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Viscoelastic material model to capture the effects of creep in concrete

When is there a need for viscoelastic concrete material models?

Viscoelastic concrete material models are of interest when you're dealing with scenarios where the long-term behaviour of concrete under sustained loads, temperature changes, or dynamic effects is crucial to the performance and safety of the bridge. A viscoelastic concrete material model allows you to predict and mitigate potential issues that could arise due to the time-dependent nature of concrete, ensuring the structure's durability and functionality over its intended lifespan.

This article is an excerpt from the BRIGADE tutorial "Viscoelastic creep modelling" available for BRIGADE users to download from here, which includes step by step instructions on how to set up the material model in BRIGADE/Plus; including an excel sheet prepared to calculate the target curve according to EN 1992-1-1:2005 Appendix B.

LONG-TERM LOAD EFFECTS (CREEP)

Concrete exhibits time-dependent deformation under sustained loads, a phenomenon known as **creep**. Similarly, concrete shrinks over time due to loss of moisture, known as **shrinkage**. In a bridge, these effects can lead to:

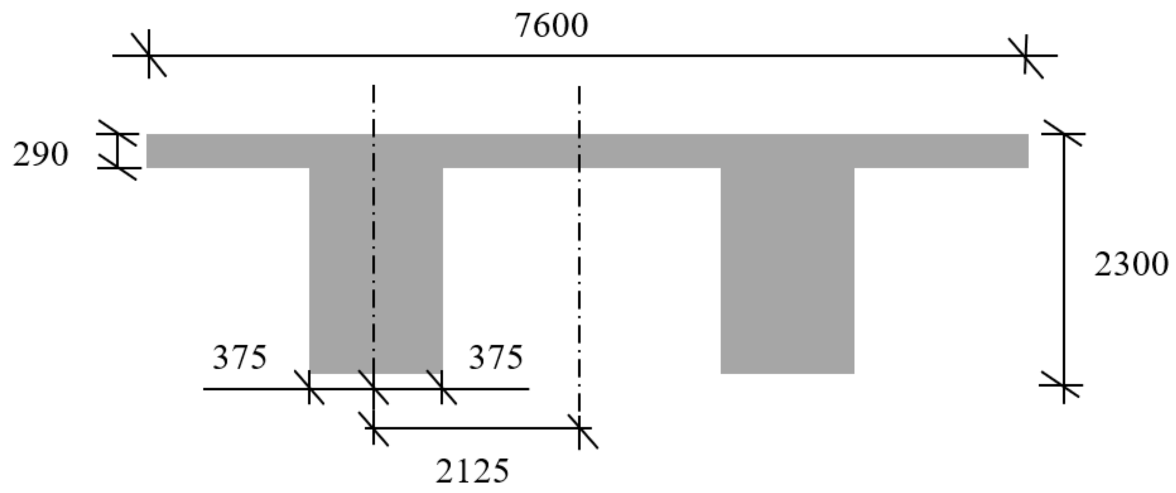
- Gradual deflection of the bridge deck.
- Redistribution of stresses in the structure.
- Potential issues with pre-stressed or post-tensioned concrete members.

In such cases, viscoelastic models help predict how the concrete will deform over time, allowing for better long-term performance analysis and design adjustments. Here we will focus on the effects of creep and how it can be considered in an FE-model calibrated to match the time-dependent concrete creep factor expressed in EN 1992-1-1:2005 Appendix B.

Example of setting up a material model in BRIGADE/PLUS

PRECONDITIONS

Consider the cross section in the figure below. The deck will dry faster than the beams due to the smaller width and will therefore experience more creep deformation for the same load. An option is to define one material for the deck and one material for the beams with different creep properties. However, here we'll simplify and define one average concrete creep model over the entire cross section.



For that we need to calculate the area and circumference of the cross section in the cross-section, which are:

$$A_c = 7.6 \cdot 0.290 + 2 \cdot 0.75 \cdot 2.01 = 5.219\, m^2$$

$$u = 7.6 \cdot 2 + 0.290 \cdot 2 + 2.01 \cdot 4 = 23.82\, m$$

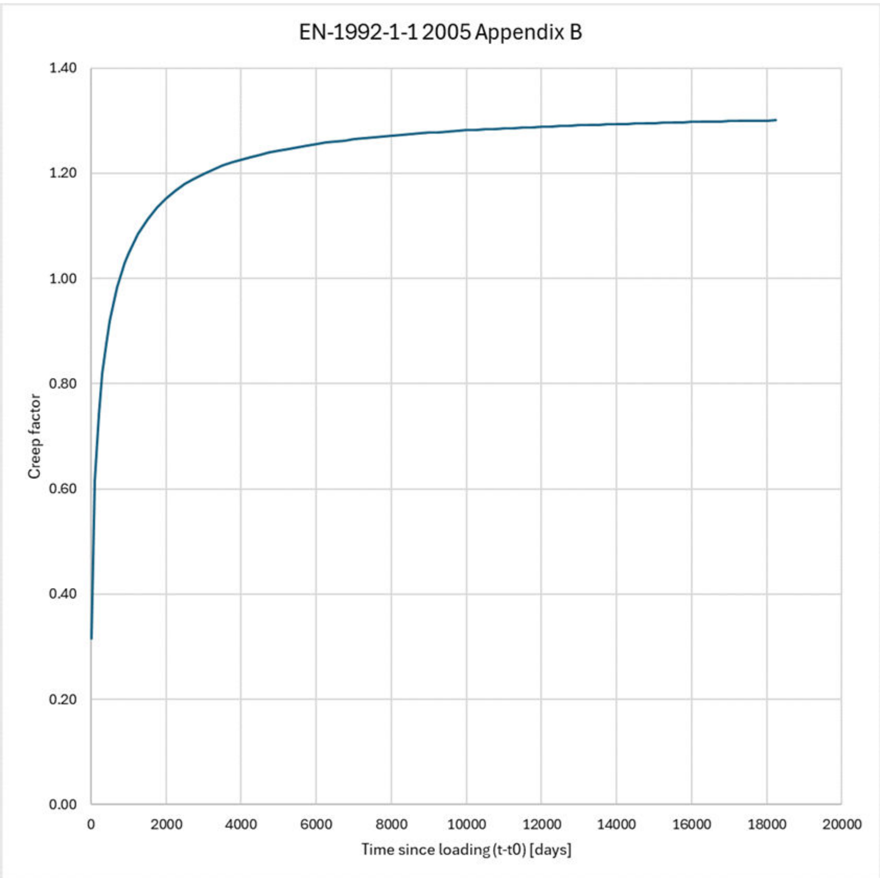
The equivalent thickness according to EN 1992-1-1:2005 is then:

$$h_0 = 1000 \cdot \frac{2 \cdot A_c}{u} = 440\, mm$$

The age of the concrete needs to be considered in relation to when loading is applied on the structure. If the loading is applied to young concrete, the creep deformation will be accelerated. Furthermore, humidity, concrete quality and cement type are factors that affect the creep factor. All assumptions made for our example are presented in the table below.

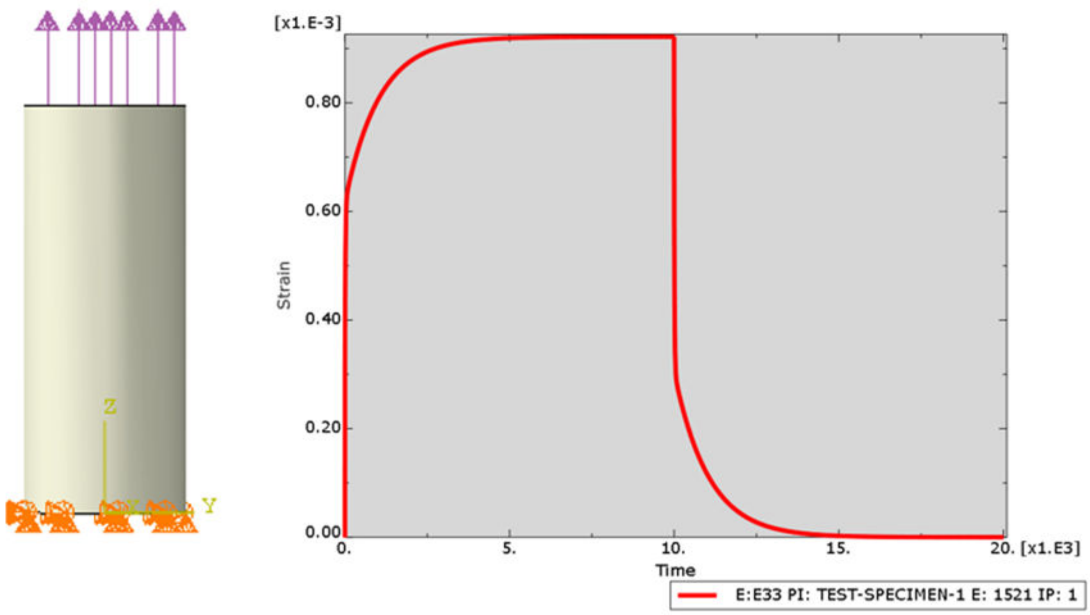
What	Value	Unit
Equivalent thickness	440	[mm]
Concrete age at time of loading	40	[days]
Relative humidity	80	[%]
Concrete mean compressive strength	48	[MPa]
Cement type	N	[-]

The resulting time-dependent creep-factor $\varphi(t,t0)$ calculated according to EN 1992-1-1:2005 Appendix B is shown in the figure below (curve calculated with the excel sheet attached to the BRIGADE tutorial):



THEORY

Viscoelastic materials have, as the name suggests, both an elastic and a viscous component. The elastic component of the strain responds immediately to applied stress while the strain magnitude of the viscous component depends on the loading time. The behaviour is demonstrated in Figure 3.1 where a viscoelastic specimen is loaded at t = 0 days and unloaded at t = 10 000 days. It is worth pointing out that the creep strain is completely reversible when the model is unloaded. This does not necessarily reflect the behaviour of real concrete and this tutorial is therefore not intended for reversible loading.



Note that a viscoelastic material where the creep strains are unable to develop due to constraints will experience stress relaxation instead. When we calibrate a viscoelastic material, we are in fact looking for material properties that control the stress relaxation. The stress relaxation for a viscoelastic material in BRIGADE/Plus follows a Prony series expansion. It looks like the following.

$$g_R(t) = \left(1 - \sum_{k=1}^{N} \bar{g}^P{}_k \left(1 - e^{-\frac{t}{\tau_k^G}}\right)\right)$$

τ_k^G and $\bar{g}^P{}_k$ are material parameters that need to be calibrated to fit a desired relaxation function. The number of Prony parameters is arbitrary.

Expansions of Prony series are not elaborated on here. However, it is useful to know that the material behaviour is bound to follow the expression and that it is an iterative process of choosing parameters until the Prony series is accurate enough. For more theory on viscoelasticity, see the Abaqus Theory Guide under Mechanical Constitutive Theories.

Advanced users can provide the Prony parameters directly to the software. It is also possible to provide creep test-data to BRIGADE/Plus, which in turn will convert it to relaxation test-data and then perform an iterative process of fitting the material properties of the Prony series expansion.

By convention, creep test-data should be provided in terms of normalized *shear compliance* $j_S(t)$ and/or *volumetric compliance* $j_K(t)$.

$$j_S(t) = G_0 \cdot \frac{\gamma(t)}{\tau}$$

$$j_K(t) = K_0 \cdot \frac{\varepsilon^{vol}(t)}{P}$$

G_0 and K_0 are the initial shear and bulk modules.

$\gamma(t)$ and $\varepsilon^{vol}(t)$ are the time-dependent total shear strain and total volumetric strain (total = elastic + creep), respectively.

τ and P are the constant shear stress and pressure stress, respectively.

These functions may not be convenient for engineers who are used to code-based creep-factors related to Young's modulus; however, the relationship can easily be established.

Let's consider the "effective" shear modulus:

$$G_{eff}(t) = \frac{\tau}{\gamma(t)}$$

and the bulk-modulus:

$$K_{eff}(t) = \frac{P}{\varepsilon^{vol}(t)}$$

The compliance functions may then be written as:

$$j_S(t) = \frac{G_0}{G_{eff}(t)}$$

$$j_K(t) = \frac{K_0}{K_{eff}(t)}$$

Furthermore, the shear and bulk-modulus are related to Young's modulus through Poisson's ratio. If Poisson's ratio remains constant, the effective shear and bulk modules are related to the effective value of Young's modulus $E_{eff}(t)$.

$$G_{eff}(t) = \frac{E_{eff}(t)}{2(1+\upsilon)}$$

$$K_{eff}(t) = \frac{E_{eff}(t)}{3(1-2\upsilon)}$$

Insertion into the compliance functions yields:

$$j_S(t) = \frac{G_0}{G_{eff}(t)} \Big| = G_0 \cdot \frac{2(1+\upsilon)}{E_{eff}(t)} = \frac{E_0}{E_{eff}(t)}$$

$$j_K(t) = \frac{K_0}{K_{eff}(t)} = K_0 \cdot \frac{3(1-2\upsilon)}{E_{eff}(t)} = \frac{E_0}{E_{eff}(t)}$$

Hence, shear and bulk compliances are therefore equal:

$$j_S(t) = j_K(t) = \frac{E_0}{E_{eff}(t)}$$

According to EN-1992-1-1, the effective Young's modulus, with respect to total deformation (elastic + creep), can be written as:

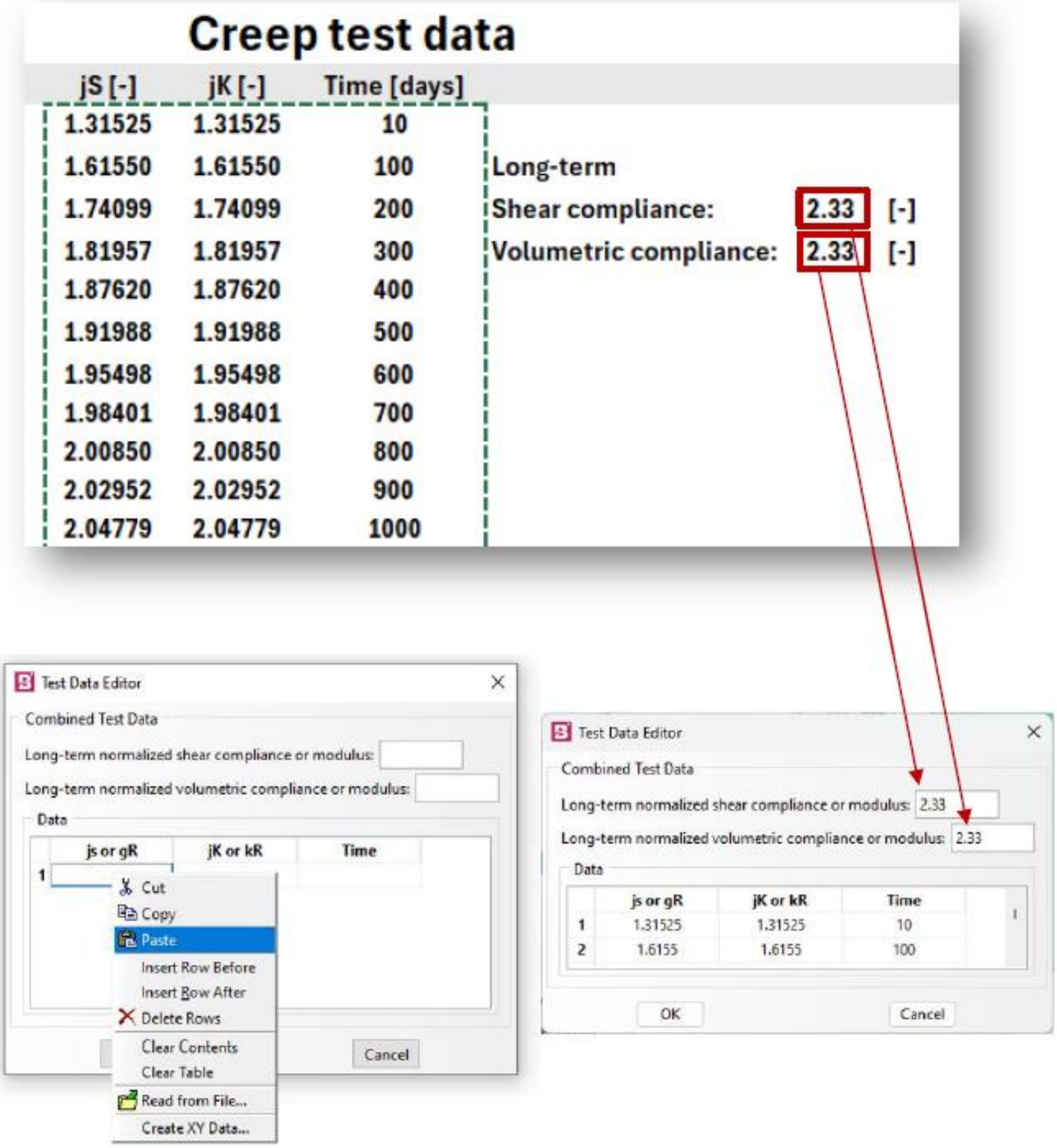
$$E_{c,eff}\,(t) = \frac{E_{cm}}{1+\varphi(\mathrm{t},\mathrm{t}_0)}$$

Insertion into the compliance functions, with $E_0 = E_{cm}$ and $E_{eff}(t) = E_{c,eff}(t)$, yields:

$$j_S(t) = j_K(t) = 1 + \varphi(\mathrm{t},\mathrm{t}_0)$$

BRIGADE/PLUS TUTORIAL

For BRIGADE/Plus users, there is a tutorial available in which a material model is created and calibrated to match the time-dependent concrete creep factor expressed in EN 1992-1-1:2005 Appendix B. A spread sheet is included in which the creep factor is calculated. You will find the the tutorial "Viscoelastic creep modelling" on our download site. Here you will also find our other task specific tutorials.



Summary

The creep test-data should be provided in terms of shear and volumetric compliance. Assuming constant Poisson's ratio, shear and volumetric compliance are equal and relate to the creep factor in Eurocode using the last expression above for $j_S(t)$.