2014 CREBS Workshop at Deltares

Surcharge Loading On Reduction of Secondary Compression

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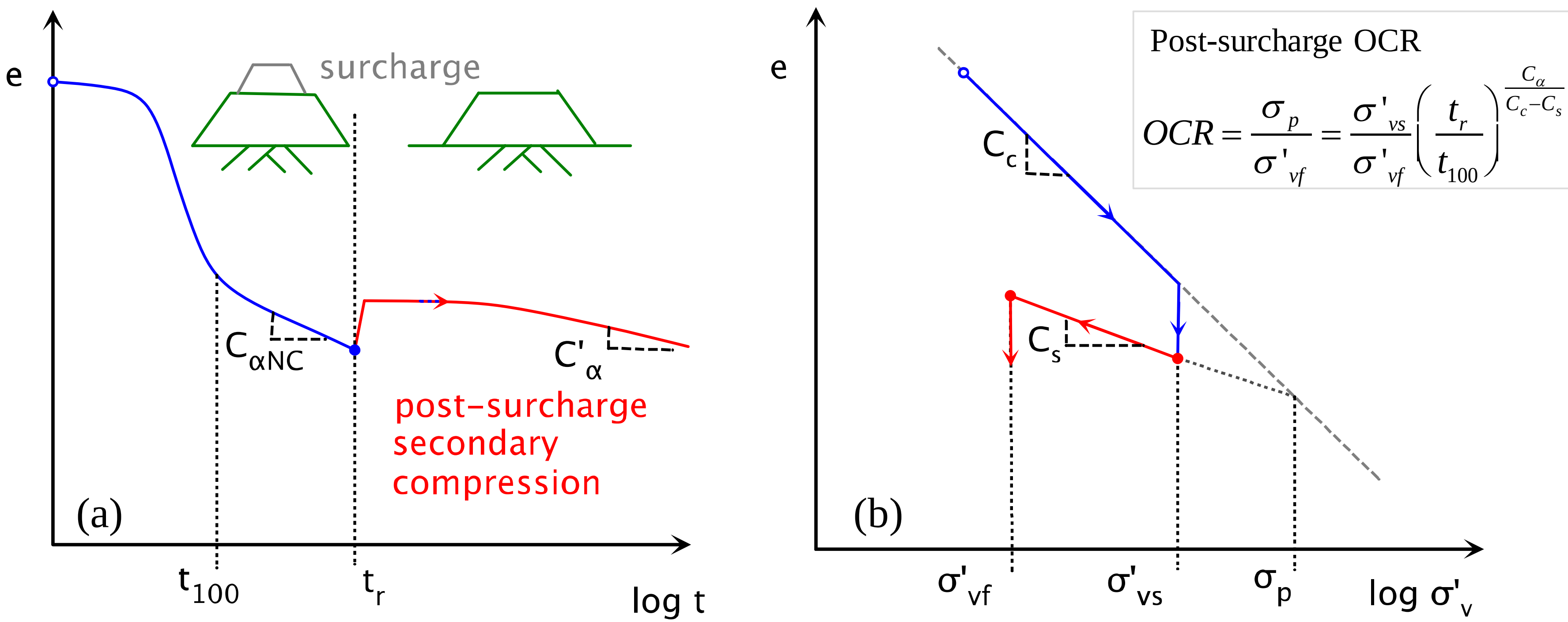
Surcharging to Reduce Secondary Compression



Post-surcharge OCR

$$OCR = \frac{\sigma_p}{\sigma'_{vf}} = \frac{\sigma'_{vs}}{\sigma'_{vf}}\left(\frac{t_r}{t_{100}}\right)^{\frac{C_\alpha}{C_c - C_s}}$$

(after MIT 1.322 notes by Prof. Ladd 1989)

<u>Amount Of Surcharge</u> $AOS = \left(\sigma'_{vs} - \sigma'_{vf}\right) / \sigma'_{vf}$

<u>Adjusted Amount Of Surcharge</u> $AAOS = \left(\sigma'_{p} - \sigma'_{vf}\right) / \sigma'_{vf}$

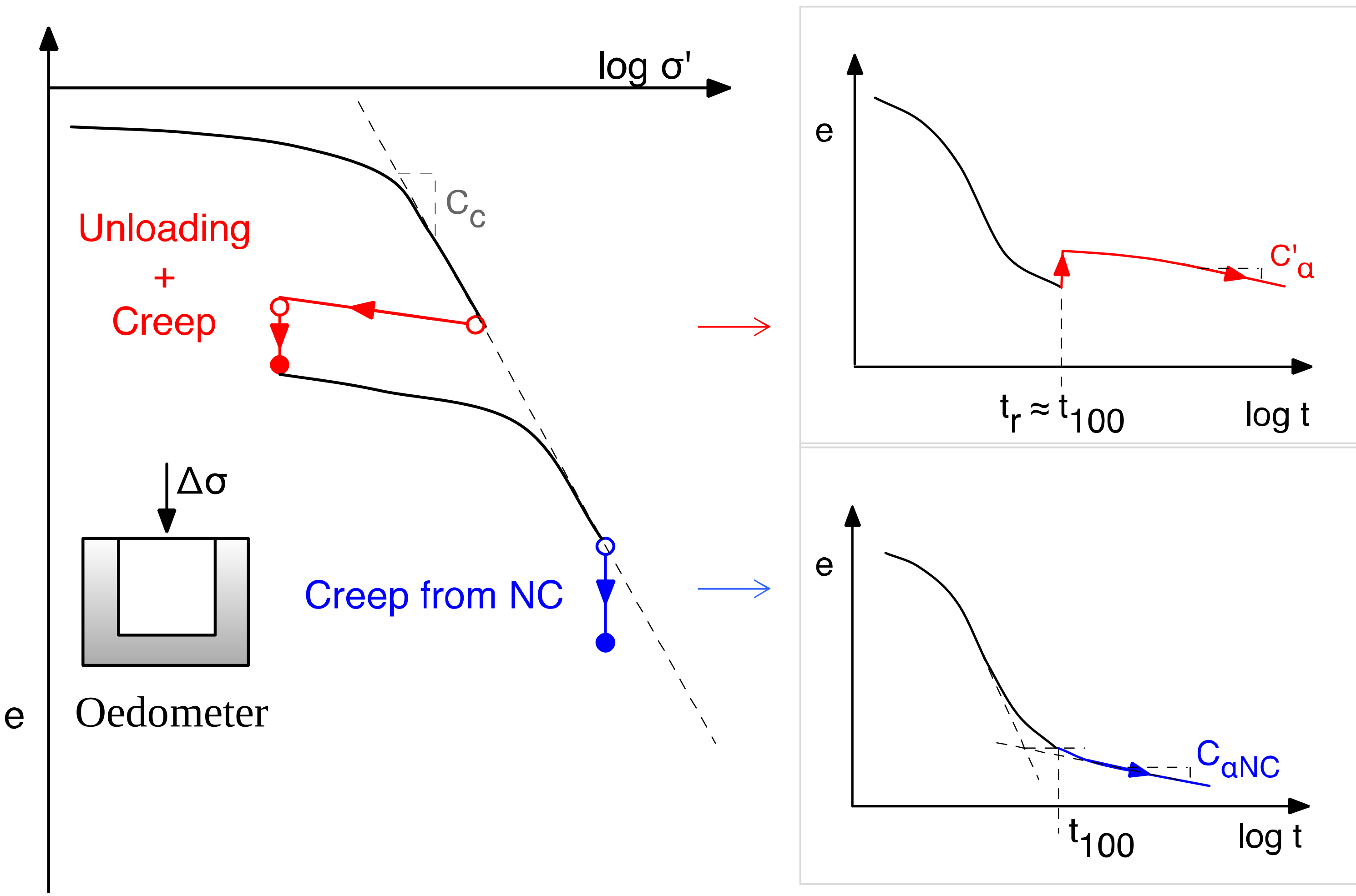
$= OCR - 1$

Outline

- Modeling Post-surcharge secondary compression
- Influence of surcharge on creep behavior
- Suggestions for more realistic Isotache models

Prior Experimental Study

[Ng, SM Thesis 1998]



$t_r \approx t_{100}$

C'_{α}

$OCR = AAOS + 1$

$t_{100} \rightarrow \dot{\varepsilon}_{100}$

$C_{\alpha NC}$

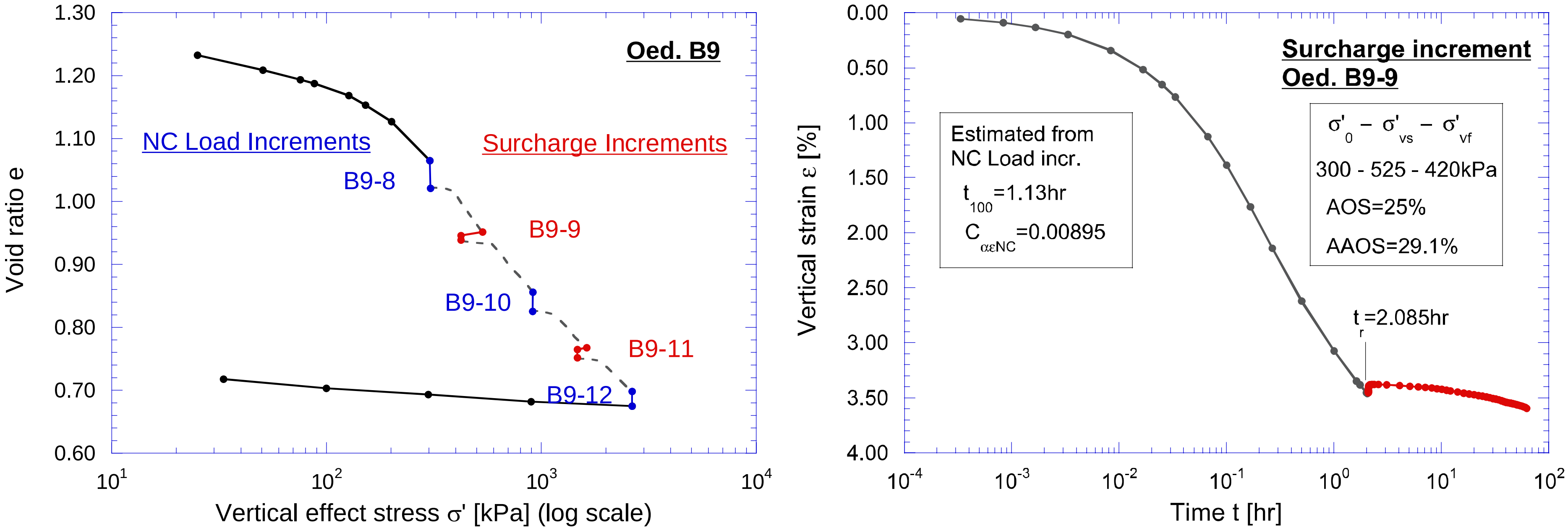
Salt Lake City [SLC] clay

W_P=22.3 ± 3.1%	W_L=43.6 ± 7.6%	G_s=2.73 ± 0.04

Test # (Boring)	Depth [m]	W_N [%]	e_0	C_c	σ_{p0} / σ'_0 [kPa]
B4 (B102A)	9.60	45.5	1.386	0.51-0.48	144 / 94
B7 (B102A)	8.05	57.2	1.643	0.89-0.70	156 / 81
B8 (B102A)	6.39	44.0	1.257	0.56-0.41	185 / 66
B9 (B105A)	12.90	42.2	1.282	0.51-0.37	225 / 133
B10 (B105A)	11.38	47.6	1.292	0.95-0.39	264 / 120

5 oedometer tests, 10 surcharge increments in total

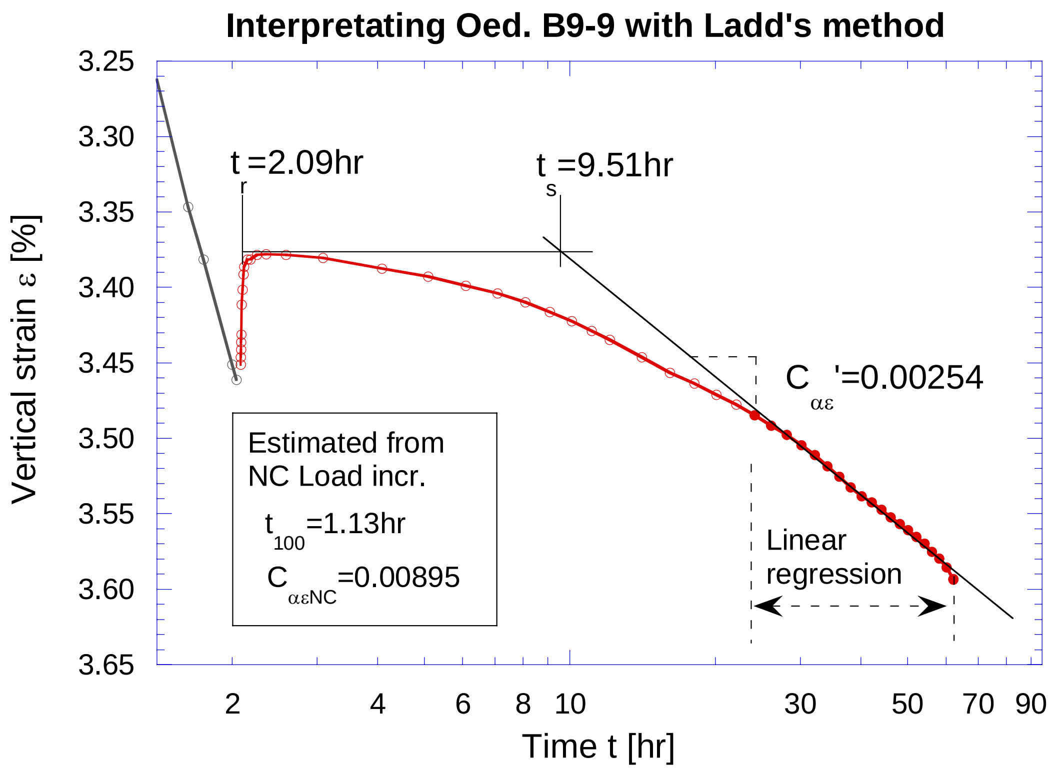
Typical Results



(from Ng 1998)

Empirical Interpretation [Ladd's Method]

(This method was proposed by Prof. Ladd in MIT 1.322 "soil behavior" course since 1989)



Linear tangential fit

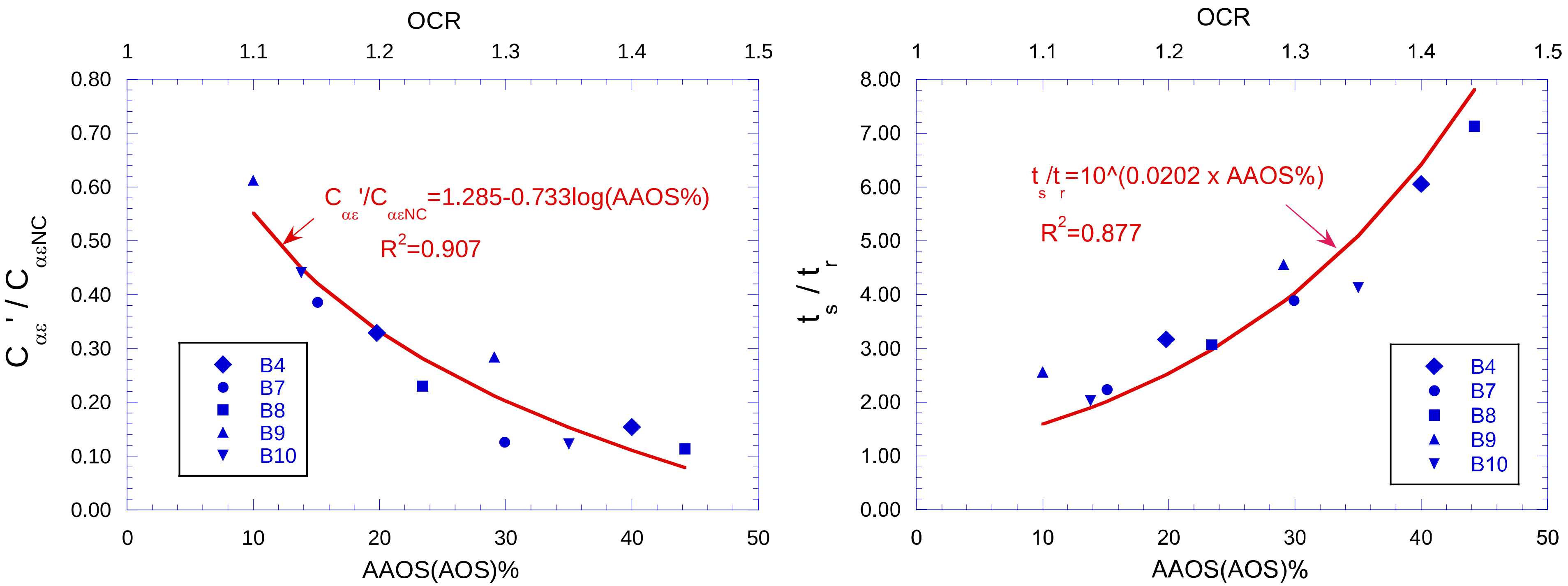
⟶ $C_{\alpha\varepsilon}$'

Bilinear intersection

⟶ t_s

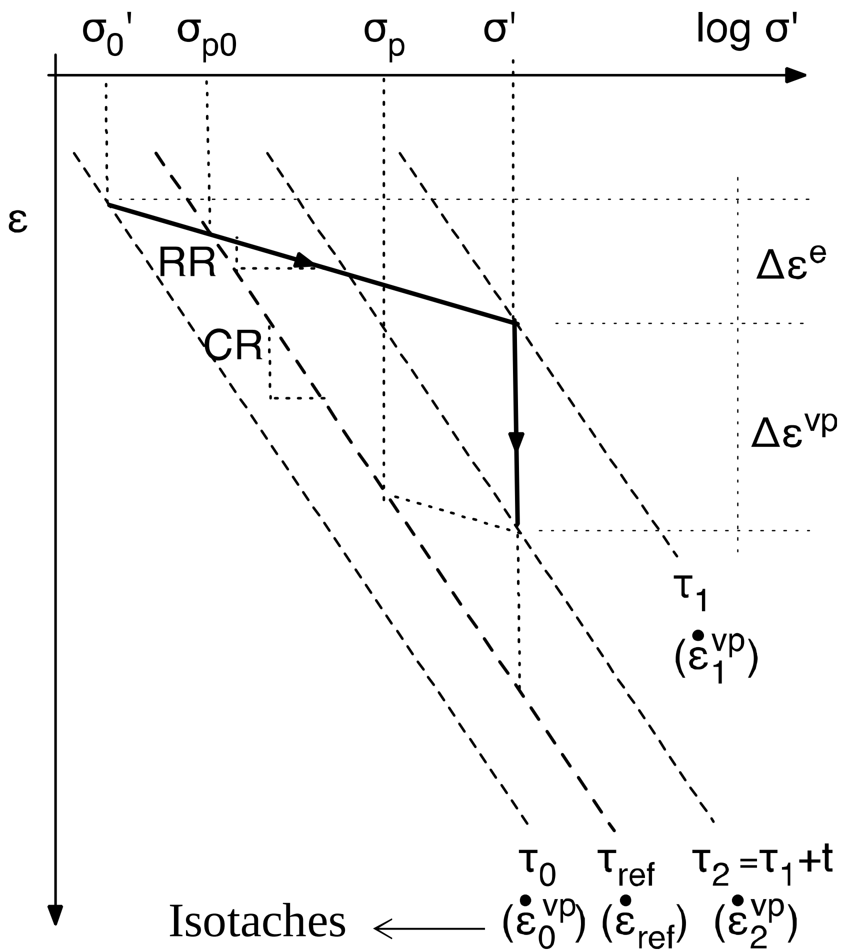
- Easy for practical use
- Range of linear regression needs subjective judgment

Empirical Correlations



(from Ng 1998)

Formulation of SSC [Vermeer & Neher 1999]



Decomposition

$$\dot{\varepsilon} = \dot{\varepsilon}^{e} + \dot{\varepsilon}^{vp}$$

Elastic

$$\dot{\varepsilon}^{e} = 0.434\, RR \frac{\dot{\sigma}'}{\sigma'}$$

Viscoplastic (flow rule)

$$\dot{\varepsilon}^{vp} = 0.434 \frac{C_{\alpha\varepsilon}}{\tau_{ref}} \left(\frac{\sigma'}{\sigma_p} \right)^{\frac{CR-RR}{C_{\alpha\varepsilon}}}$$

Hardening

$$\sigma_p = \sigma_{p0} \exp\left[\frac{\Delta\varepsilon^{vp}}{0.434(CR-RR)} \right]$$

- $\sigma' > 0$: always creep

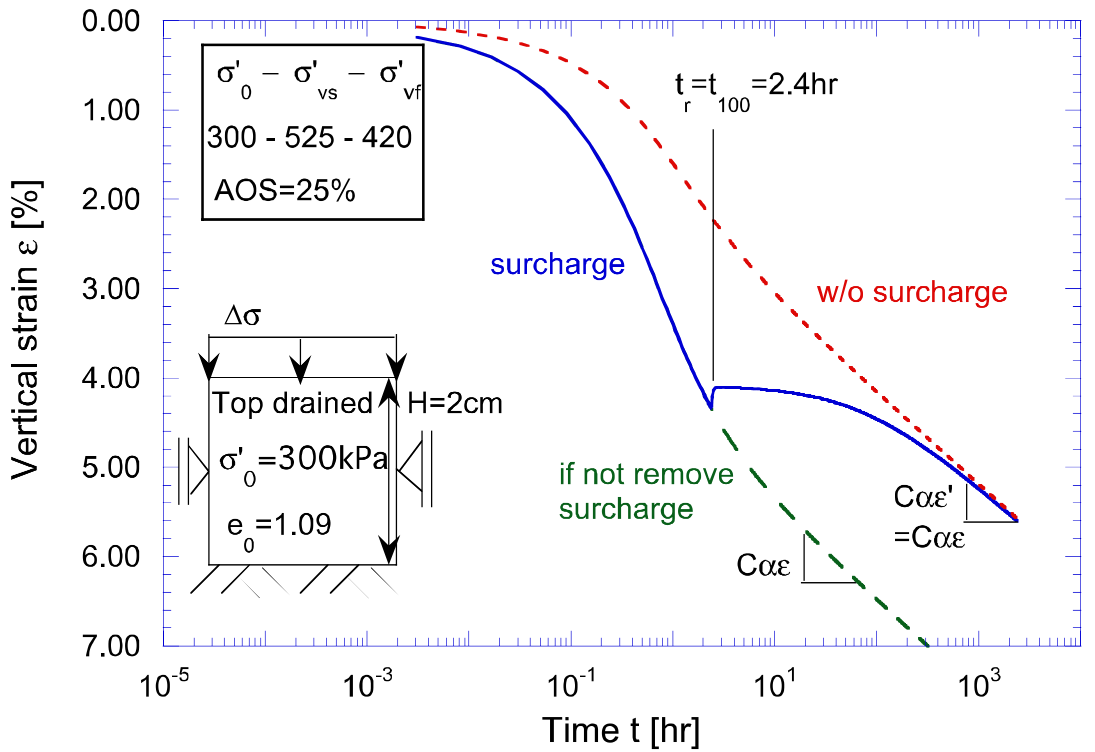
- Constant isotache distance $C_{\alpha\varepsilon}$

SSC Parameters

Parameters		Suggested value or data for calibration
Compression ratio	CR	1D (or Isotropic) compression curve in ε-$\log_{10}\sigma$ space
Recompression ratio	RR	Reloading curve of 1D (or Isotropic) consolidation
Secondary compression coefficient	$C_{\alpha\varepsilon}$	Secondary compression curve or from $C_{\alpha\varepsilon}$/CR ratio
Reference time	τ_{ref}	Normally assumed as 24 hrs
Initial value of state parameter	σ_{p0}	Preconsolidation pressure from 24hr-IL oedometer test
		Data fitting CRS compression curve in ε-$\log_{10}\sigma$ space

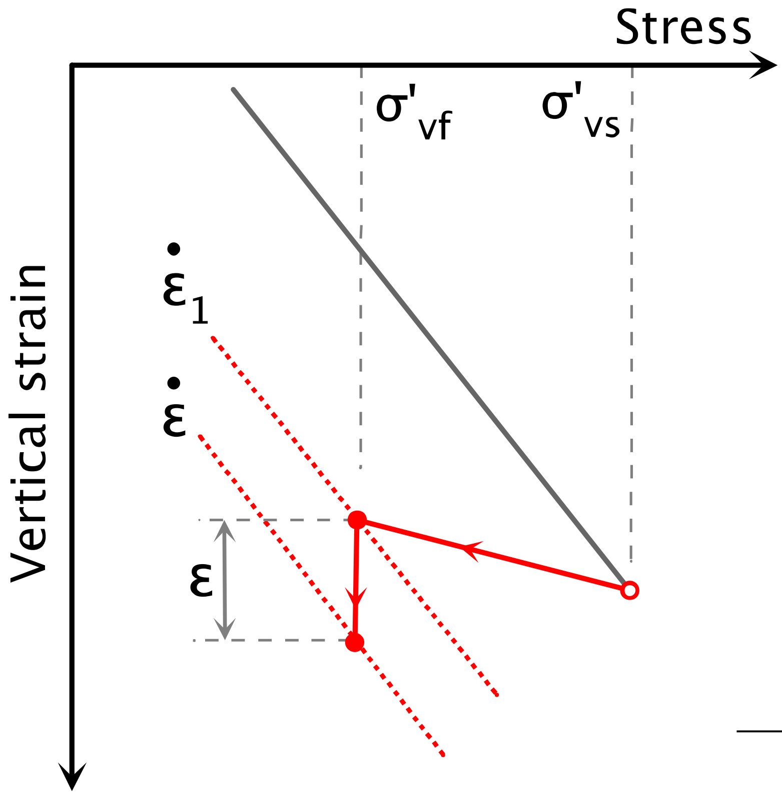
SSC Simulation of 1D Surcharge Test

Soil	k_0 [m/day]	C_k	CR	RR	$C_{\alpha\varepsilon NC}$	τ_{ref} [hr]	σ_{pc0} [kPa]	e_0	σ'_0 [kPa]
SLC clay	$2\text{x}10^{-5}$	0.5	0.24	0.036	0.0102	24	300	1.09	300



Constant $C_{\alpha\varepsilon}$

Isotache Concept [Suklje 1957]



Isotaches

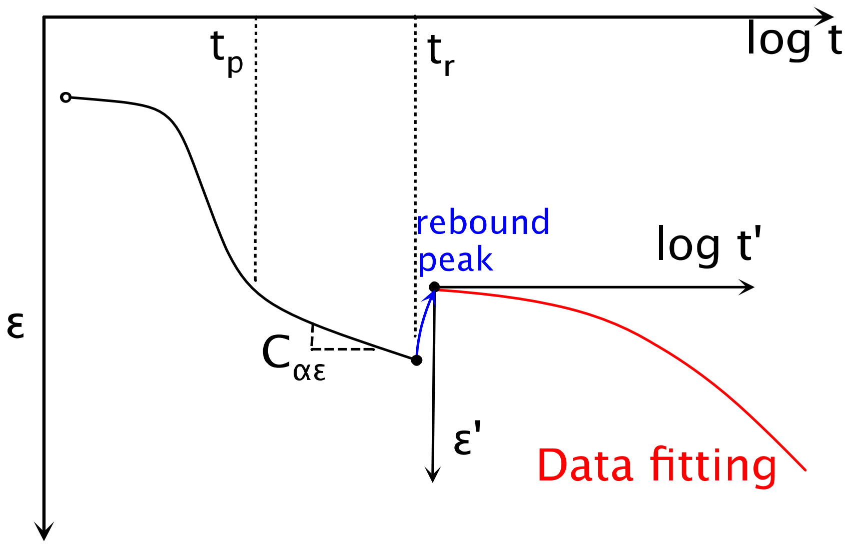
$$\varepsilon = -0.434\hat{C}_{\alpha\varepsilon}\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_1}$$

Integration

$$\int_{\varepsilon_0=0}^{\varepsilon'}\exp\left(\frac{\varepsilon}{0.434\hat{C}_{\alpha\varepsilon}}\right)d\varepsilon = \int_{t_0=0}^{t'}\dot{\varepsilon}_1\,dt$$

$$\varepsilon' = 0.434\hat{C}_{\alpha\varepsilon}\ln\left(\frac{\dot{\varepsilon}_1}{0.434\hat{C}_{\alpha\varepsilon}}t'+1\right)$$

Interpreting Post-surcharge Creep with Isotache Concept



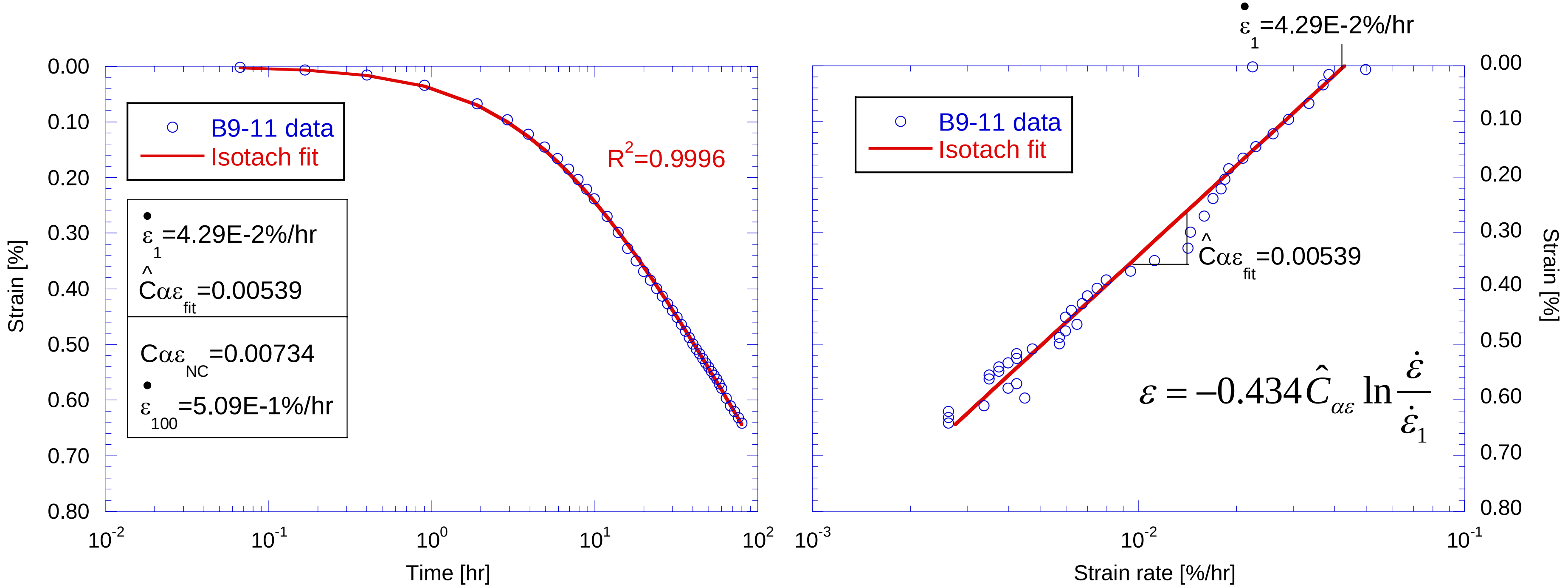
Post-surcharge secondary compression can be captured by

$$\varepsilon' = 0.434\,\hat{C}_{\alpha\varepsilon}\ln\left(\frac{\dot{\varepsilon}_1}{0.434\,\hat{C}_{\alpha\varepsilon}/t'}+1\right)$$

Fitting two parameters: $\dot{\varepsilon}_1$ and $\hat{C}_{\alpha\varepsilon}$

Example I: Fitting to Increment B9-11

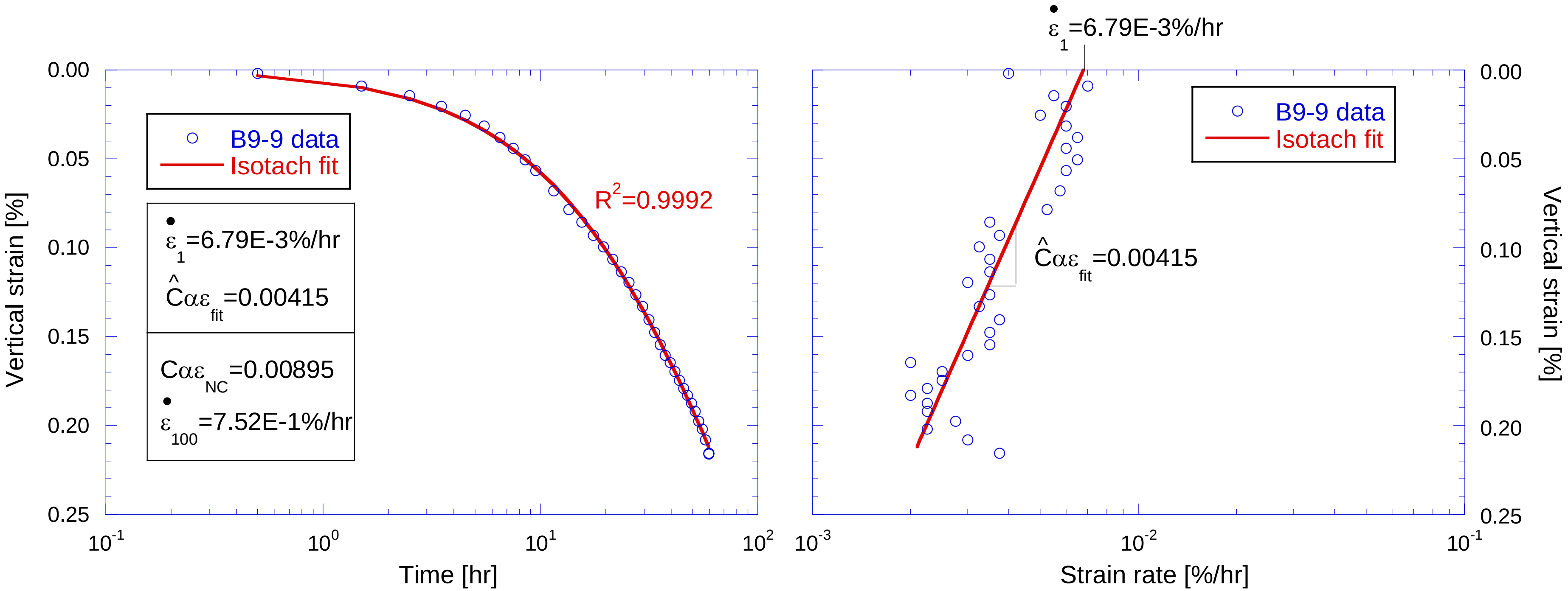
(AOS=10%; OCR=1.10)



Post-surcharge data is consistent with Isotache concept [Nash, 2001]

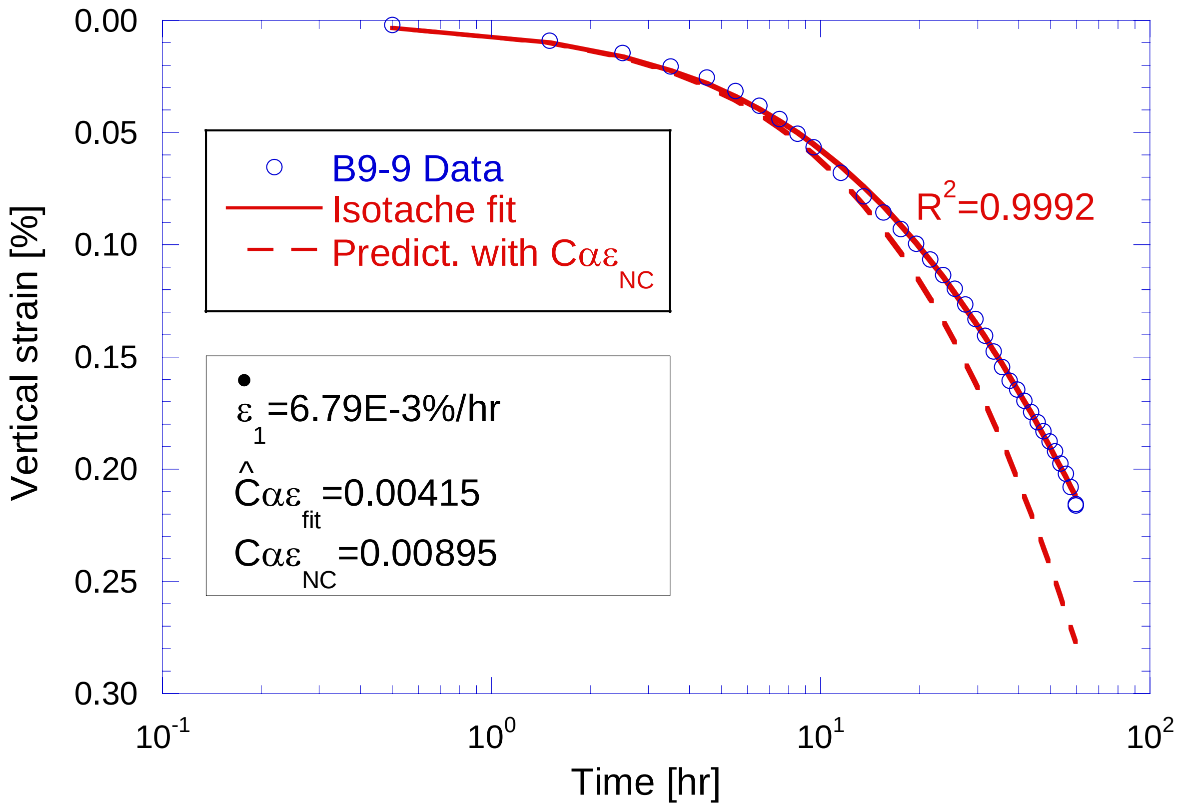
Example II: Fitting to Increment B9-9

(AAOS=29.1%; OCR=1.291)



Derived equation represents the entire evolution of post-surcharge creep

Existing Models Overestimate Creep Strains



Existing models overestimate post-surcharge settlement with constant $C_{\alpha\varepsilon NC}$

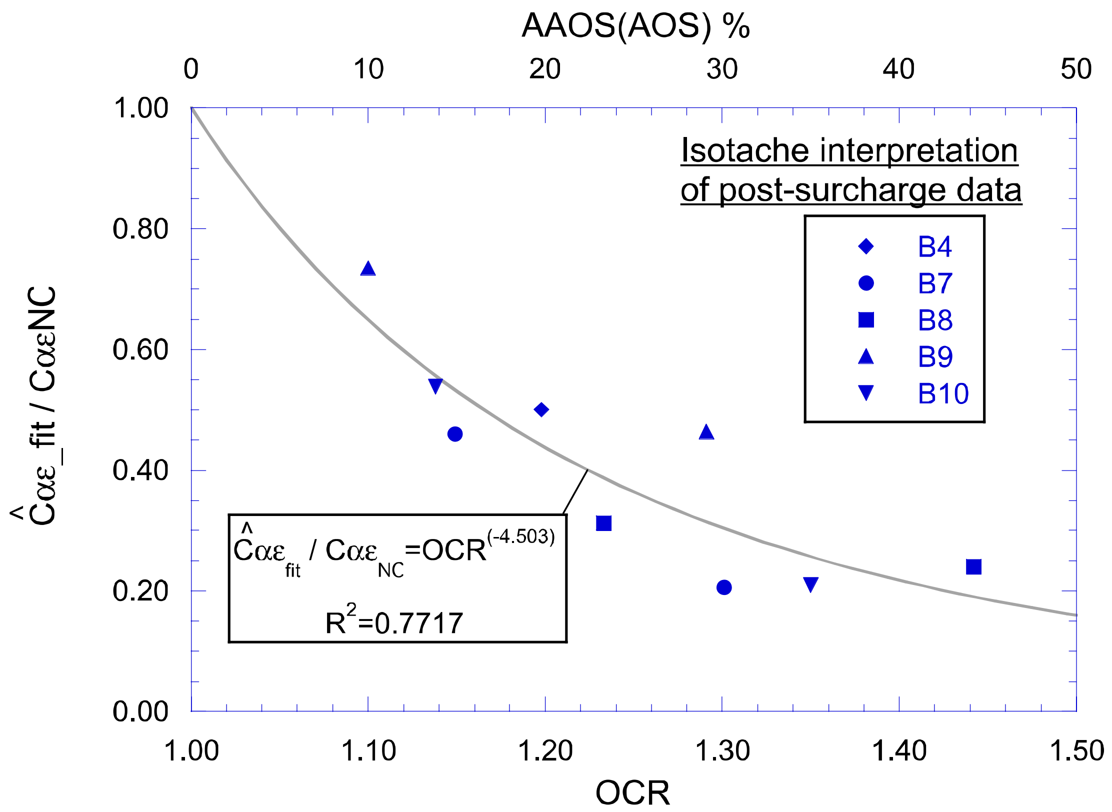
Summary of Data fitting

Surcharge Incr.	OCR	$\hat{C}_{\alpha\varepsilon}$	$\dot{\varepsilon}_1$ [%/hr]	R^2
B10-8	1.350	0.00257	0.0046	0.998
B10-9	1.138	0.00398	0.0207	0.999
B9-9	1.291	0.00415	0.0068	0.999
B9-11	1.100	0.00539	0.0429	0.999
B8-10	1.233	0.00235	0.0310	0.998
B8-11	1.442	0.00171	0.0047	0.998
B7-6	1.149	0.00533	0.1229	0.999
B7-7	1.301	0.00198	0.0176	0.999
B4-7	1.198	0.00435	0.0448	0.995
~~B4-8*~~	~~1.400~~	~~0.02753~~	~~0.0041~~	??

$C_{\alpha\varepsilon NC}$	$\dot{\varepsilon}_{100}$ [%/hr]
0.01224	0.562
0.00739	0.661
0.00895	0.752
0.00734	0.509
0.00753	2.281
0.00711	1.884
0.01159	0.986
0.00958	1.483
0.0087	0.725
0.00825	1.163

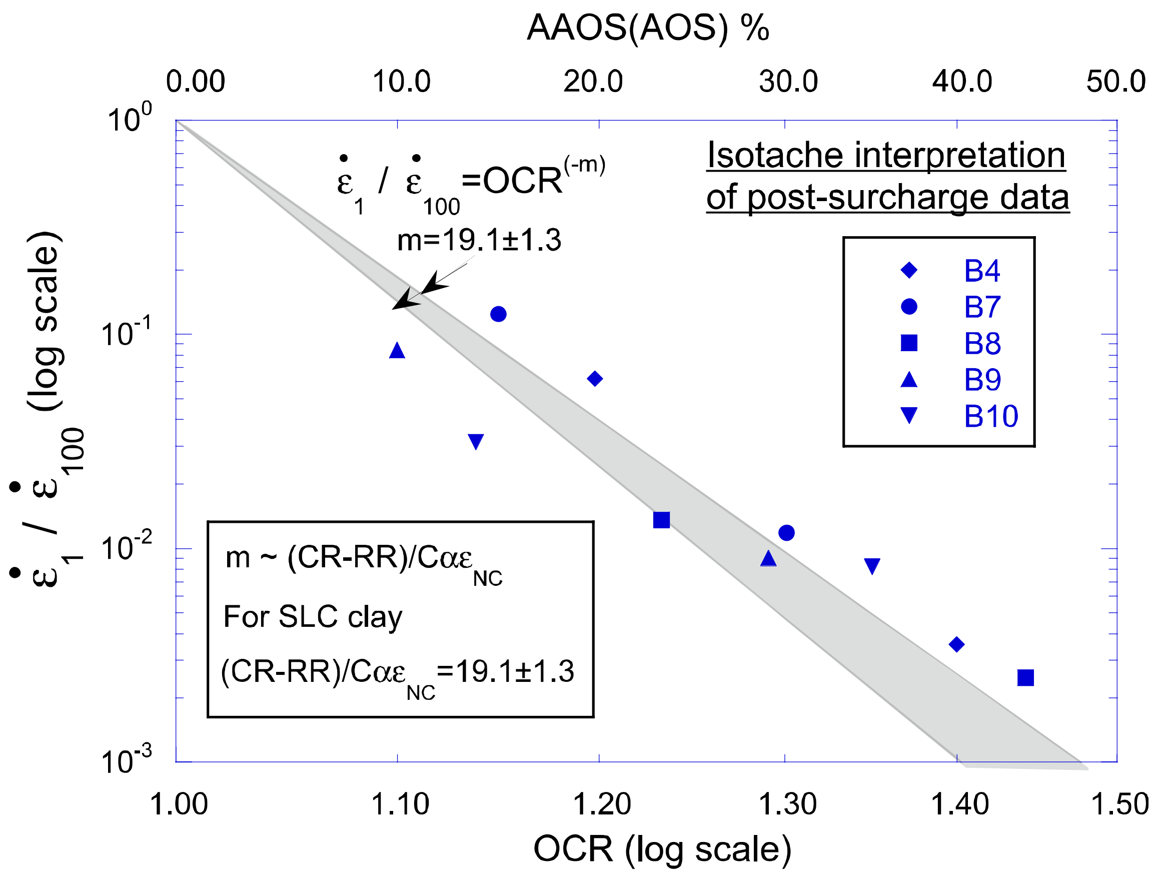
*Unreasonable $\hat{C}_{\alpha\varepsilon} > C_{\alpha\varepsilon NC}$; Erratic changes in strain rate + short in data points for fitting

Creep Decays with OCR



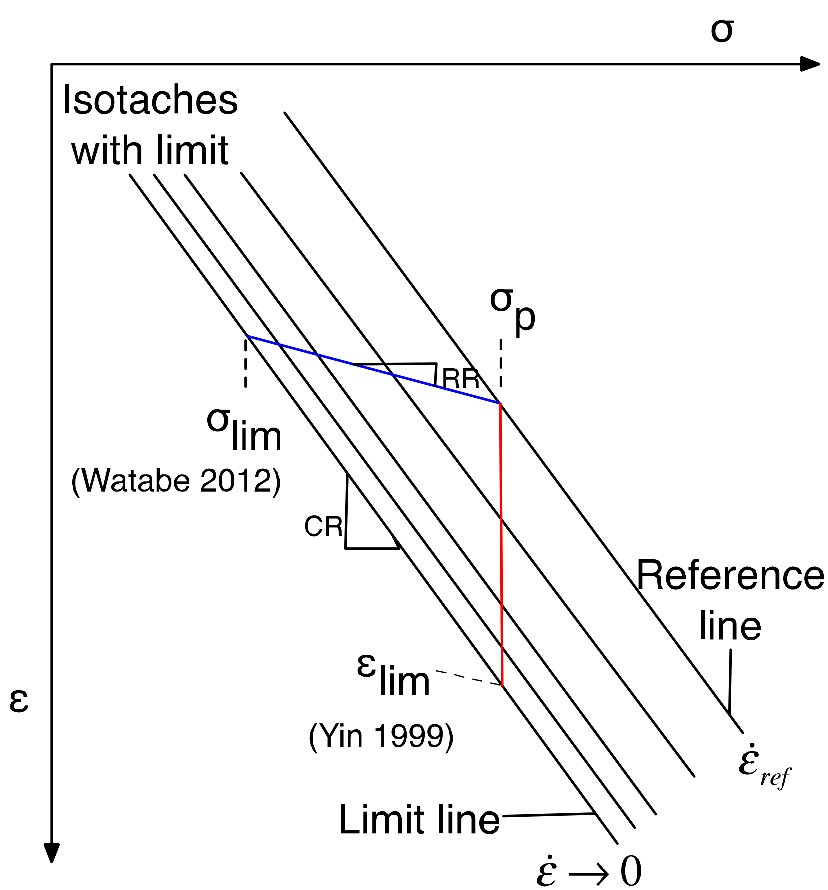
$\hat{C}_{\alpha\varepsilon}/C_{\alpha\varepsilon NC}$ decreases dramatically with OCR

Initial Strain Rate Decreases with OCR



$\dot{\varepsilon}_1 / \dot{\varepsilon}_{100}$ decreases with OCR following power law

Isotache with Creep Limit



after Watabe (2012)

$$\frac{\hat{C}_{\alpha\varepsilon}}{C_{\alpha\varepsilon NC}} = \frac{OCR_{\lim} - OCR}{OCR_{\lim} - 1}$$

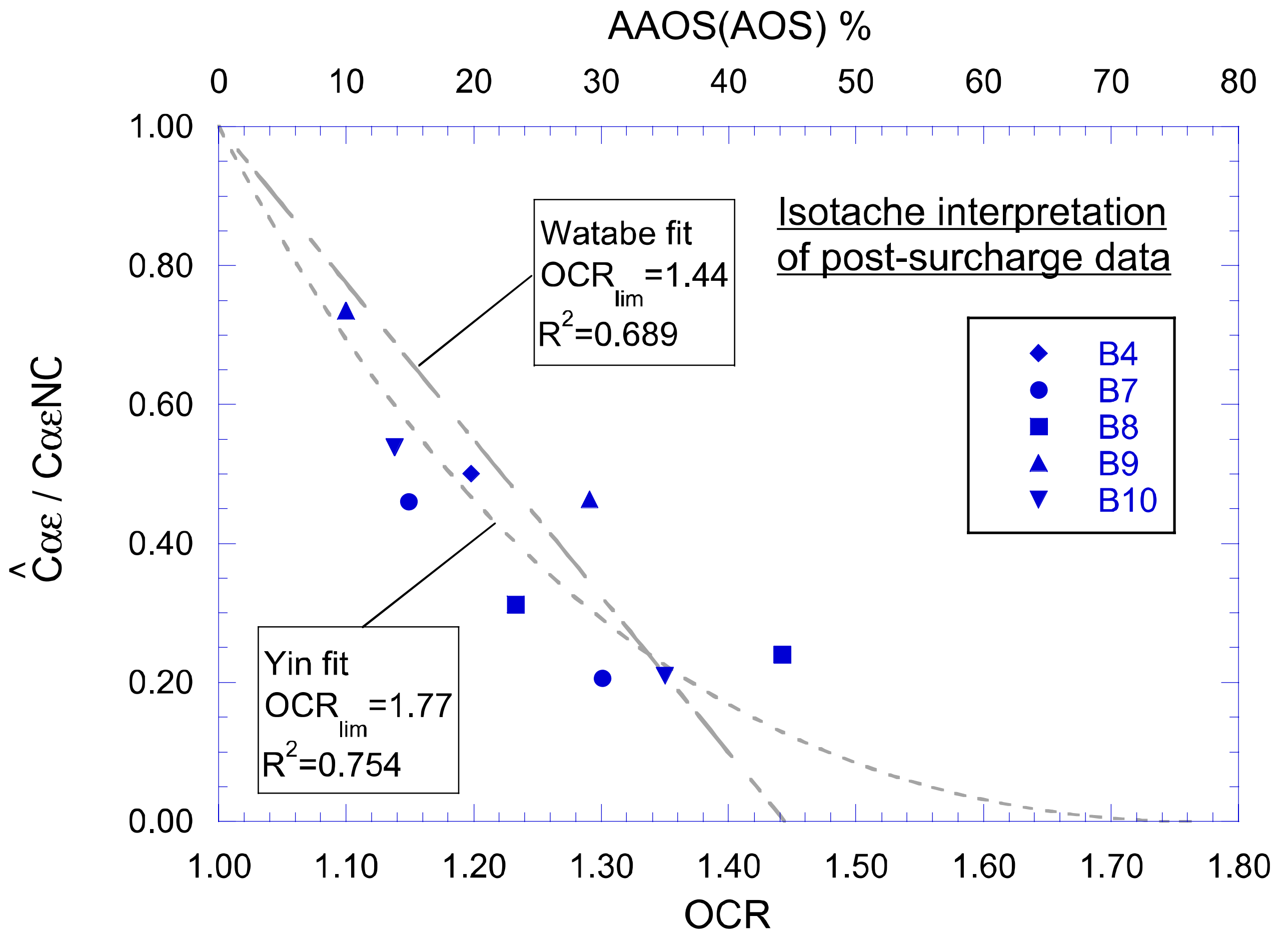
$$OCR_{\lim} = \sigma_p / \sigma_{\lim}$$

after Yin (1999)

$$\frac{\hat{C}_{\alpha\varepsilon}}{C_{\alpha\varepsilon NC}} = \left(1 - \frac{\ln OCR}{\ln OCR_{\lim}}\right)^2$$

$$OCR_{\lim} = \exp\left[\frac{\varepsilon_{\lim}}{0.434\left(CR - RR\right)}\right]$$

Interpretation of Models with Creep Limit



Summary

- Simple model of creep dependence with stress history is proposed.
- This captures development of post-surcharge creep
  - more systematic than existing empirical methods to study effect of surcharge
- Interpretation of experimental data shows that surcharging indeed reduces 2 ° compression $\hat{C}_{\alpha\varepsilon}$ and post-surcharge creep rate $\dot{\varepsilon}_1$.
- The results highlight the importance of general stress history influence on the creep properties and suggest improvements on isotache model.

Reference

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Thank you!