CZECH TECHNICAL UNIVERSITY IN PRAGUE

Size Effect on the Ultimate Drying Shrinkage of Concrete – Modeling with Microprestress-solidification Theory

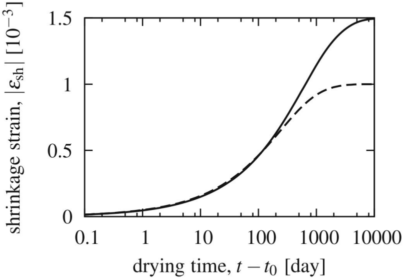
Engineering Mechanics 2020

CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Civli Engineering
Department of Mechanics

Lenka Dohnalová, Petr Havlásek

Motivation



(Z. Bažant, M. Jirásek: Creep and hygrothermal effects in concrete structures, 2018)

- the ultimate drying shrinkage of standard-size structural members is reached within several decades
- extrapolation based on short-term measurements on standard laboratory specimens presents an ill-posed problem and can lead to large errors
- final magnitude of shrinkage is size-dependent, therefore knowledge of this size-effect is essential for correct transition from very small laboratory specimens to real-size structural members

Basic structure of research

In the presented research the size-effect on the ultimate drying shrinkage was assessed on the basis of:

- experimental data from a freely available database, provided by the Northwestern University (NU database), and data from literature
- equations incorporated in the most frequently used prediction models and design codes
- results obtained from coupled hygro-mechanical finite element simulations using an advanced constitutive model based on the Microprestress-Solidification theory (MPS)

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

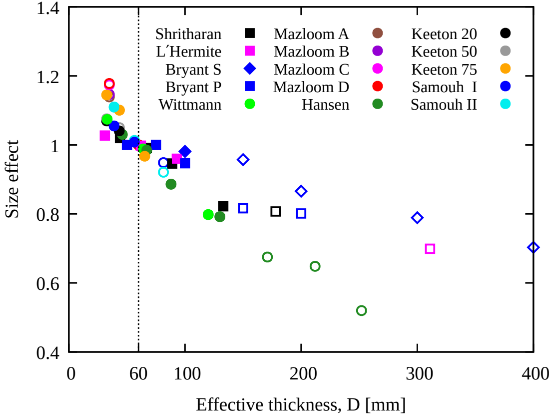
Size-effect determined from experimental data

Size-effect obtained by evaluating experimental data from the NU database, and data from literature.

Ultimate shrinkage values were normalized with respect to $D = 60$ mm.

Empty symbols mark the last data points in prematurely terminated experiments, in which further increase of shrinkage can be expected.

The experiments unanimously indicate that the ultimate drying shrinkage decreases with specimen size.



Analyzed prediction models and design codes

Prediction models:

- B3 and B4 models
- *fib* Model Code 2010

Design codes:

- Eurocode 2
- ACI 209.2R–08

Size-effect on drying shrinkage is considered in majority of the models (except for *fib* Model Code 2010), however, the formulation differs among the models.

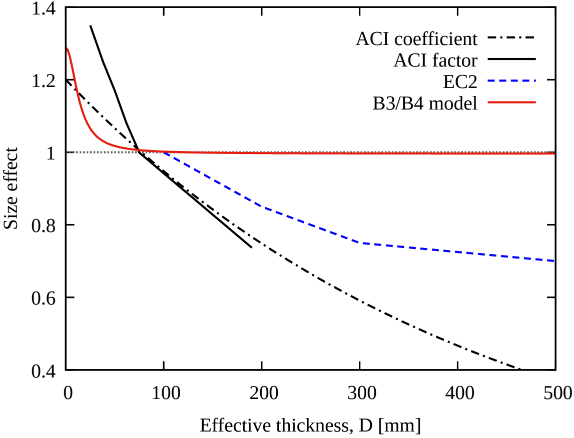
Each of the models uses a different equivalent size as a reference (for which the size-effect is equal to 1).

Size-effect according to prediction models

The *fib* Model Code 2010 completely neglects the size-effect on the ultimate drying shrinkage.

The EC2 gives a recommendation only for members with $D > 100$ mm.

According to the B3 and B4 models the size-effect is significant only for $D \leq 50$ mm, for larger specimens it completely vanishes.

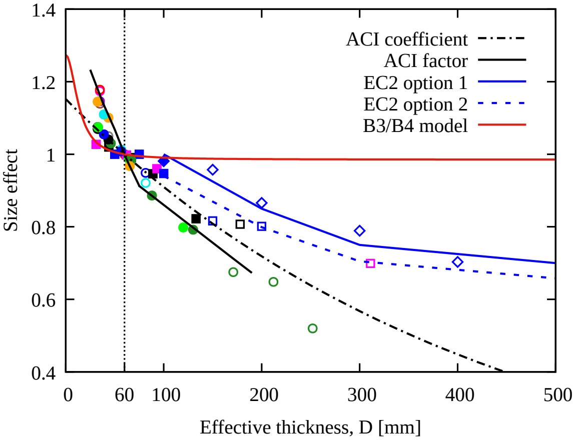


CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Comparison of prediction models with experiments

For comparison with the experimental data, the results were normalized against the reference size $D = 60$ mm.

Two alternatives of the ACI 209 code provide the best agreement with experiments.

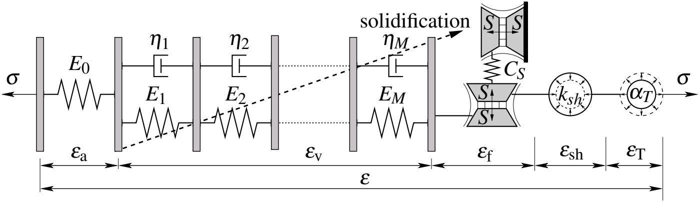


CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Brief description of FE simulations

- coupled finite element hygro-mechanical simulations were carried out using the OOFEM package
- humidity transport was described by the Bažant-Najjar constitutive model
- an advanced model based on the Microprestress-Solidification theory (MPS) was used for solving mechanical problem
- the size-effect on drying shrinkage was assessed for six different alternatives of the MPS model
- model parameters were calibrated on experimental data by Bryant and Vadhanavikkit (1987)

Rheological scheme of the MPS model



The rheological model consists of serially connected:

- non-aging spring
- solidifying Kelvin chain
- aging dashpot with humidity-dependent viscosity
- two units for shrinkage and thermal strains

One of the MPS model modifications was extended by a unit capturing tensile cracking with crack-band regularization.

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

MPS model

Simplified formulation of the governing equation for the viscosity η of the aging dashpot

$$\dot{\eta} + \frac{1}{\mu_S} \left| \frac{\dot{h}}{h} \right| (\mu_S \eta)^{\frac{p}{p-1}} = \frac{\psi_S}{q_4}$$

where h is relative humidity,
ψ_S is a humidity- and temperature-dependent factor,
μ_S is a material parameter with the meaning of fluidity,
p is a parameter determining the order of differential equation.

$p = 2$ ... original formulation – an opposite size-effect on drying creep

$p = \infty$ ... modification 1 – eliminated size-effect on drying creep,
the differential equation becomes linear,
the μ_S parameter is replaced by a dimensionless factor k_3

$p = -1.5$ ... modification 2 – correct size-effect on drying creep

MPS model

- Two other modifications of the MPS model were created by adjusting the parameter k_{sh}, desribing relationship between rates of shrinkage and relative humidity.
  The constant value of this parameter used in the original formulation was replaced by a time-dependent or a humidity-dependent function.

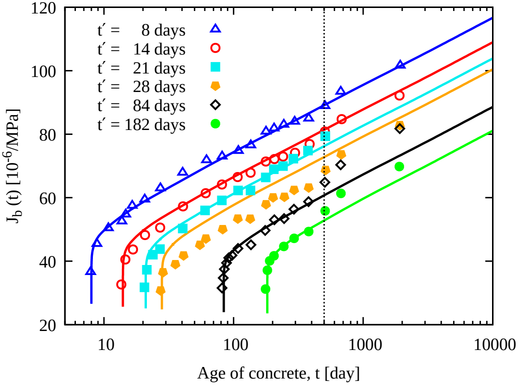
- In the last investigated modification, the MPS model with $p = \infty$ was extended by the possibility of tensile cracking. However, the influence of the formed cracks on humidity transport is not taken into account.

Calibration – basic creep

Calibration of basic creep data for different times at loading t'.

Data points correspond to the results of Bryant's experiment.

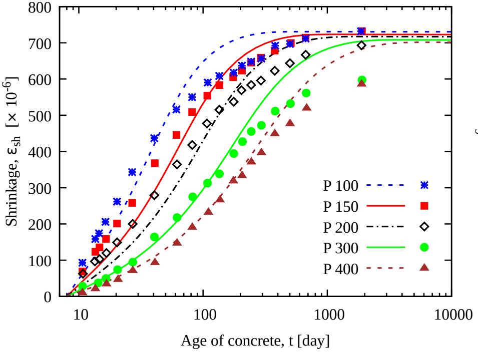
Basic creep parameters were calibrated only once and the values were used for all modifications of the MPS model.

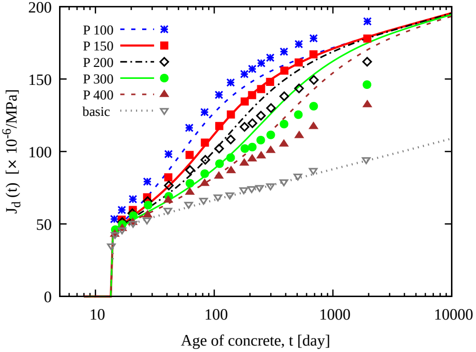


Calibration – drying shrinkage and drying creep

Parameters related to the drying shrinkage and drying creep were recalibrated for each modification of the MPS model.

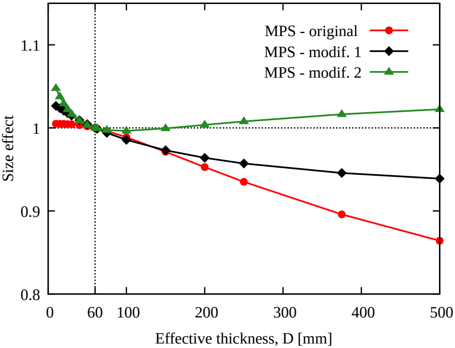
The figures show the calibration of the MPS model with eliminated size-effect on drying creep ($p = \infty$).



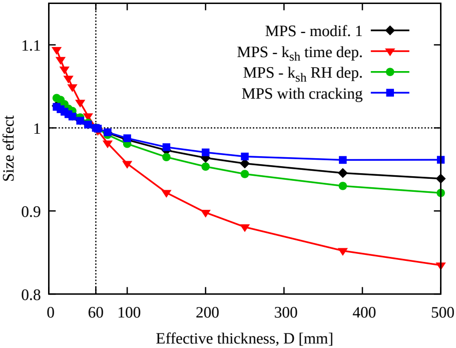


CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Size-effect obtained from FEM simulations



Modifications of the MPS model with different values of the parameter *p*. (constant value of the parameter k_{sh})



Modifications of the MPS model with $p = \infty$. (k_{sh} as a time- or humidity-dependent function and a model with cracks)

Conclusions

- the investigated experimental data support the presence of the size-effect on the ultimate drying shrinkage, however its accurate evaluation is impossible due to lacking data, especially for larger elements
- design codes and prediction models incorporate size-effect in different ways
- the standards EC2 and ACI 209 provide good agreement with the experimental results, unfortunately the analyzed prediction models either almost (B3, B4) or completely (*fib* MC2010) neglect the size-effect on the ultimate drying shrinkage
- the FEM simulations using MPS model give the best overall behavior with $p = \infty$, even though the size-effect is significantly less pronounced compared to the experimental results
- the original MPS formulation (p=2) underestimates the size-effect for smaller specimens
- the MPS model with $p = \infty$ can be improved if the original relationship between shrinkage and relative humidity is modified and the shrinkage constant k_{sh} becomes a time-dependent function

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Thank you for your attention

Financial support for this work was provided by the Czech Science Foundation (GA ČR), project number 19-20666S (Shrinkage-induced deformations and microcracking in structural concrete - monitoring, modeling and identification).