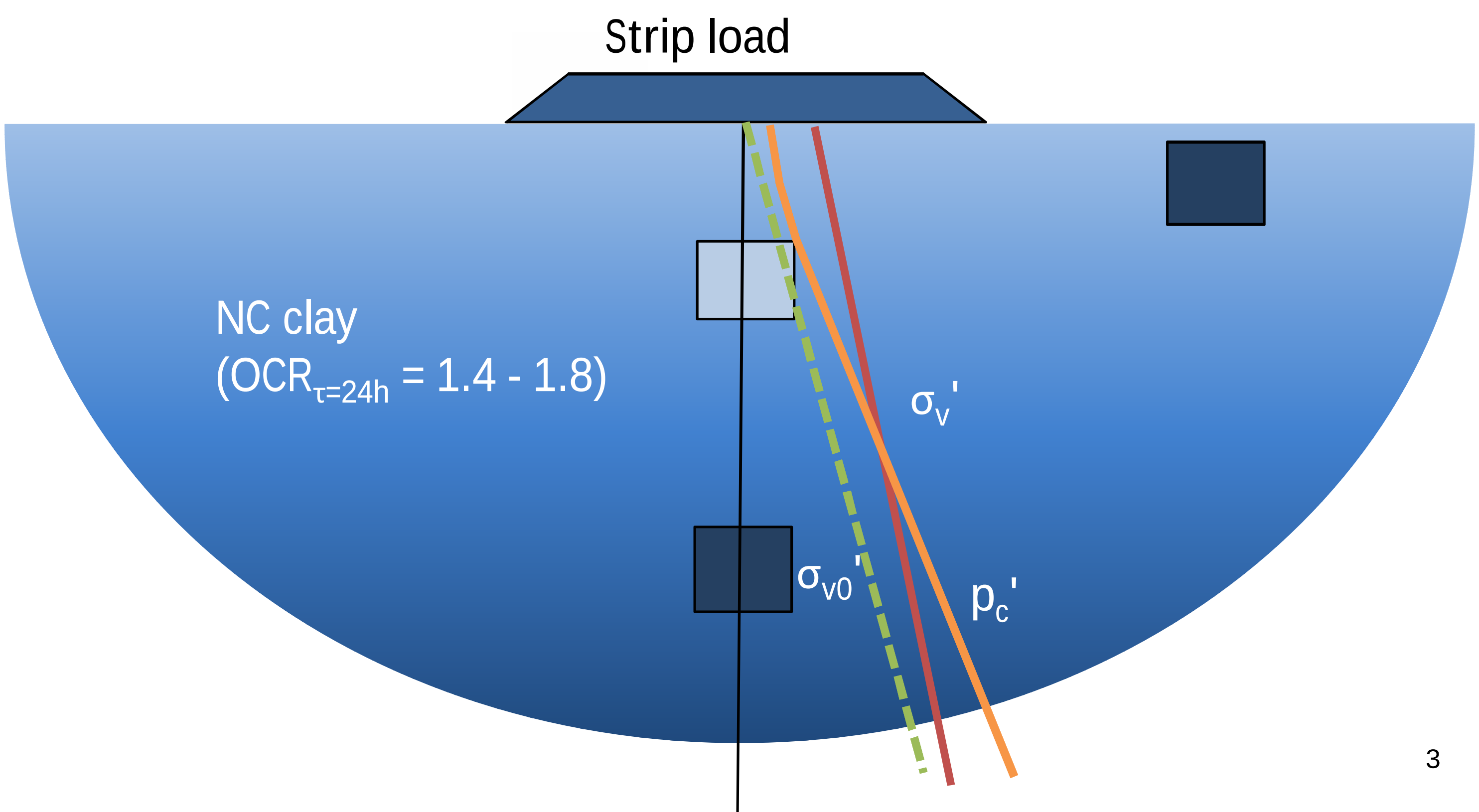
Outline

- Background
- Modelling creep
  - Time resistance concept
  - Soft Soil Creep Model (the “simple” model) in PLAXIS
  - Alternative extensions from 1D to 3D
- Implications of parameter selection
  - Creep ratio
  - Over Consolidation Ratio
- The MIT-MDPW test embankment
  - The case
  - Previous back calculations
  - Back calculation with OCR based on initial creep rate estimate
- Conclusions and recommendations

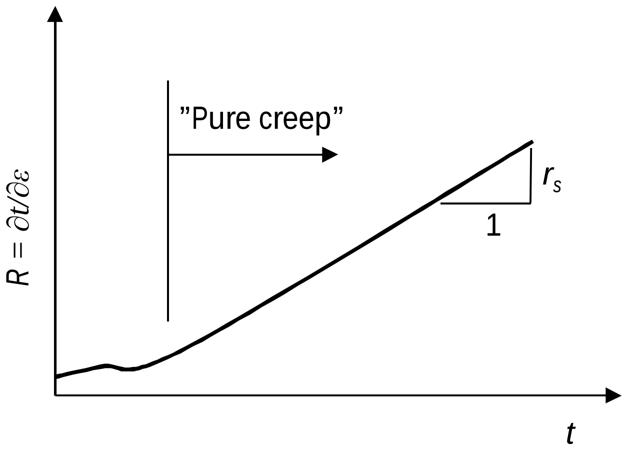
Background

- Expected new stress state to cross p_c' (24h)
- Expected new stress state below p_c' (24h)



Time resistance concept

- Described by in e.g. Janbu (1969)
- Used for 1D strain in KRYKON, Svanø & Emdal (1986)



$$r_s = \frac{d\left(\frac{\partial t}{\partial \varepsilon}\right)}{dt} = \frac{dR}{dt} = \frac{1}{\mu^*}$$

$$\frac{d\varepsilon}{dt} = \frac{\mu^*}{t}$$

$$\Delta\varepsilon\left(\Delta t = t - \tau\right) = \mu^* \cdot \ln\left(t/\tau\right)$$

Extending model to 3D

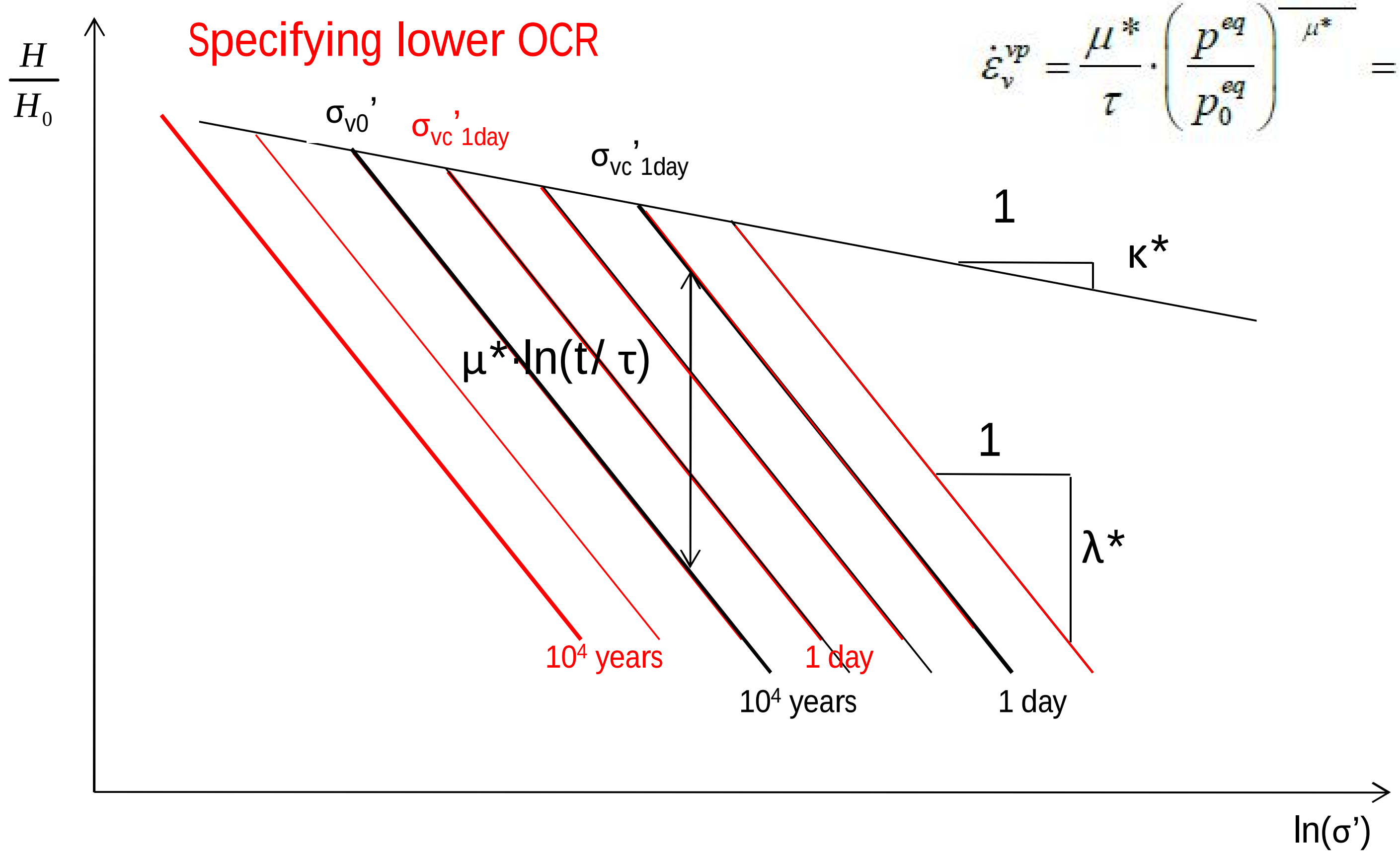
- Option 1: Volumetric strain always develops according to the equation below. The plastic multiplier is calculated by dividing with the differentiate of the plastic potential function with respect to the mean stress. (e.g. SSC, PLAXIS)

$$\dot{\varepsilon}_v^{vp} = \frac{\mu^*}{\tau} \cdot \left(\frac{p^{eq}}{p_0^{eq}} \right)^{\frac{\lambda^* - \kappa^*}{\mu^*}} = \frac{\mu^*}{\tau} \cdot OCR^{\frac{\mu^*}{\lambda^* - \kappa^*}}$$

- Option 2: The equation above is valid for 1D strain condition, i.e. it is given by the plastic multiplier and the plastic potential for this condition. (e.g. n-SAC, Grimstad et al. 2010)

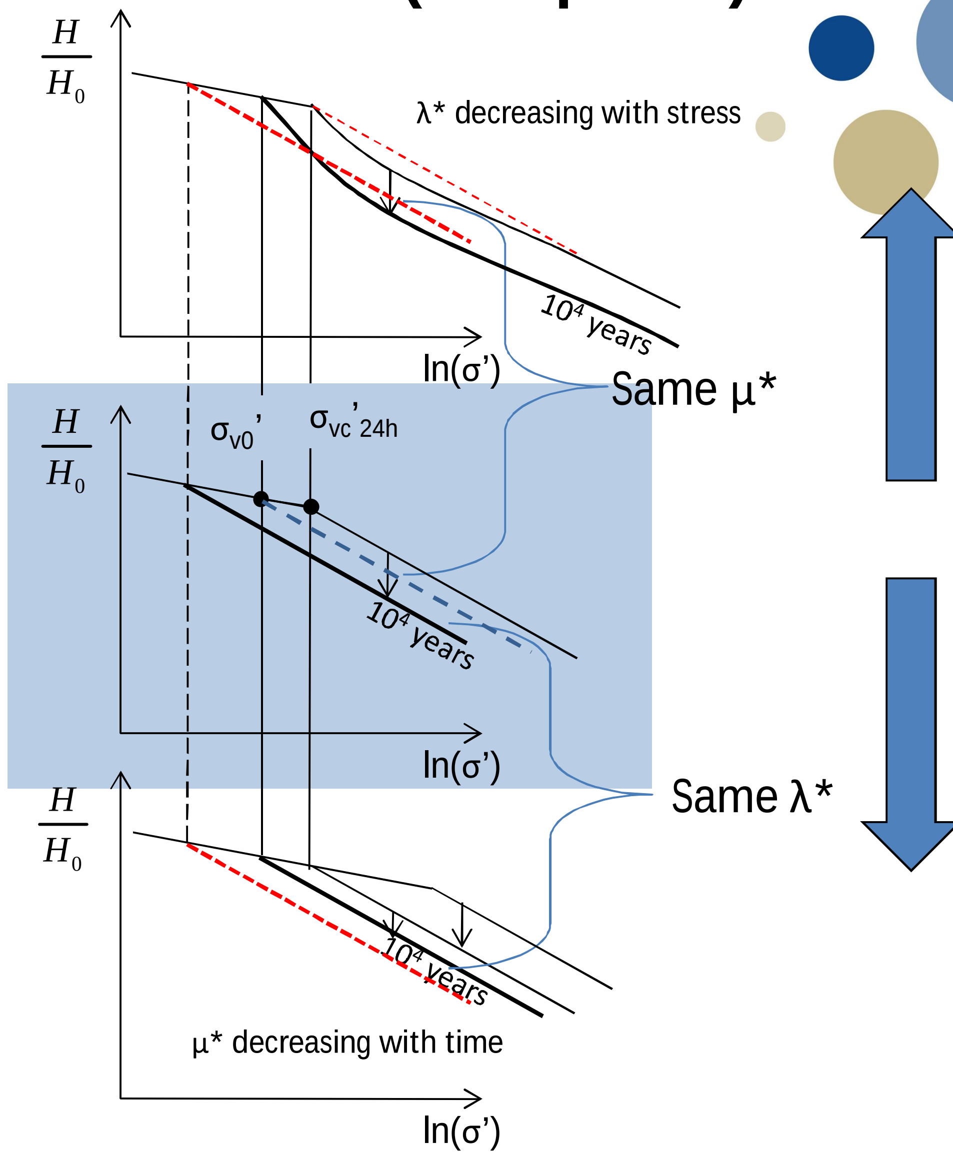
Example: SSC model - The effect of the μ*/(λ*-κ*) ratio on OCR (creep rate)

$$\dot{\varepsilon}_v^{vp} = \frac{\mu^*}{\tau} \cdot \left(\frac{p^{eq}}{p_0^{eq}} \right)^{\frac{\lambda^*-\kappa^*}{\mu^*}} = \frac{\mu^*}{\tau} \cdot OCR^{\frac{\mu^*}{\lambda^*-\kappa^*}}$$



The effect of the μ*/(λ*-κ*) ratio on OCR (creep rate)

$\frac{\mu^*}{\lambda^*-\kappa^*} = \frac{1}{r_s \cdot \zeta}$	$OCR_\tau = \left(\frac{t}{\tau}\right)^{\frac{\mu^*}{\lambda^*-\kappa^*}}$ $\tau = 1$ day $t = 10^4$ years	$t_{age} = \tau \cdot OCR_\tau^{\frac{\lambda^*-\kappa^*}{\mu^*}}$ $\tau = 1$ day $OCR_\tau = 1.3$
0.010	1.163	6.79E+08 years
0.015	1.254	1.08E+05 years
0.020	1.353	1.36E+03 years
0.025	1.459	98.9 years
0.030	1.574	17.2 years
0.035	1.697	4.93 years
0.040	1.830	1.93 years
0.050	2.129	0.520 years
0.070	2.880	0.116 years



"Recommended" range (PLAXIS manual)
~0.04 - 0.07

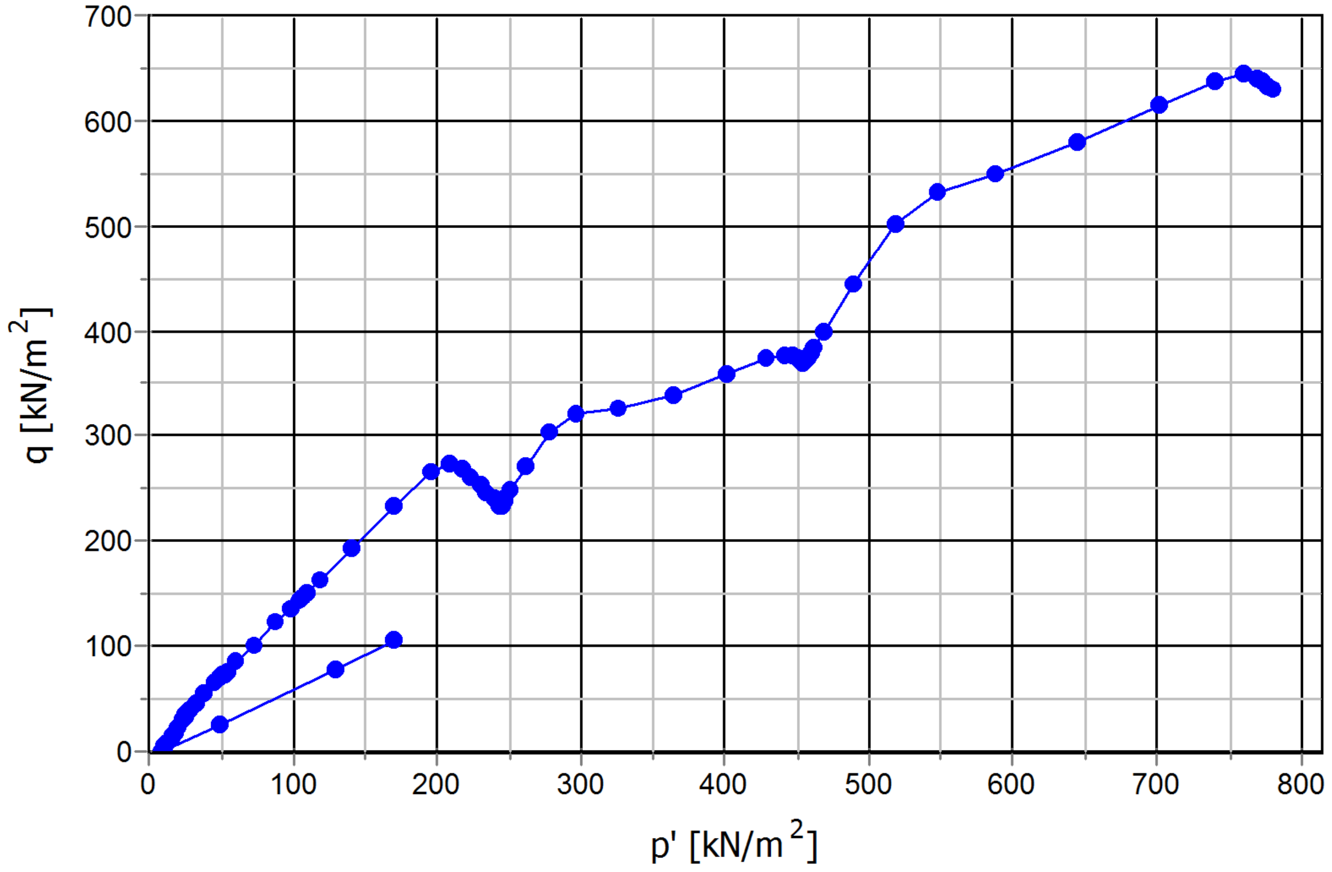
The oedometer test…

- Can we rely on OCR from IL oedometer tests?
  1) Sample disturbance, temperature? (we all know this)
  2) Stress condition?
     - Start at some unknown isotropic stress condition and consolidates to 12.5 kPa of vertical stress
     - Loads further along a line different from K_0^{NC} line (i.e. stress path hits the reference pre-consolidation at different place than it would in-situ!)

     → Do we need to simulate the oedometer test rather then interpret OCR from it?

     → Should we measure horizontal stress in the oedometer?
  3) Consolidation (is the effective stress constant for most of the 24h?, e.g. clays with low permeability)
  4) Extrapolation… (should model OCR and reality OCR be the same?)

Simulated oedometer with SSC

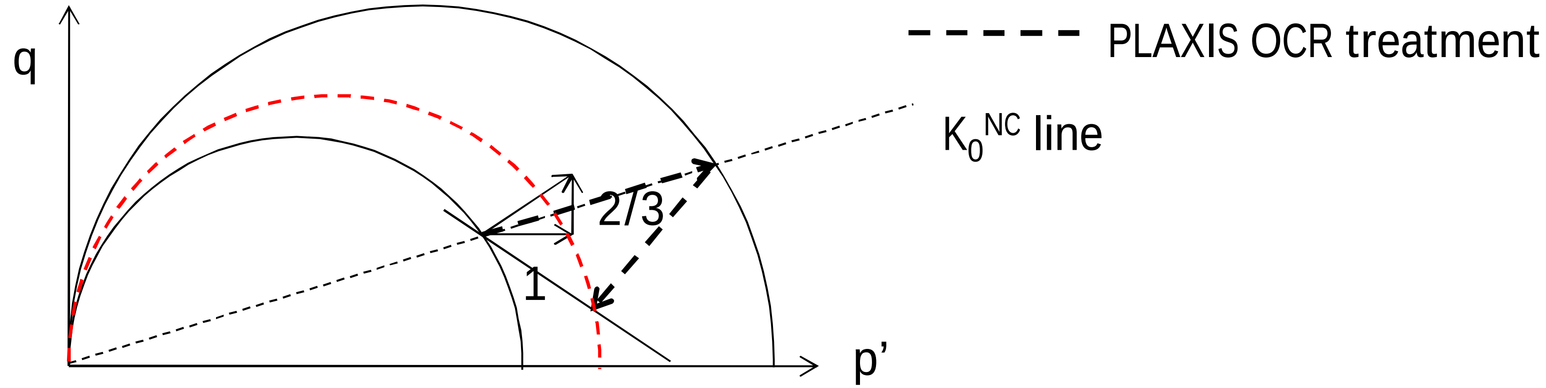


What about K_0?

- Is the in-situ K_0 affected by creep (NC clay)?
  - Model says: very limited influence, i.e. $K_0 \approx K_0^{NC}$
- Has the material been unloaded (OC clay)?
  - Model says: yes, but creep will try to make $K_0 \approx K_0^{NC}$ if the model is not changing its plastic potential, since the volumetric strain should be equal to the vertical strain
- Should we then set $K_0 \approx K_0^{NC}$ for models like SSC?

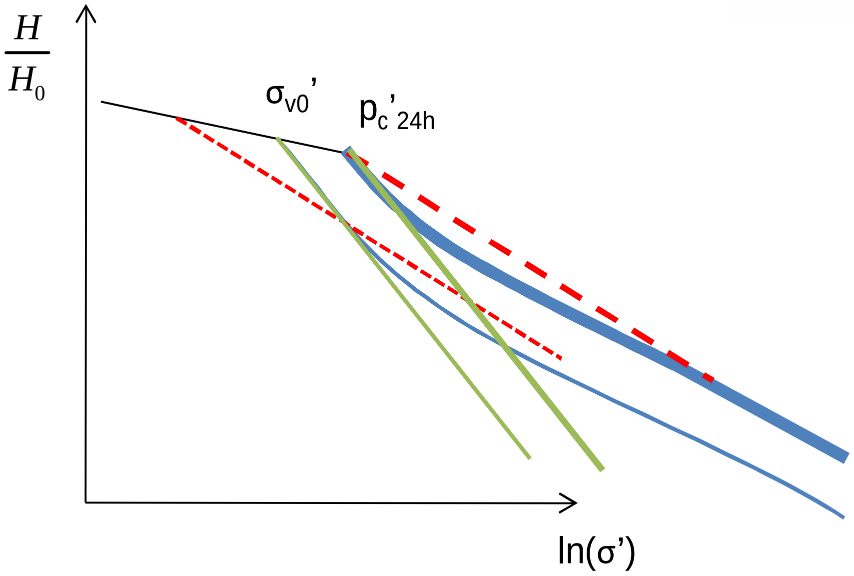
OCR and K_0

- The K_0 value does not change significantly in a 1D creep case due to the increase in OCR. Since 1D creep requires $d\varepsilon_1^{vp} = d\varepsilon_v^{vp}$, then the stress state is fixed to one point at the potential surface.
- In PLAXIS if one specify a OCR (due to creep alone), the suggested initial horizontal stress generated (suggested K_0) is based on the assumption of unloading. Remember to change this back to a value close to the real K_0^{NC}



Stress increment in the field

- No need to fit the whole lab curve…
  - What is the experienced stress change?
  - For most of the soil it is little change (around p_c' or less)



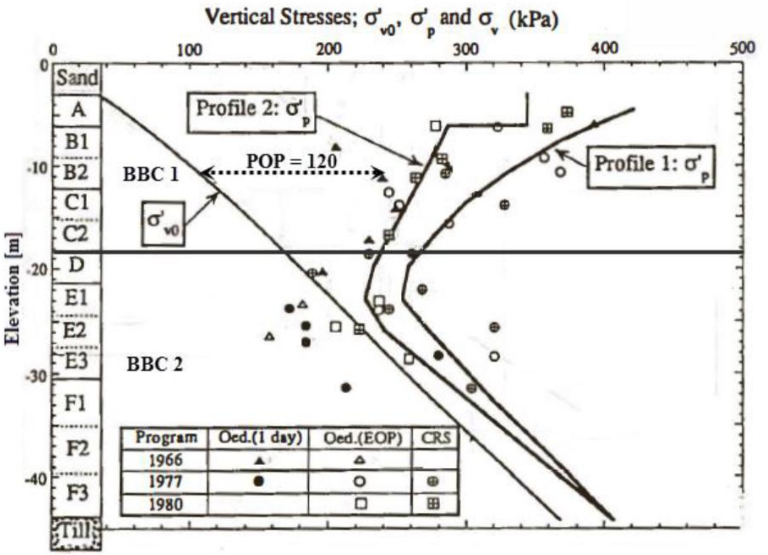
Accept wrong OCR – Fit at large stress change, well above p_c'

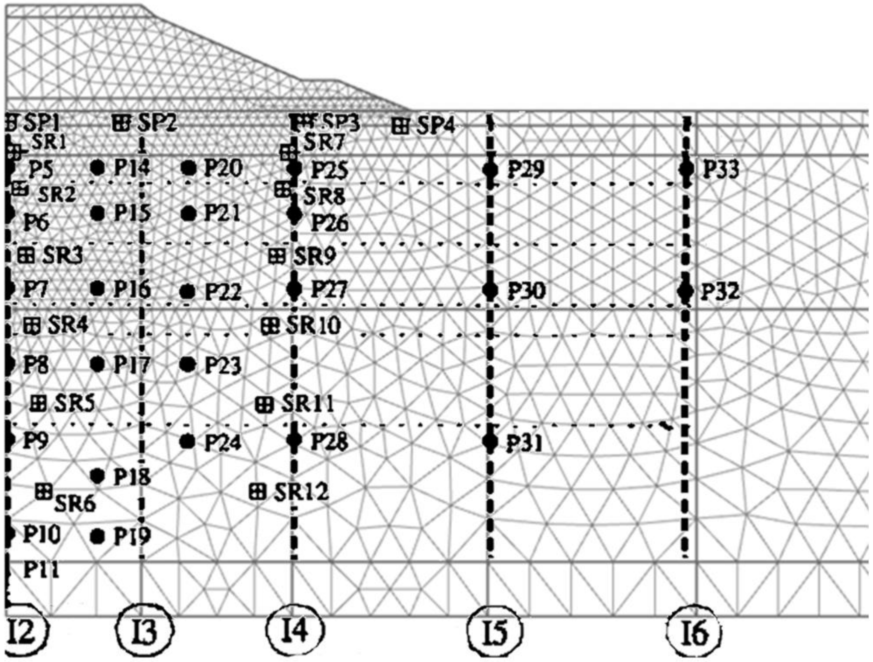
Accept that Inital creep rate is too big

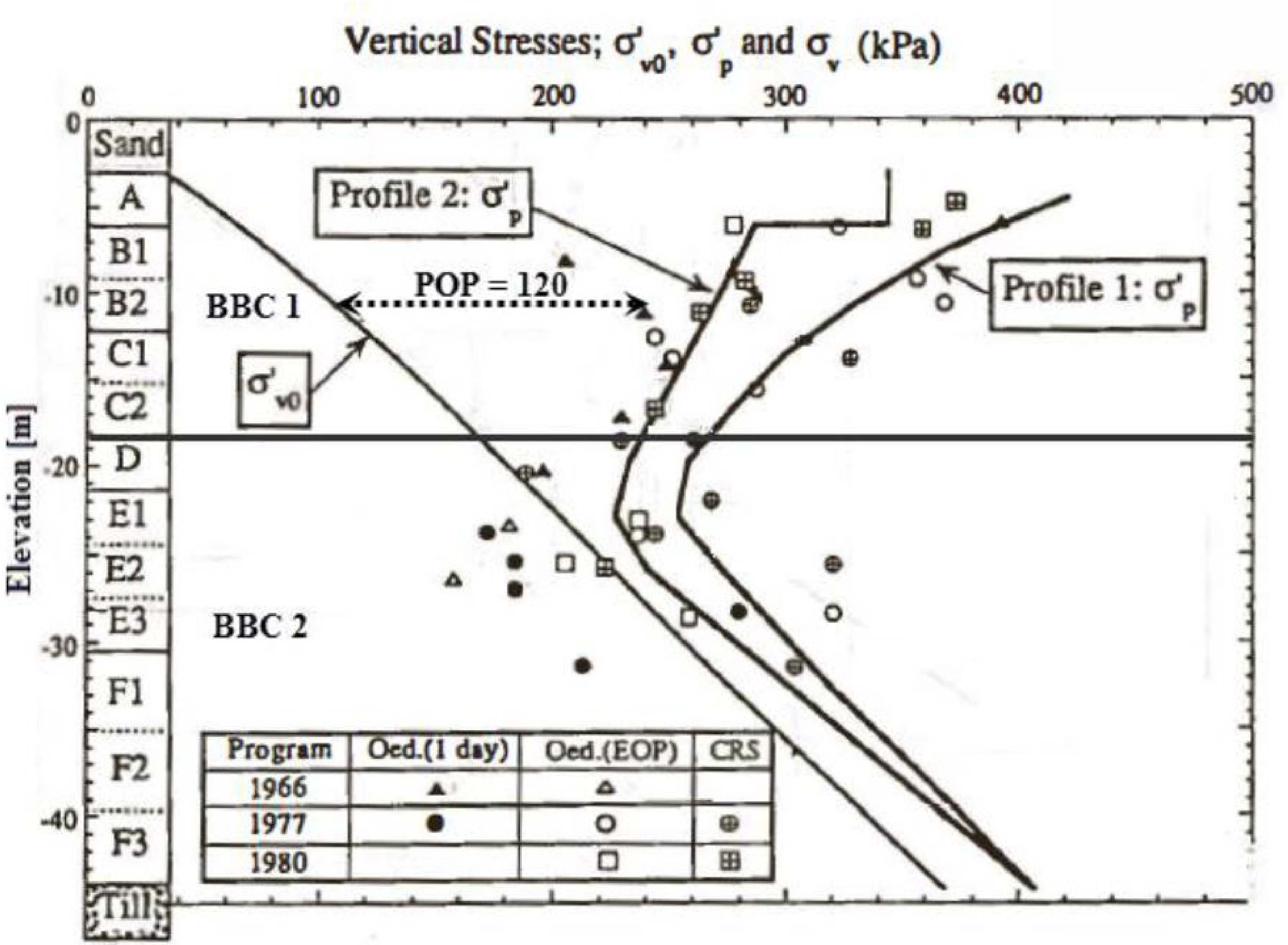
In most cases: Fit for the actual stress change in the region around p_c', higher λ^* gives lower OCR for same μ^*

The MIT–MDPW embankment

- Latest paper looking at back calculating this is from 2012 (Fatahi et al.)

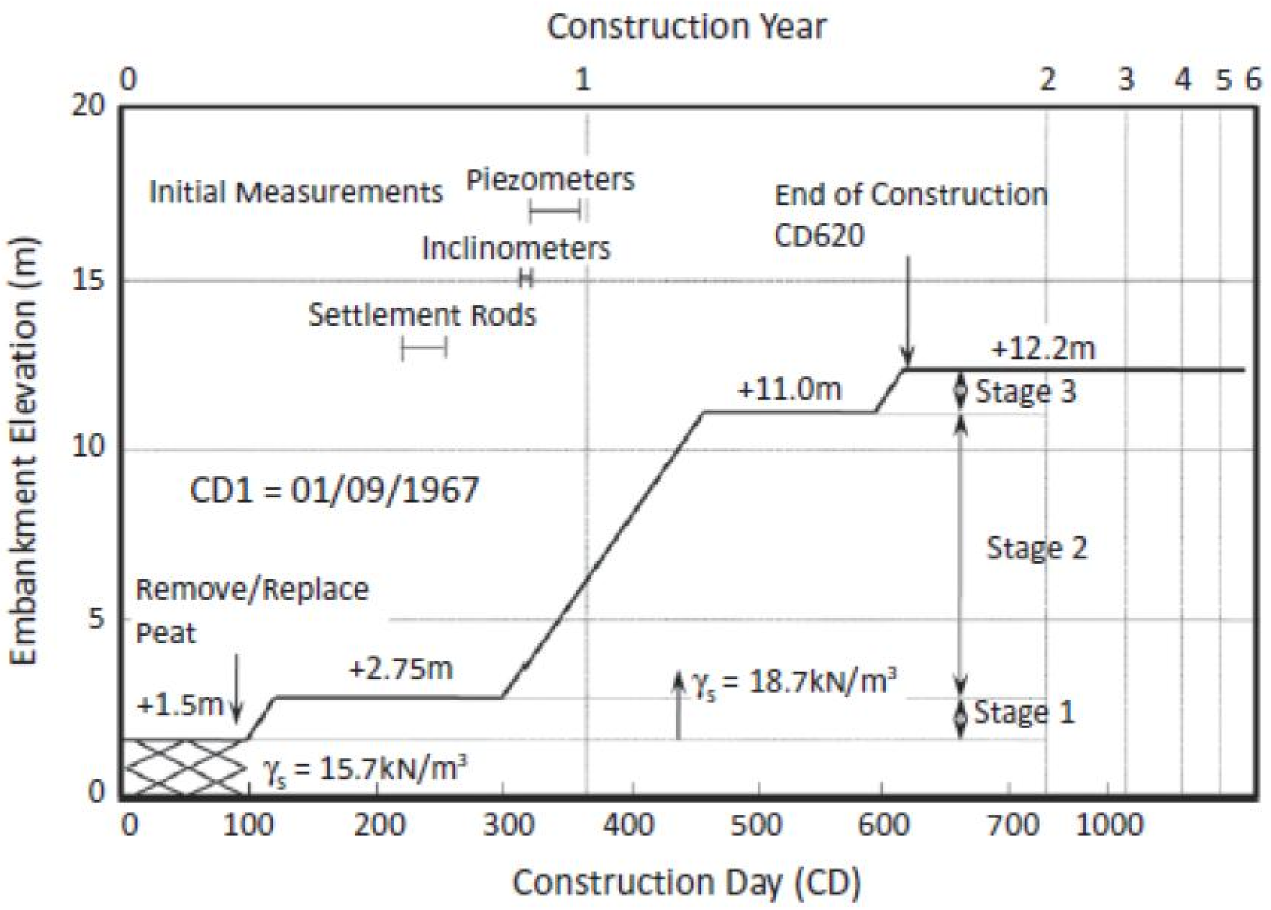




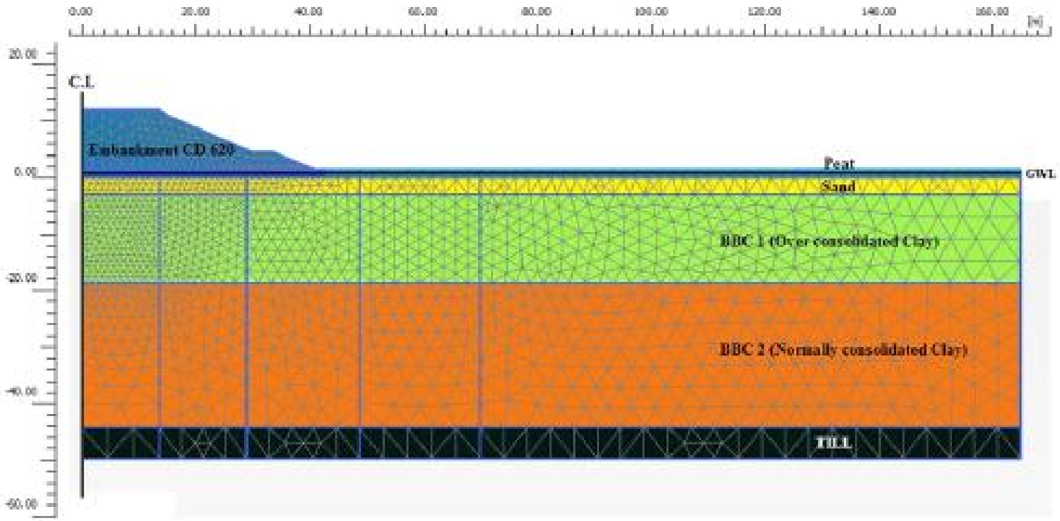


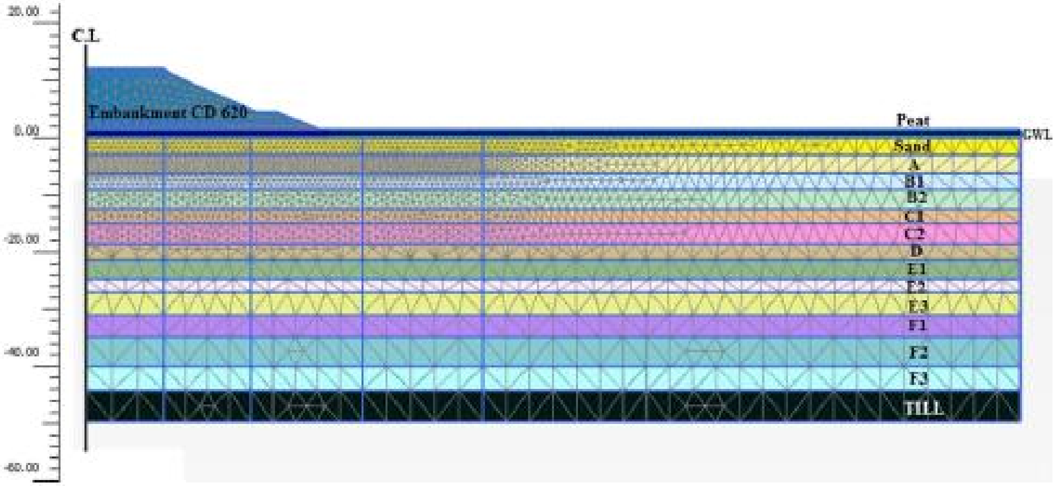
Vertical Stresses; σ'v0, σ'p and σv (kPa)
0
100
200
300
400
500
Elevation [m]
0
-10
-20
-30
-40
Sand
A
B1
B2
C1
C2
D
E1
E2
E3
F1
F2
F3
Till
Profile 2: σ'p
Profile 1: σ'p
POP = 120
BBC 1
BBC 2
σ'v0
Program
Oed.(1 day)
Oed.(EOP)
CRS
1966
1977
1980

The trial embankment

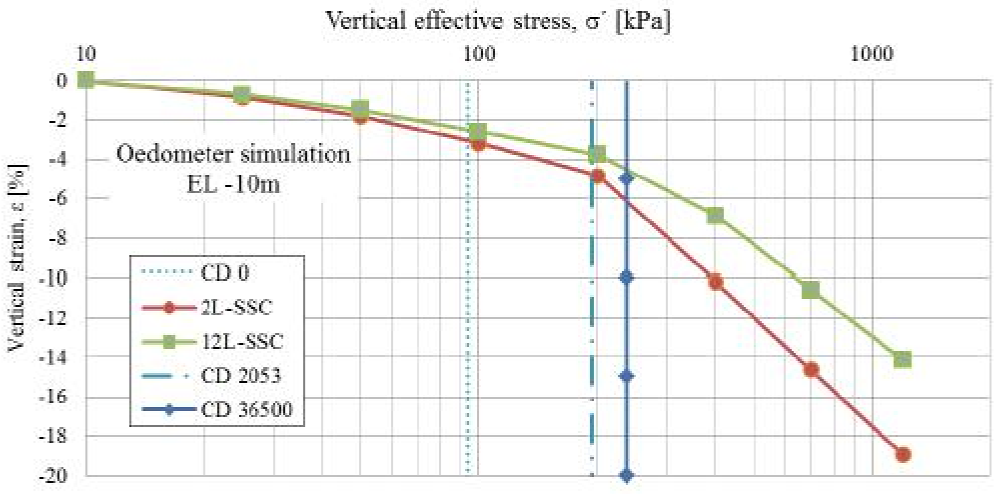


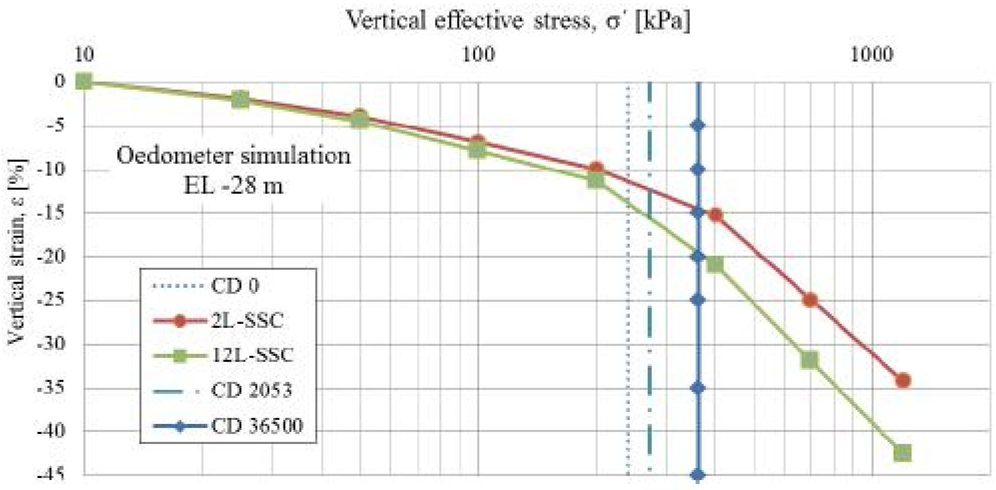
Alternative models



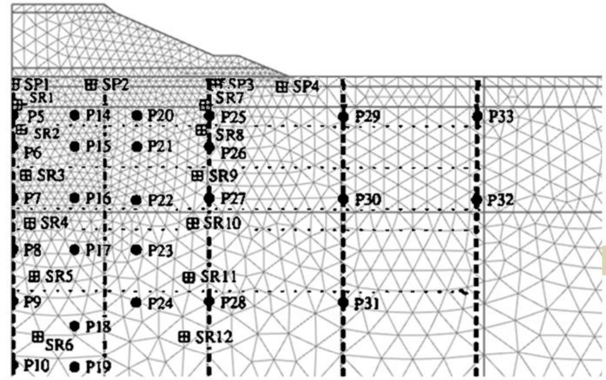


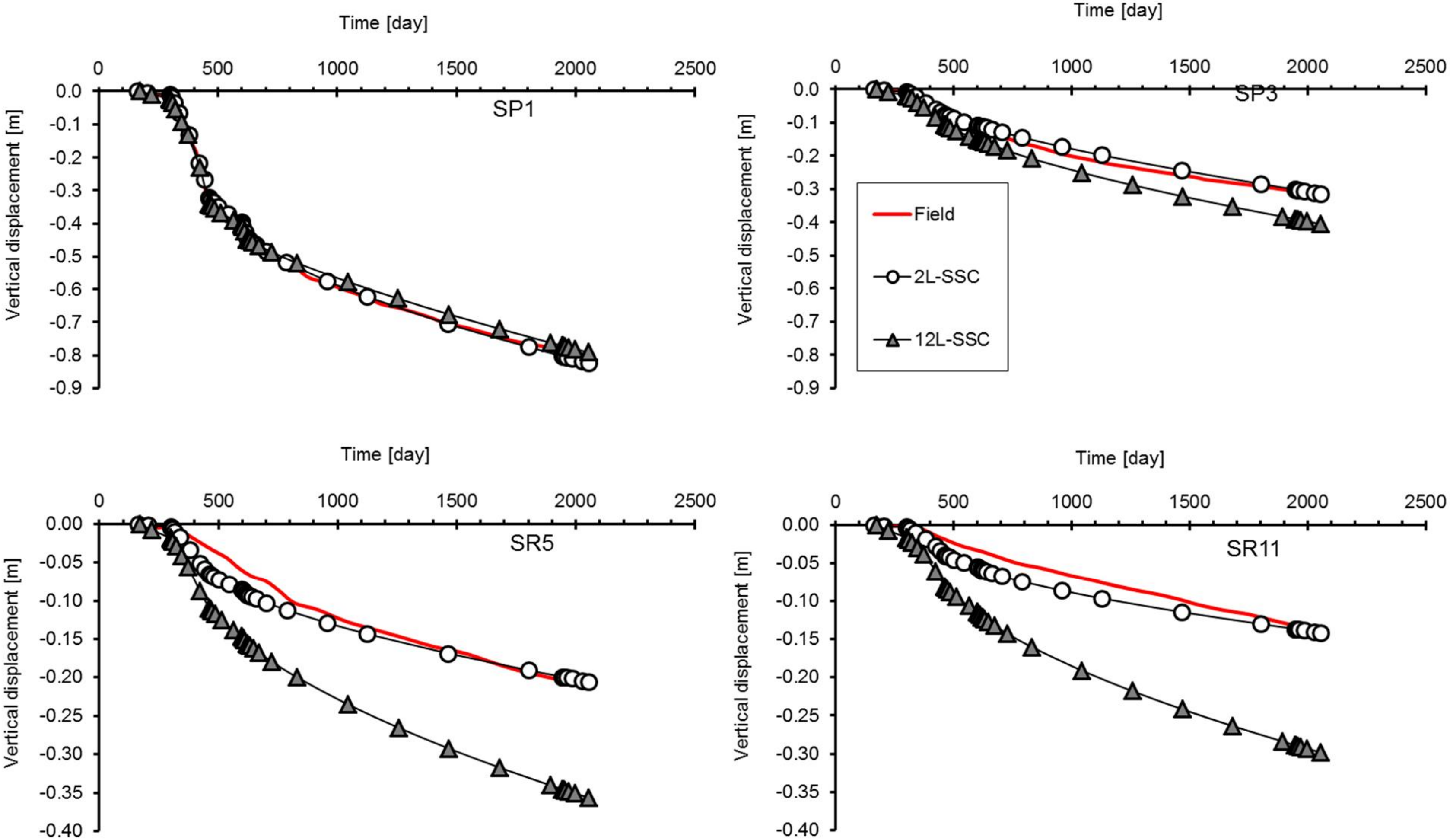
Oedometer simulations

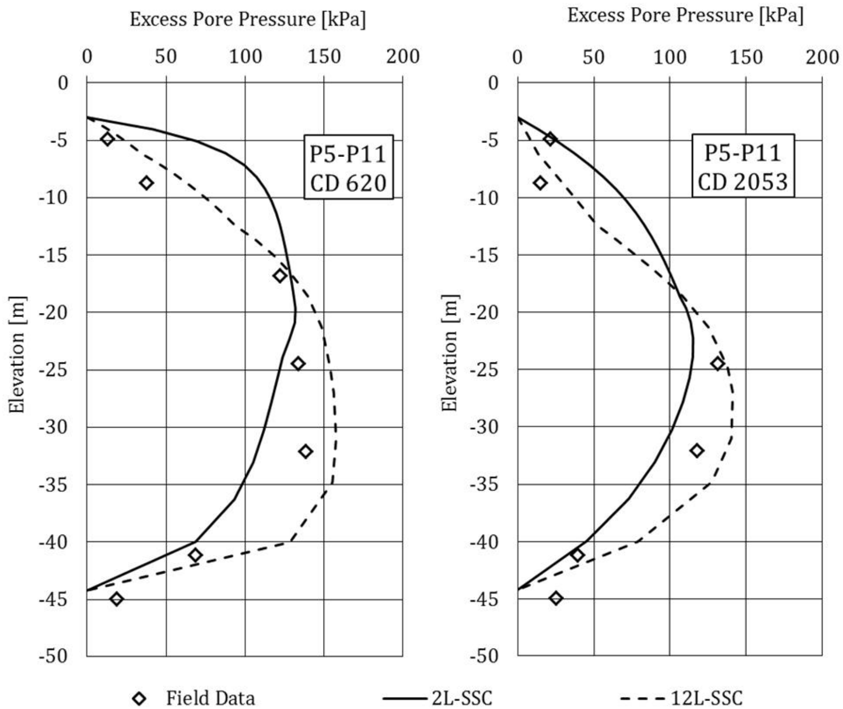


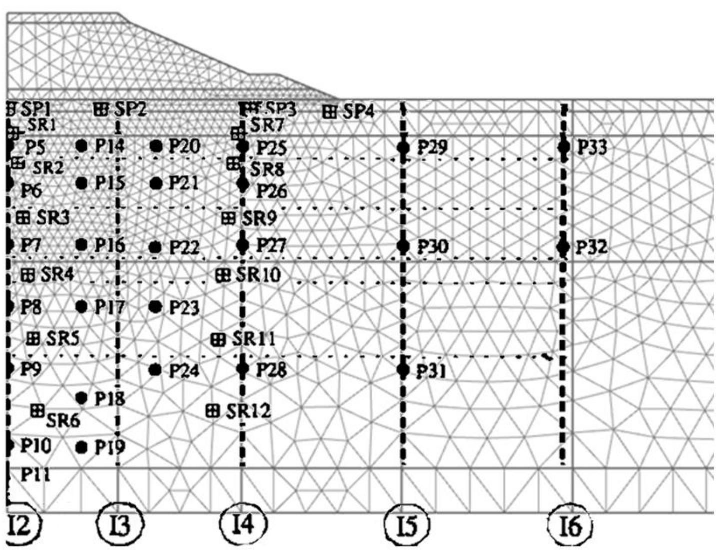


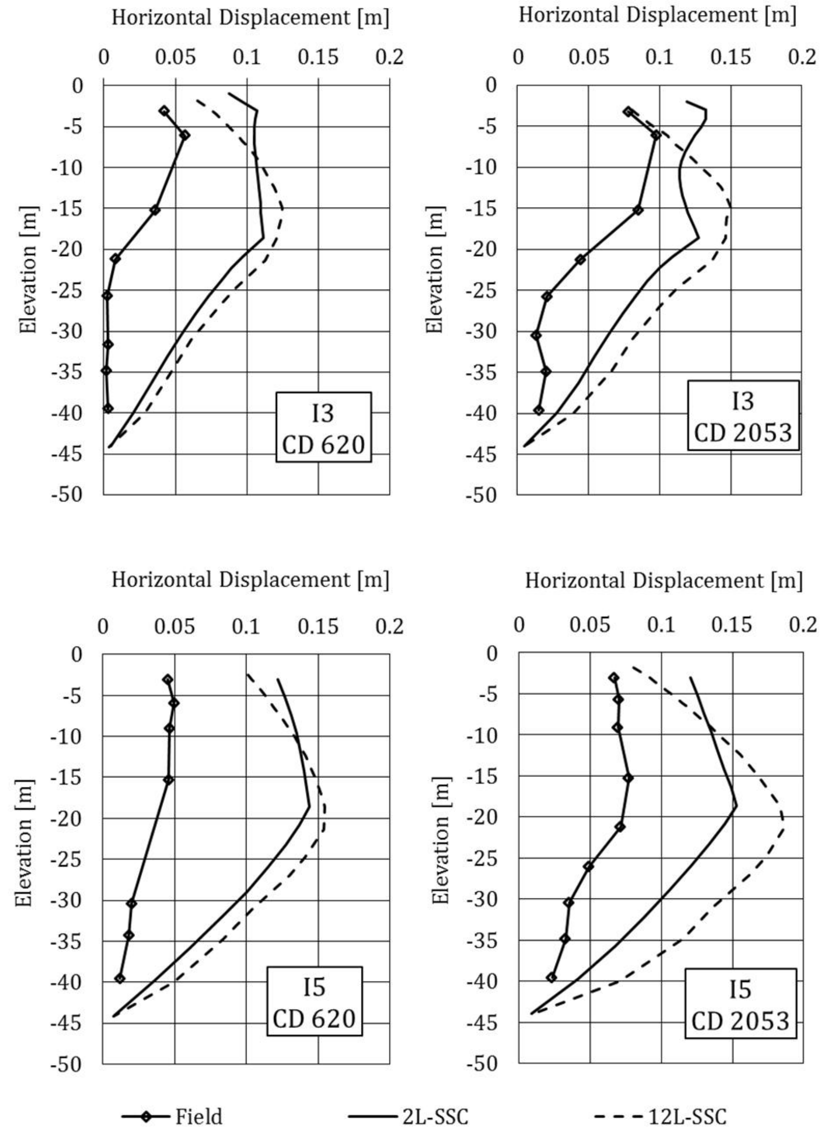
Results


SP1
SP2
SP3
SP4
SR1
SR2
SR3
SR4
SR5
SR6
SR7
SR8
SR9
SR10
SR11
SR12
P5
P6
P7
P8
P9
P10
P14
P15
P16
P17
P18
P19
P20
P21
P22
P23
P24
P25
P26
P27
P28
P29
P30
P31
P32
P33


Time [day]
Vertical displacement [m]
SP1
SP3
SR5
SR11
Field
2L-SSC
12L-SSC
0
500
1000
1500
2000
2500
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40


Excess Pore Pressure [kPa]
Elevation [m]
P5-P11
CD 620
Excess Pore Pressure [kPa]
Elevation [m]
P5-P11
CD 2053
Field Data
2L-SSC
12L-SSC


SP1
SP2
SP3
SP4
SR1
SR7
P5
P14
P20
P25
P29
P33
SR2
SR8
P6
P15
P21
P26
SR3
SR9
P7
P16
P22
P27
P30
P32
SR4
SR10
P8
P17
P23
SR5
SR11
P9
P24
P28
P31
P18
SR6
SR12
P10
P19
P11
I2
I3
I4
I5
I6


Horizontal Displacement [m]
Elevation [m]
I3
CD 620
Horizontal Displacement [m]
Elevation [m]
I3
CD 2053
Horizontal Displacement [m]
Elevation [m]
I5
CD 620
Horizontal Displacement [m]
Elevation [m]
I5
CD 2053
Field
2L-SSC
12L-SSC

Conclusions

- Evaluate the parameters over relevant stress increments
- Do not blindly take OCR from odeometer tests
  - Stress path
  - Sample disturbance
- The “simple” SSC model performs OK when we are after vertical deformation profile and pore pressure. As long as we take some care for the OCR we use in modelling.
  - NC clay does not usually have OCR of 1.1…
  - OCR in SSC is a material parameter that defines initial state of the soil (i.e. the state variable p_0^{eq}), it is not more holy than the other parameters that we use to fit our model to “reality”

$$\lambda^*,\ \kappa^*,\ \mu^*,\ \nu,\ \varphi,\ c,\ K_0^{NC}$$

Any Q?

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