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Accounting for long term effects for the structural design of deep tunnels in claystones

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Summary

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Introduction

- Complex behaviour of claystones or shales: multiscale material, thermo-hydro-mechanical couplings, brittle/ductile, anisotropy, short and long term behaviour …

- Large bibliography with complex models: hard to choice and certainly to use

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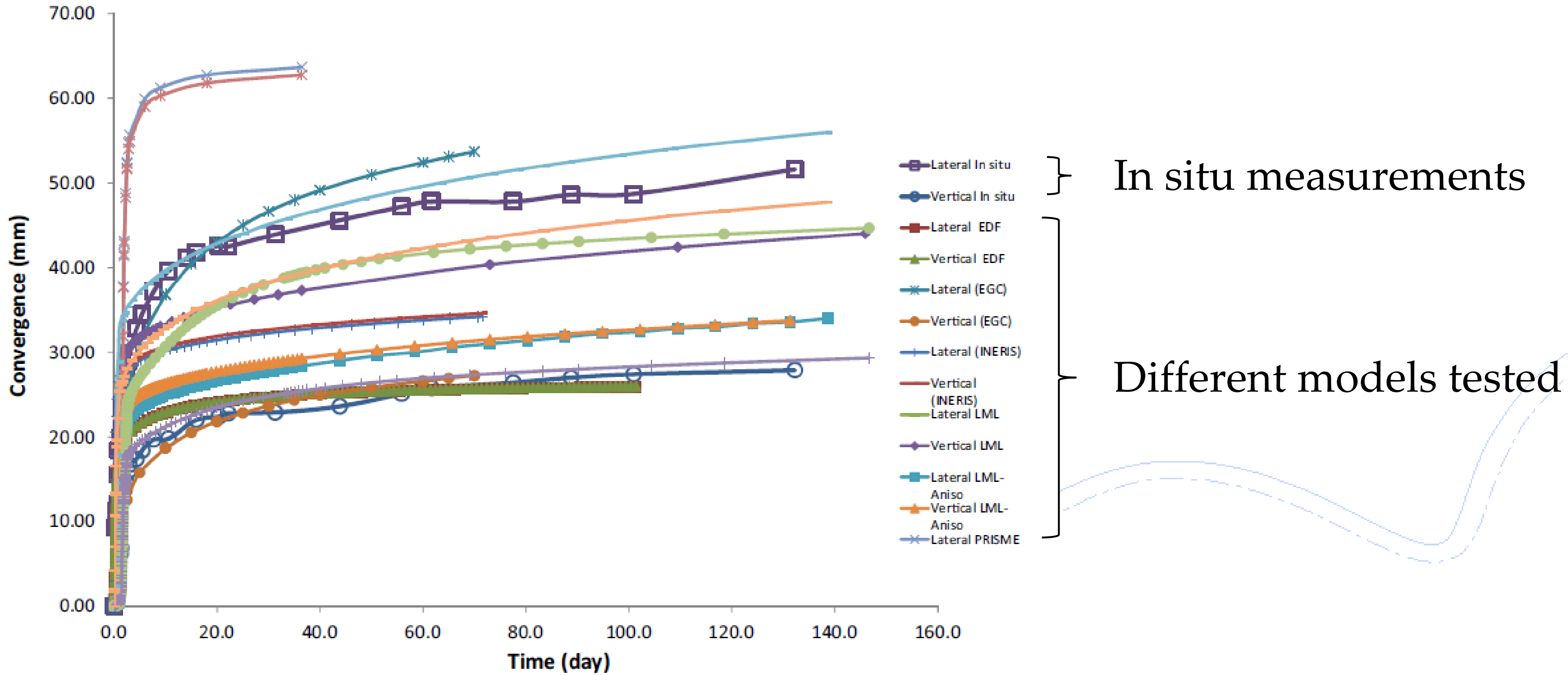
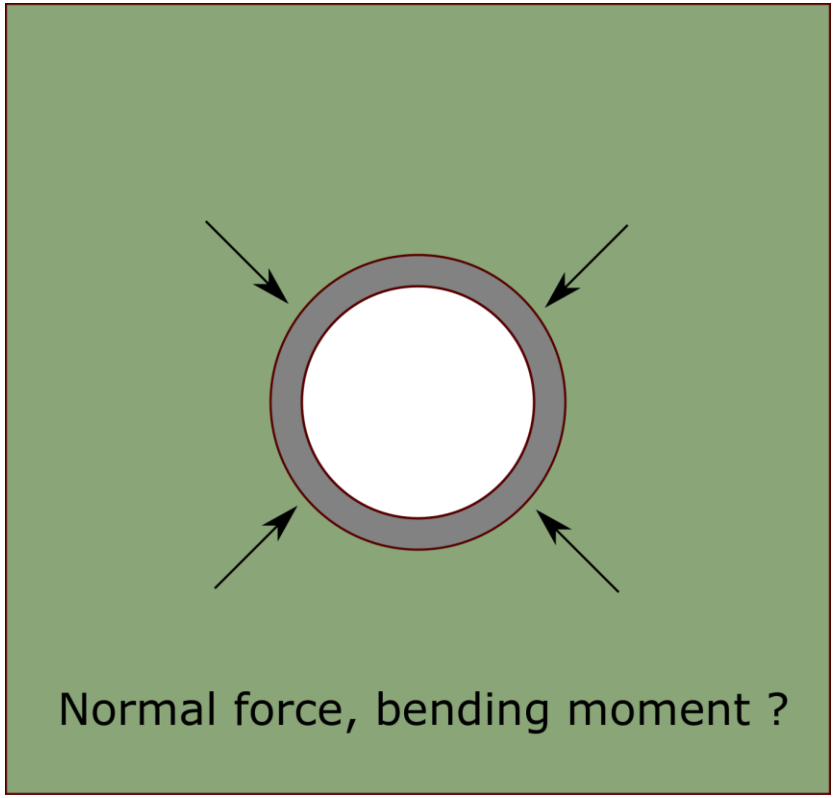


Seyedi et al. (2017)

Introduction

From an engineer point of view, where structures have to be designed:

- "simple" models are preferred but able to catch evolution of forces in structure
- especially when long term effects play an important part in final loadings = extrapolation



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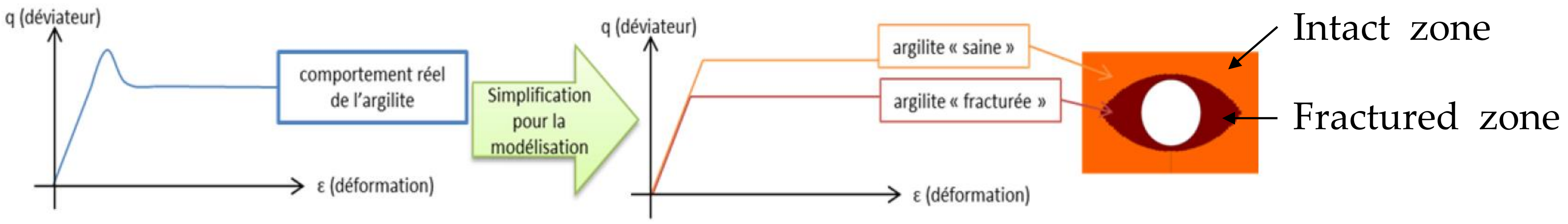
Introduction

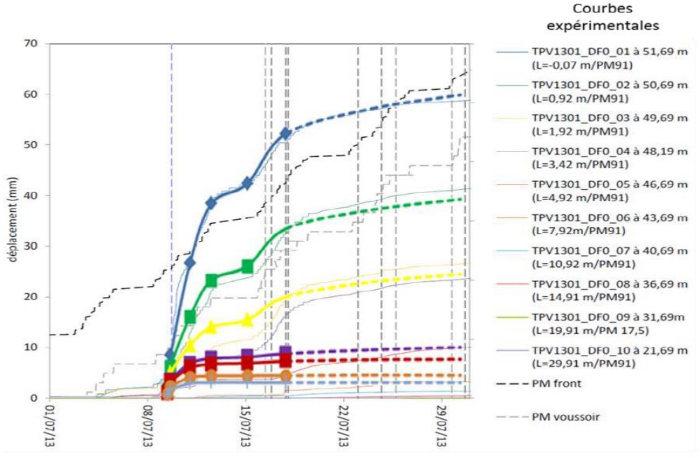
Example of “simple” model in the context of the Meuse/Haute-Marne laboratory - Saitta et al. (2017) :

- Mohr-Coulomb’s criterion and Norton’s law
- 2 domains define from in-situ observations (intact and disturbed zones) -> anisotropy forced



Saitta et al. (2017)

- In consistency with principal results in terms of displacement of the soil in a quasi-isotropic stress state and with isotropic laws



Saitta et al. (2017)

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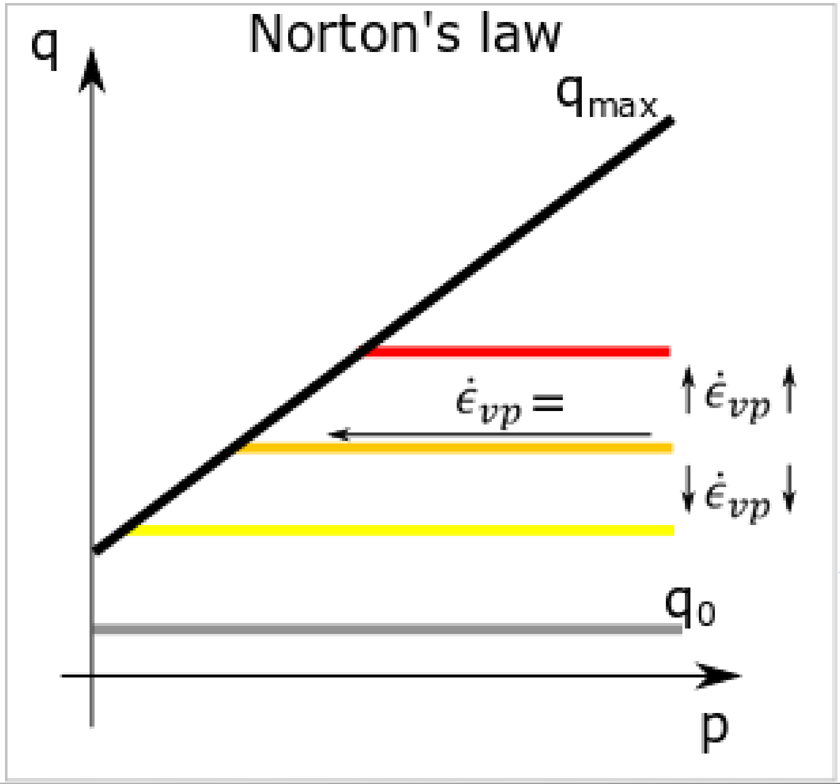
Accounting for long term effects

Norton’s law, initially developed for steels at high temperatures (1929)
- visco-plastic strain rate:

$$\dot{\epsilon}_{ij}^{vp} = \frac{3}{2}\,(\dot{\epsilon}_{vp})\,\frac{s_{ij}}{q} \quad \text{where } \dot{\epsilon}_{vp} = \gamma < q - q_0 >^n$$



$\dot{\epsilon}_{vp}$ depends only of deviatoric stress ***q***

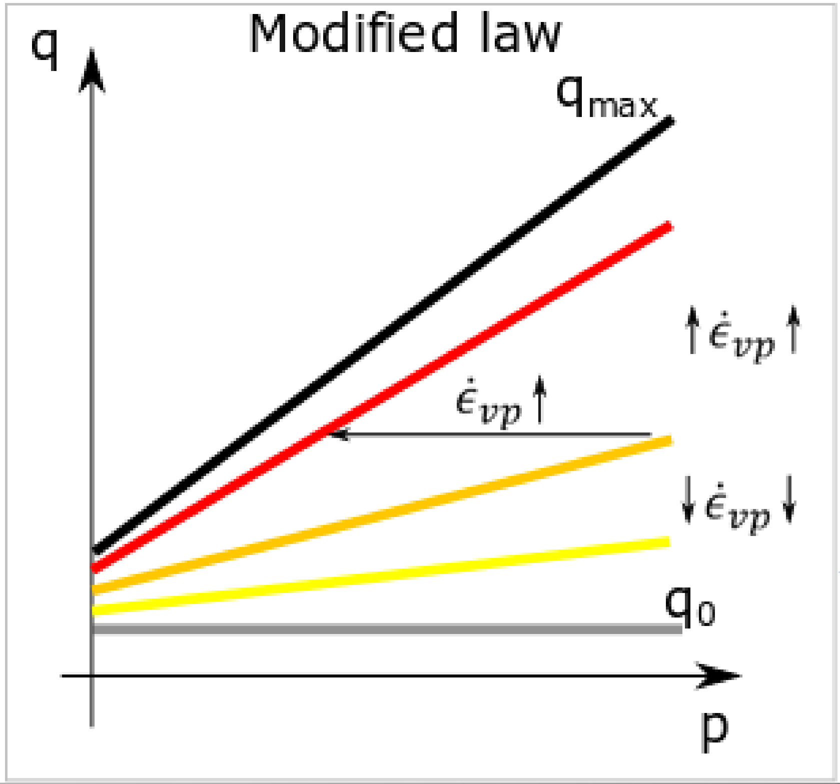
independent of mean stress ***p***

Accounting for long term effects

Modified Norton's law

- $\dot{\epsilon}_{vp}$ depends on the strength mobilization (*p*,*q* and Lode angle θ):

$$\dot{\epsilon}_{ij}^{vp} = \frac{3}{2}\,(\dot{\epsilon}_{vp})\,\frac{\mathrm{s_{ij}}}{q} \text{ where } \dot{\epsilon}_{vp} = A \times f(X)$$



with

$$f(X) = \frac{1}{1+\left(\frac{a}{X}\right)^{\alpha}} \qquad f(X) \in [0,1]$$

$$X = \frac{d_1}{d_2} \qquad X \in [0,+\infty]$$

Accounting for long term effects

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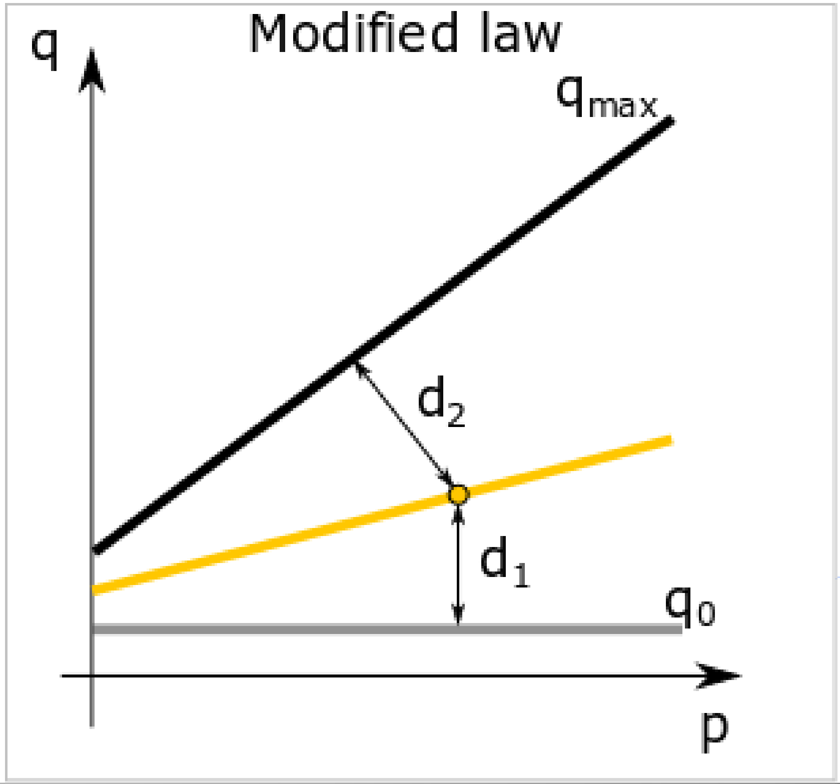

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$$d_1(q) = < q - q_0 >$$

$$d_2(p,q,\theta) = \frac{|M(\theta) \times p + q - N(\theta)|}{\sqrt{M(\theta)^2 + (1)^2}}$$

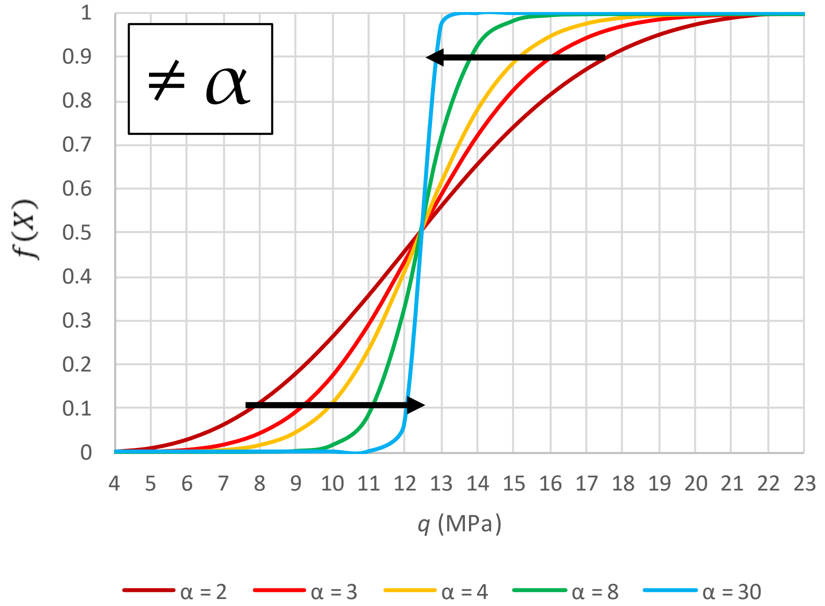
$$\cos 3\theta = \frac{3\sqrt{3}}{2} \times \frac{J_3}{J_2^{3/2}}$$

Accounting for long term effects

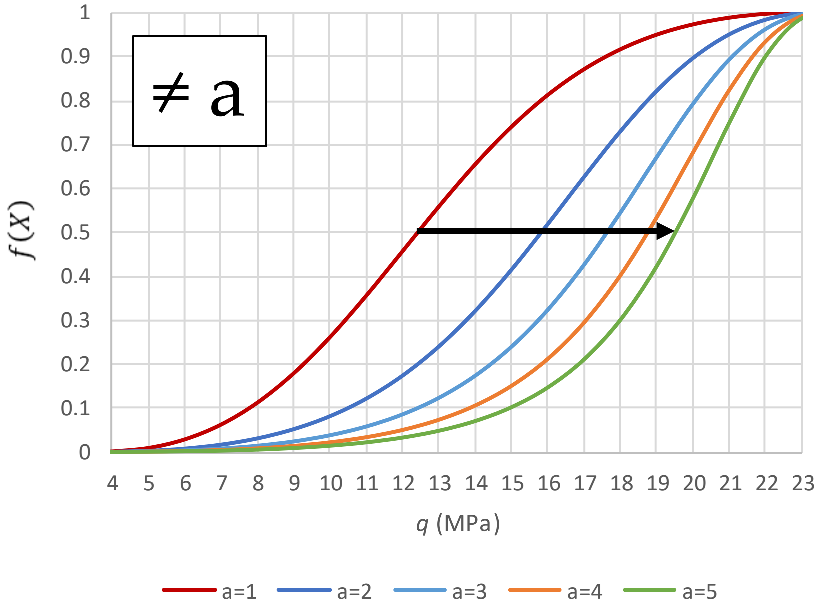
Modified Norton's law

- $q = q_0$: $X = \frac{d_1}{d_2} = 0 \rightarrow f(X) = 0 \rightarrow \dot{\epsilon}_{vp} = 0$
- $q = q_{max}$: $X = \frac{d_1}{d_2} = \infty \rightarrow f(X) = 1 \rightarrow \dot{\epsilon}_{vp} = A$

$$f(X) = \frac{1}{1 + \left(\frac{1}{X}\right)^{\boxed{\alpha}}}$$



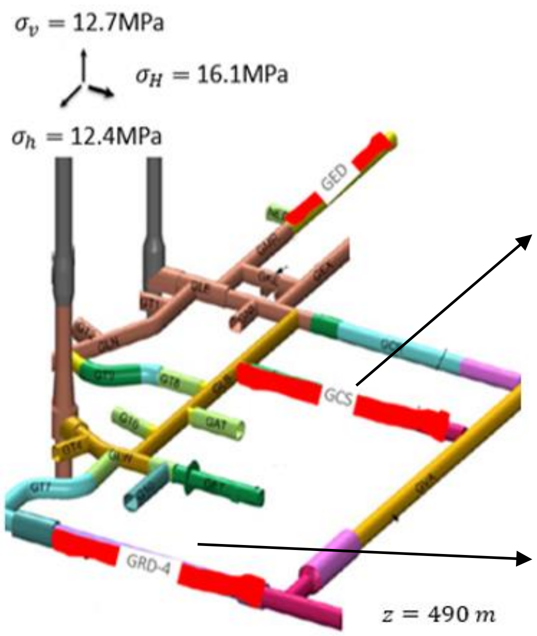
$$f(X) = \frac{1}{1 + \left(\frac{\boxed{a}}{X}\right)^{2}}$$

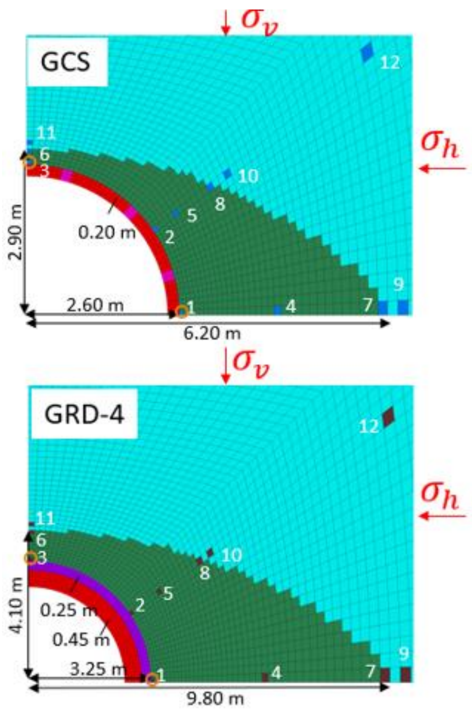


$\theta = \pi/3$, $p = 13.8$ MPa, $q_0 = 0$, $c = 6$ MPa and $\phi = 20$

Calibration with measurements in terms of displacements

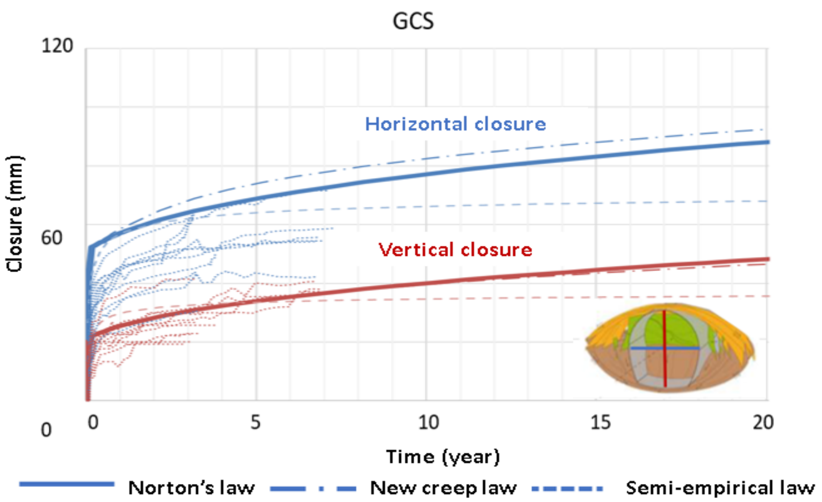
Application to the Meuse/Haute-Marne laboratory

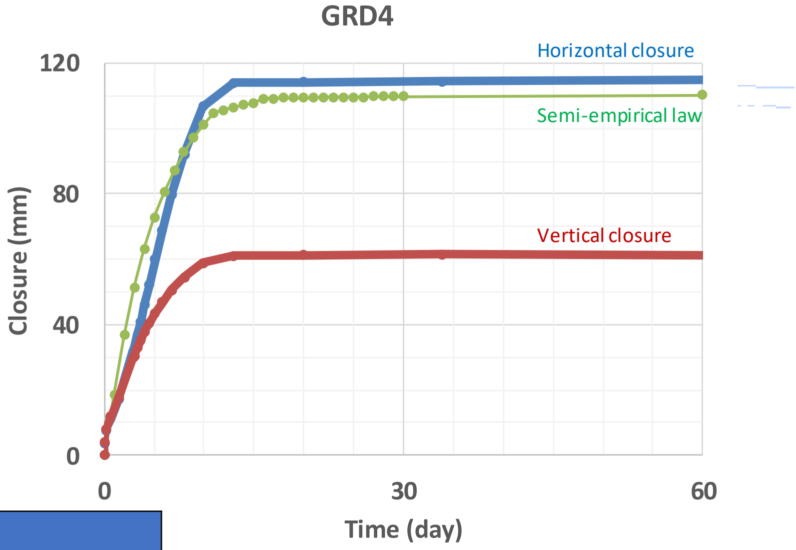




Flexible support with deformable concrete

Rigid support with liner concrete





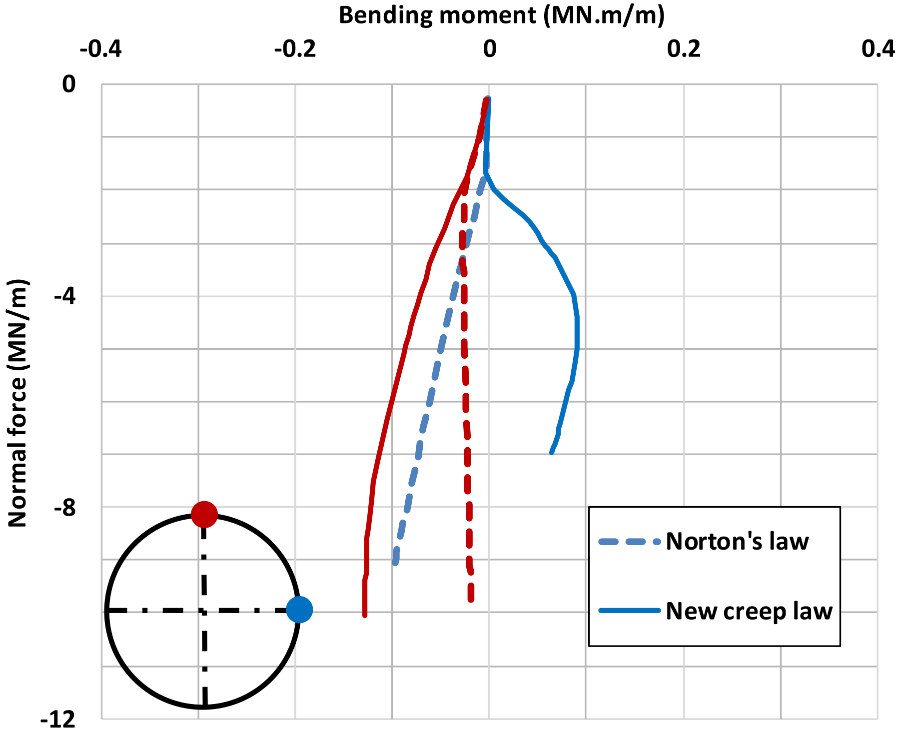
Parameters:

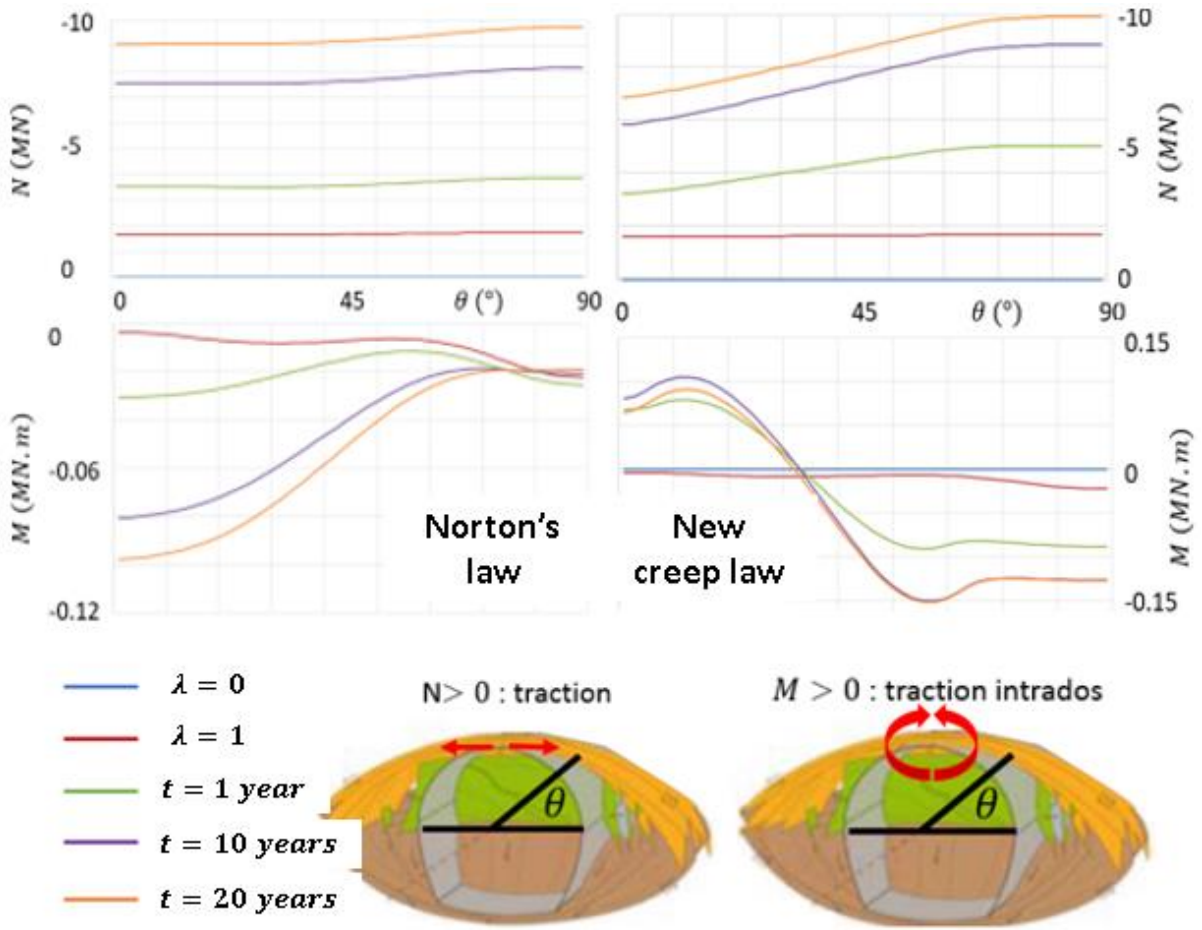
$\dot{\epsilon}_{vp} = A \times < q - \sigma_s >^n$	n [-]	A $[s^{-1}Pa^{-6.8}]$
GCS – GRD4	6.8	2.5×10^{-59}

$\dot{\epsilon}_{vp}(t) = A \times \frac{1}{1+\left(\frac{a}{(d_1)/(d_2)}\right)^{\alpha}}$	A $[s^{-1}]$	a [-]	α [-]
GCS – GRD4	4×10^{-11}	2	3

Comparison in terms of structural forces

Forces in rigid structure





- Normal force : quite similar
- Bending moment : quite different and more logical with in-situ observations (to be confirm)
- Bending moment more sensitive with variations of normal and shear stresses.

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Conclusion

- Models (simple and complex) have to be compared to measurements in terms of displacements <u>and</u> forces (only displacement not sufficient for structure design)

- Modified Norton's law proposed here:

    - is still a simple law based on a simple approach

    - seems more reliable

- Others comparisons have to be done to confirm these results

- Test new idea is quite simple with Flac thanks to fish functions !

Acknowledgements

Andra for experimental data used in this study