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WG II

Size effect considerations for linear structural elements of timber

In the frame of COST E55
'Modelling of the performance of timber structures'

Center of Competence
for Timber Engineering and Wood Technology

at Center for Structural Engineering
Graz University of Technology

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Content:

- Linkage to MoU
- TOPIC I – **Some general thoughts – independent of the material**
  - **Definition**
  - **Types of 'size effects'**
  - **'Sub-size effects'**
- TOPIC II – **'statistical length effects'**
  - **Theoretical examinations – independent of the material**
  - **Practical examinations on timber**

'Size effects' – Linkage to MoU of COST E55:

Main objective of COST E55:

"… to provide the basic framework and knowledge required for the efficient and sustainable use of timber as a structural and building material …"

→ Every material property is general related to boundary conditions

→ Especially every strength property is related to a reference size / volume

→ Design of the ultimate load requires the conversion of strength values

Specific objectives of COST E55 (selected):

"… to improve the fundamental understanding of timber material and engineered timber products …"

→ Material properties of structures depend on size and loading situation

"… to assess robustness and system aspects for timber structures …"

→ 'Size effects' are in dependence of the system structure itself

TOPIC I:

Some general thoughts concerning ‘size effects’

- Definition
- Types of ‘size effects’
- ‘Sub-size effects’

TOPIC II:

Examinations concerning ‘statistical length effect’

- Theoretical examinations
- Practical examinations

What are 'size effects'?

'Size effects' result from the dependency of material characteristics on the structural size.

EVERY native and EVERY artificial material is subjected to 'size effects'

General, the interest on 'size effects' is focused on strength properties → $f \rightarrow \{size \mid \theta\}$

Types of ‘size effects’

Main ‘size effects’ and describing theories (acc. Bažant), advanced I/II:

‘Statistical size effects’:

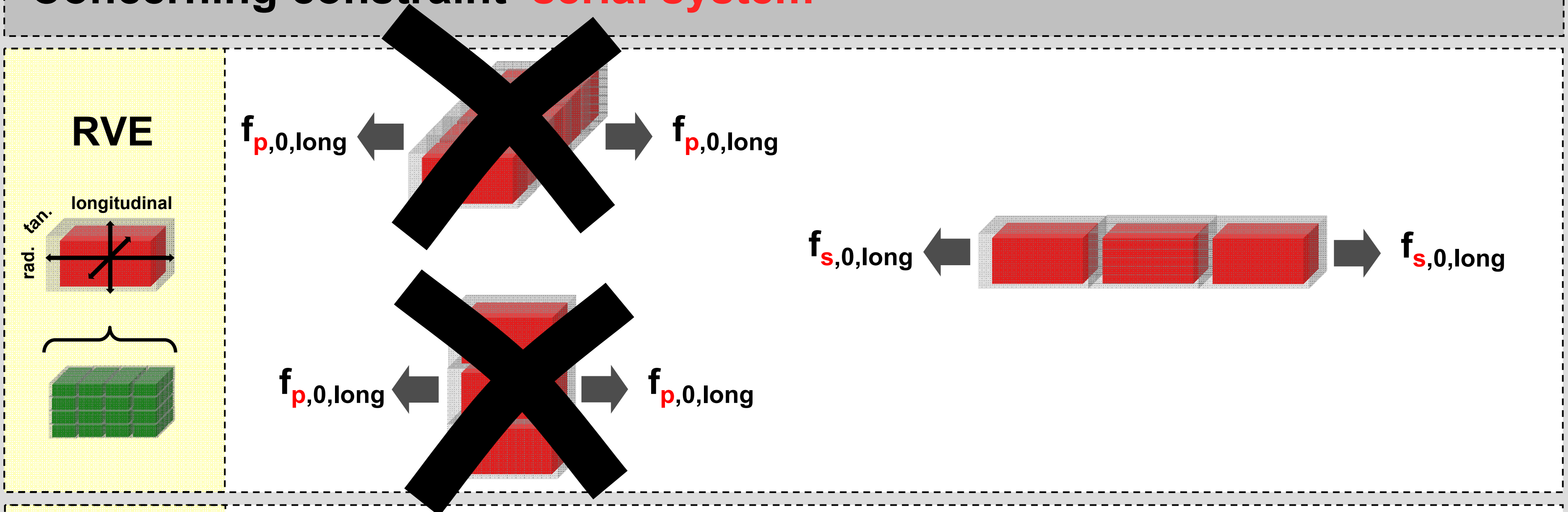
- **As a result of the randomness of material characteristics**
- **Describable by the ‘extreme statistics theory’ → ‘weakest link theory’ acc. Weibull**
- **Constraints and basis of theory:**
    - **Perfect brittle material behaviour**
    - **Serial system (like a chain)**
    - **Equal distributed characteristic of single elements**
    - **Equal stressed single elements**
    - **Appr. of lower tail of life cycle distribution by exp. distr.**

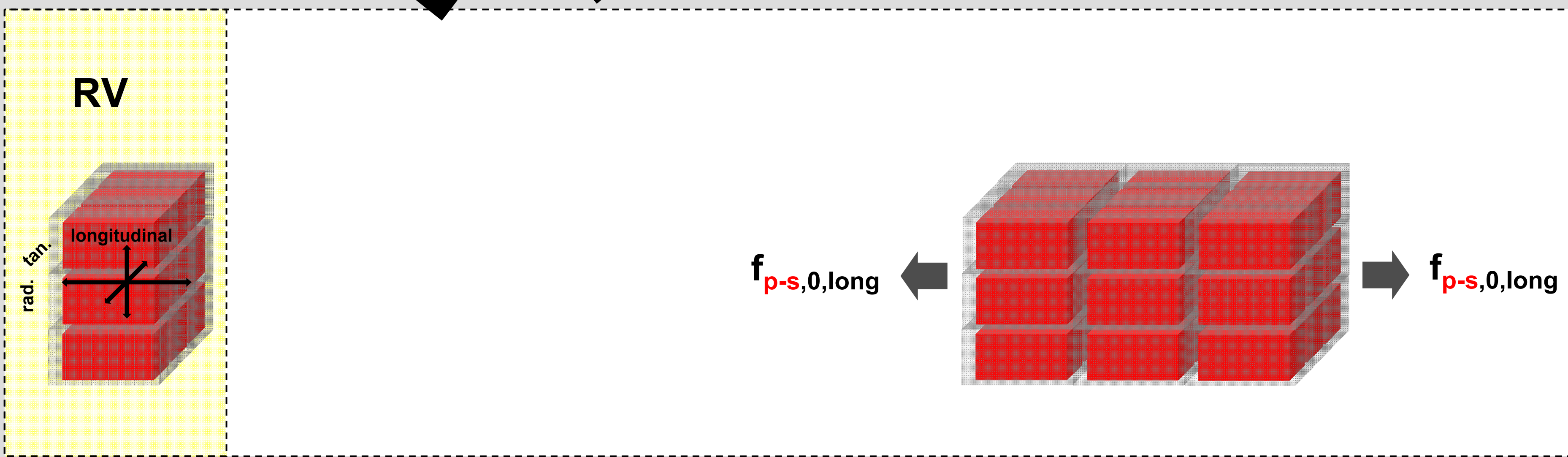
$f_{RVE} \xrightarrow{iid} f(X_i \mid \theta)$

Failure at the ‚weakest link‘

$$\left(\frac{f_1}{f_2}\right) = \left(\frac{V_2}{V_1}\right)^{k_V}$$

Concerning constraint ‘serial system’





Types of ‘size effects’

Main ‘size effects’ and describing theories (acc. Bažant), advanced II/II:

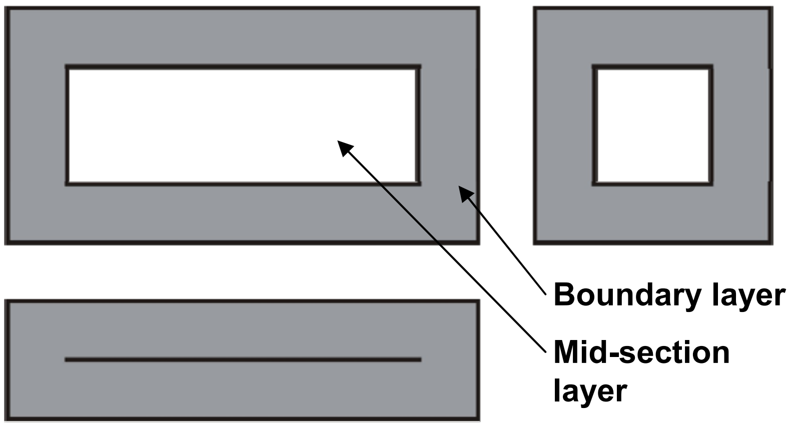
‘Energy release size effects’ / ‘fracture mechanics size effects’:

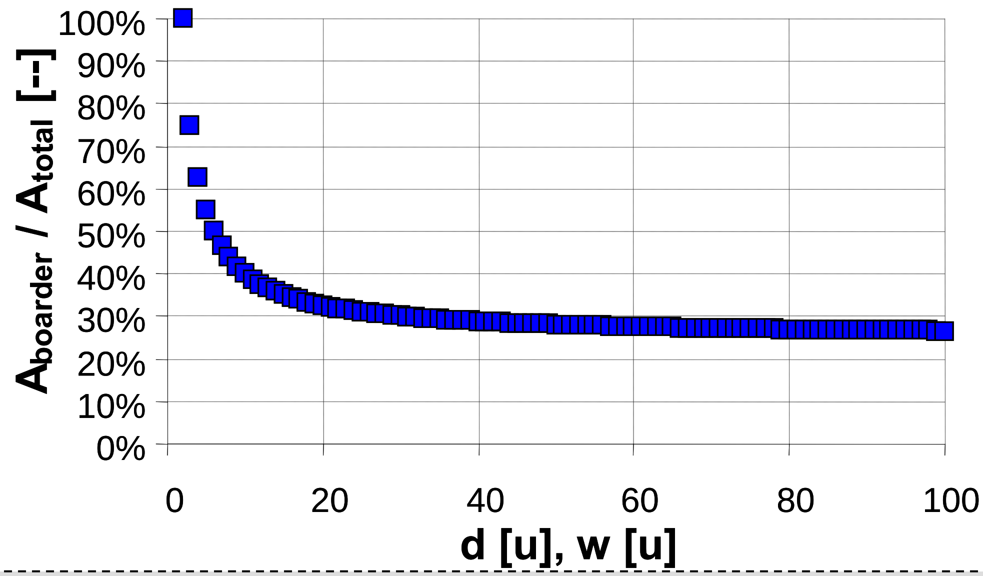
- **Due to release of stored energy and redistribution of load within residual elements within a system structure after partial failures**
- **In case of non perfect brittle material behaviour like ‘quasi brittle materials’**
- **Describable by ‘fracture mechanics theory’**

'Sub-size effects' acc. Bažant, advanced I/IV

'Boundary layer effects':

- **Differences in build-up between boundary- and midsection layer**
  - **Due to natural material build up**
    - E.g. timber: cut fibers, juvenile and adult timber sections, cut knots, knot position at the edges, etc.
  - **Due to production of artificial materials**
    - Flaws in mid section
    - Hardening of boundaries
    - Distribution of aggregates, etc.

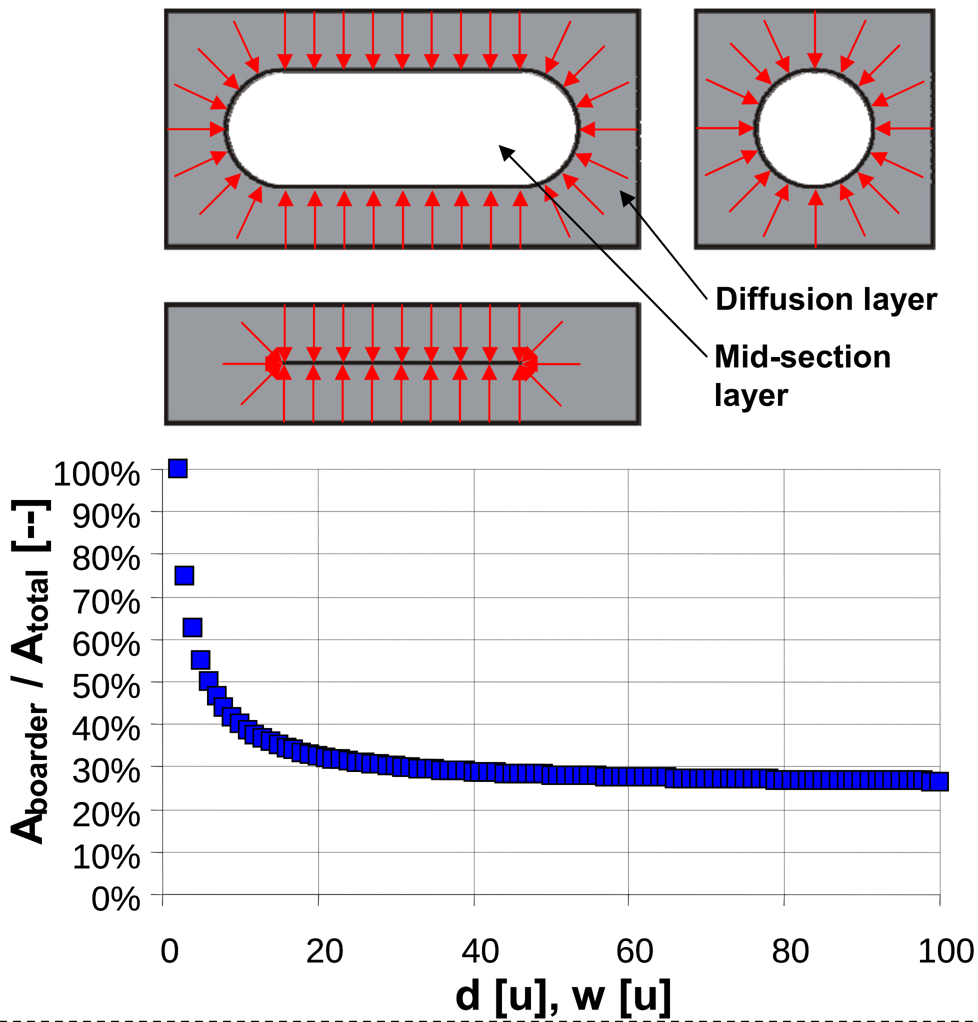




‘Sub-size effects’ acc. Bažant, advanced II/IV

‘Diffusion phenomena’:

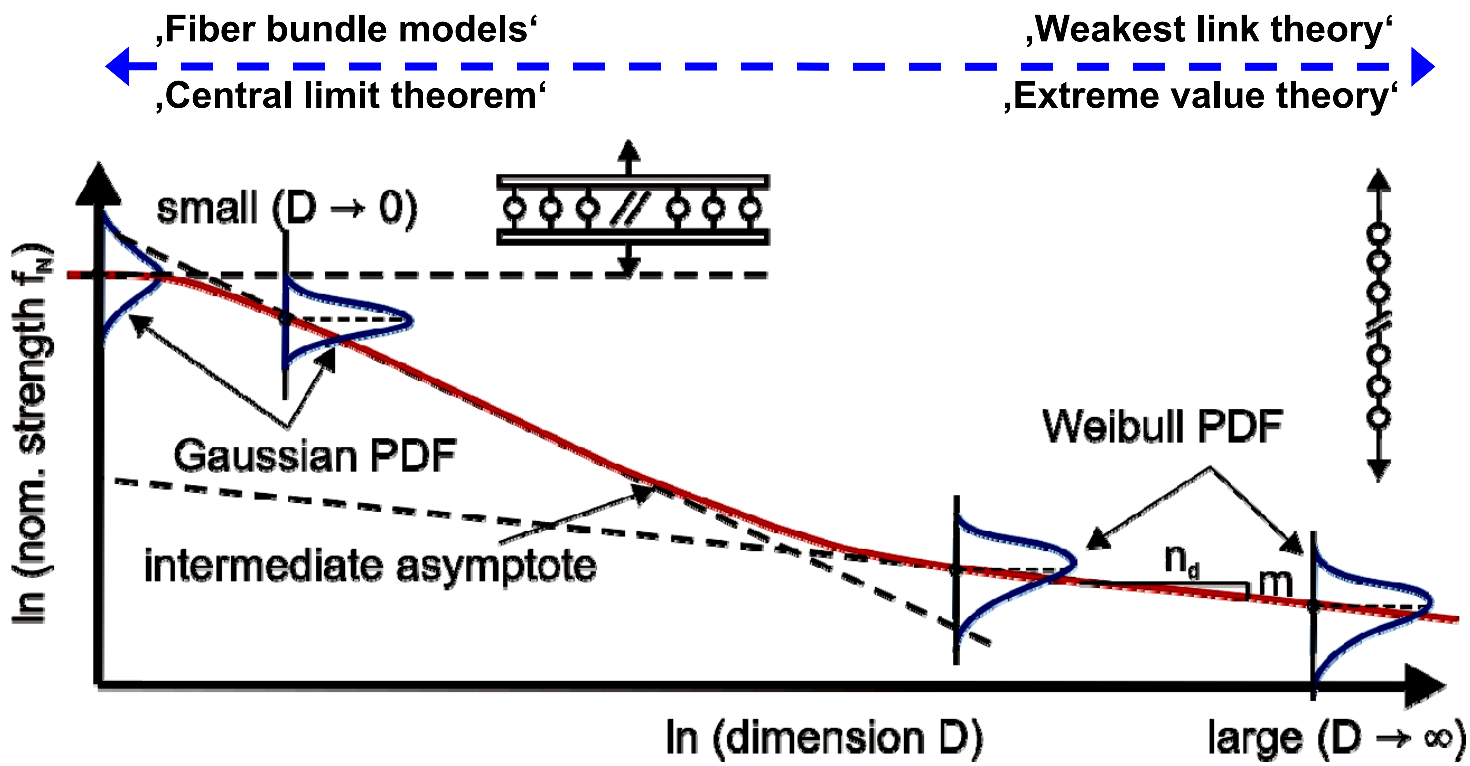
- **Delayed transport of water, temperature, other chemicals and climate effects in cyclic loading**
    - E.g. timber: orthotropic behaviour in diffusion of substances
    - Ratio of surface vers. volume → geometric effect



‘Sub-size effects’ acc. Bažant, III/IV

‘Transition of system classification’:

- **System $_{D \to DRV}$ → parallel (averaging effect)**
- **System $_{D \to \infty}$ → serial**



‘Sub-size effects’ acc. Galileo, IV/IV

‘Material inherent constraint’:

- **Finite properties defined by the material inherent maximum capacity**

‘… a small dog could probably carry on his back two or three dogs of his own size; but I believe that a horse could even not carry even one of his own size.’

(Galileo 1700’s)

- **With increase of volume own weight becomes more and more important even for light-weight structures**
- **High failure probability if structures are loaded near their maximum capacity**

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Linear timber structures – Analysis of 'statistical size effect':

Theoretical examination:

→ **Examined statistical distribution models:**

  → **WD (2-p. and 3-parametric)**

  → **LND (2-p. and 3-parametric)**

→ **Application of Monte-Carlo simulations due to lack of closed solution of Integrals based on 'extreme statistic theory – minimum' – 'weakest link theory'**

Practical examination:

→ **Tension tests of finger jointed construction timber (KVH®)**

→ **Two series**

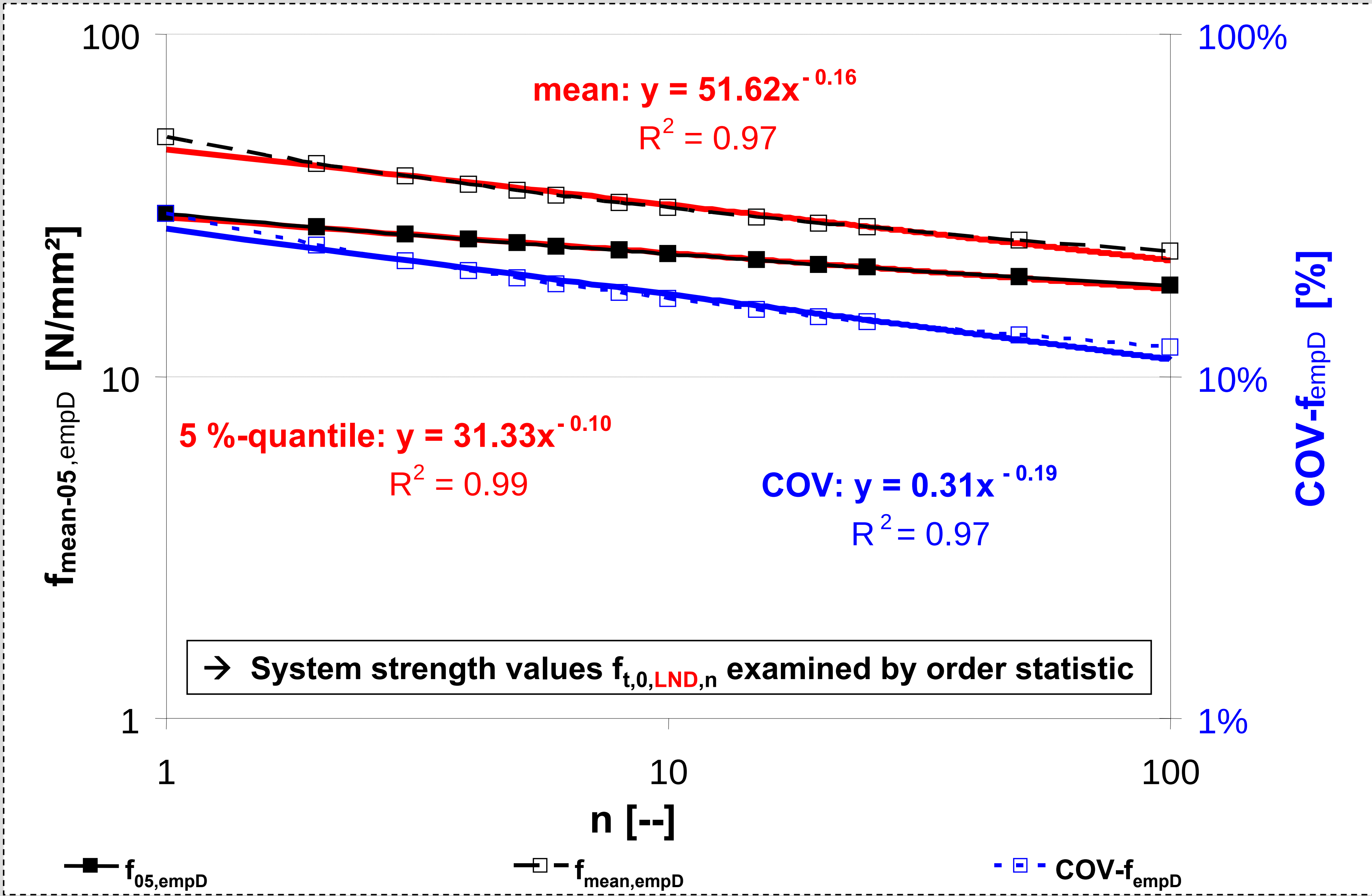
  → **Spruce, Middle Europe, b / h = 200 / 60 mm, ungraded**

    → **Free testing length: 2,800 mm (210 #)**

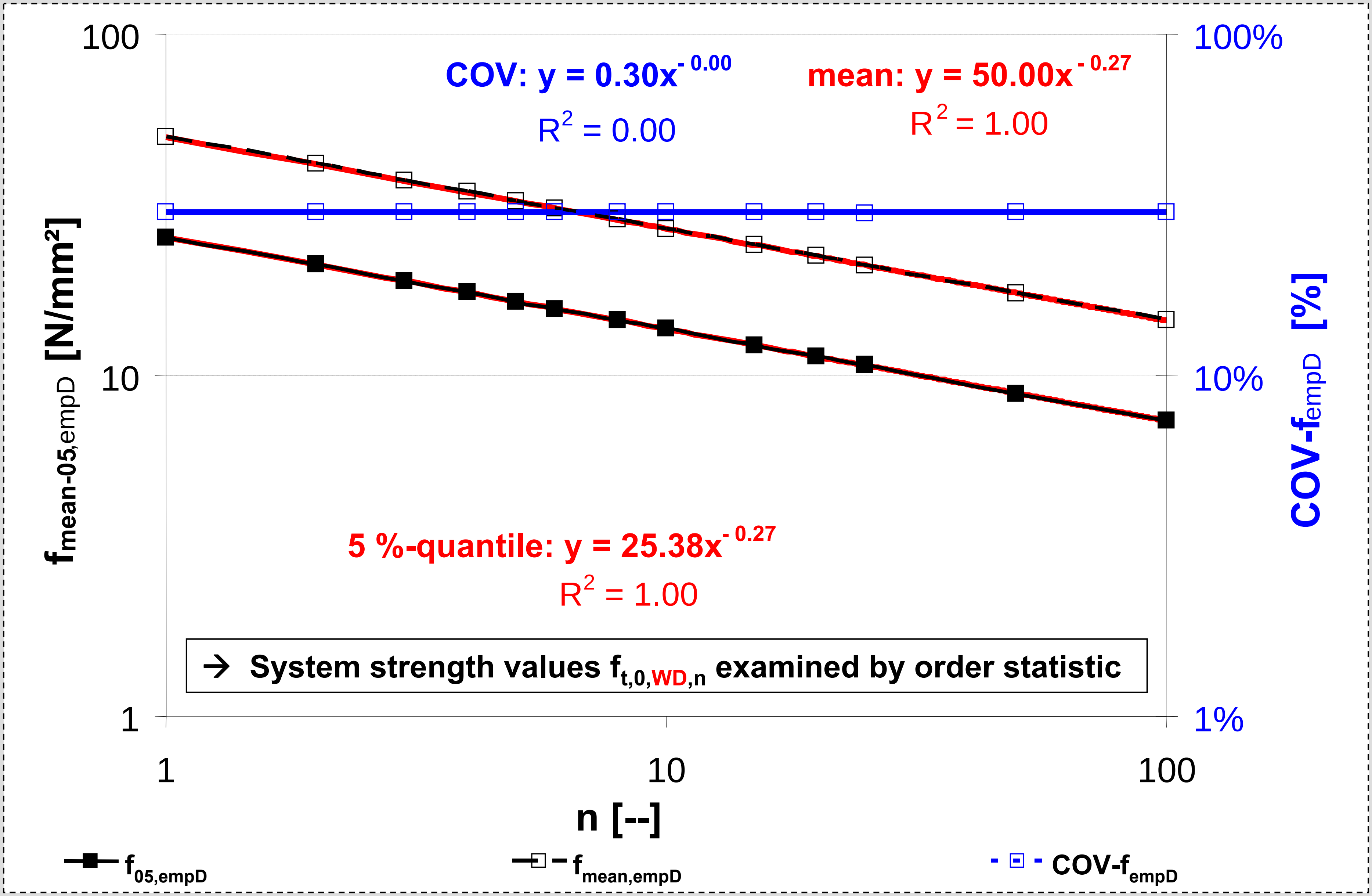
  → **Spruce, Middle Europe, b / h = 160 / 60 mm, graded S10 (acc. DIN 4074)**

    → **Free testing span: 1,440 mm (98 #), 7,982 mm (52 #), 17,222 mm (42 #)**

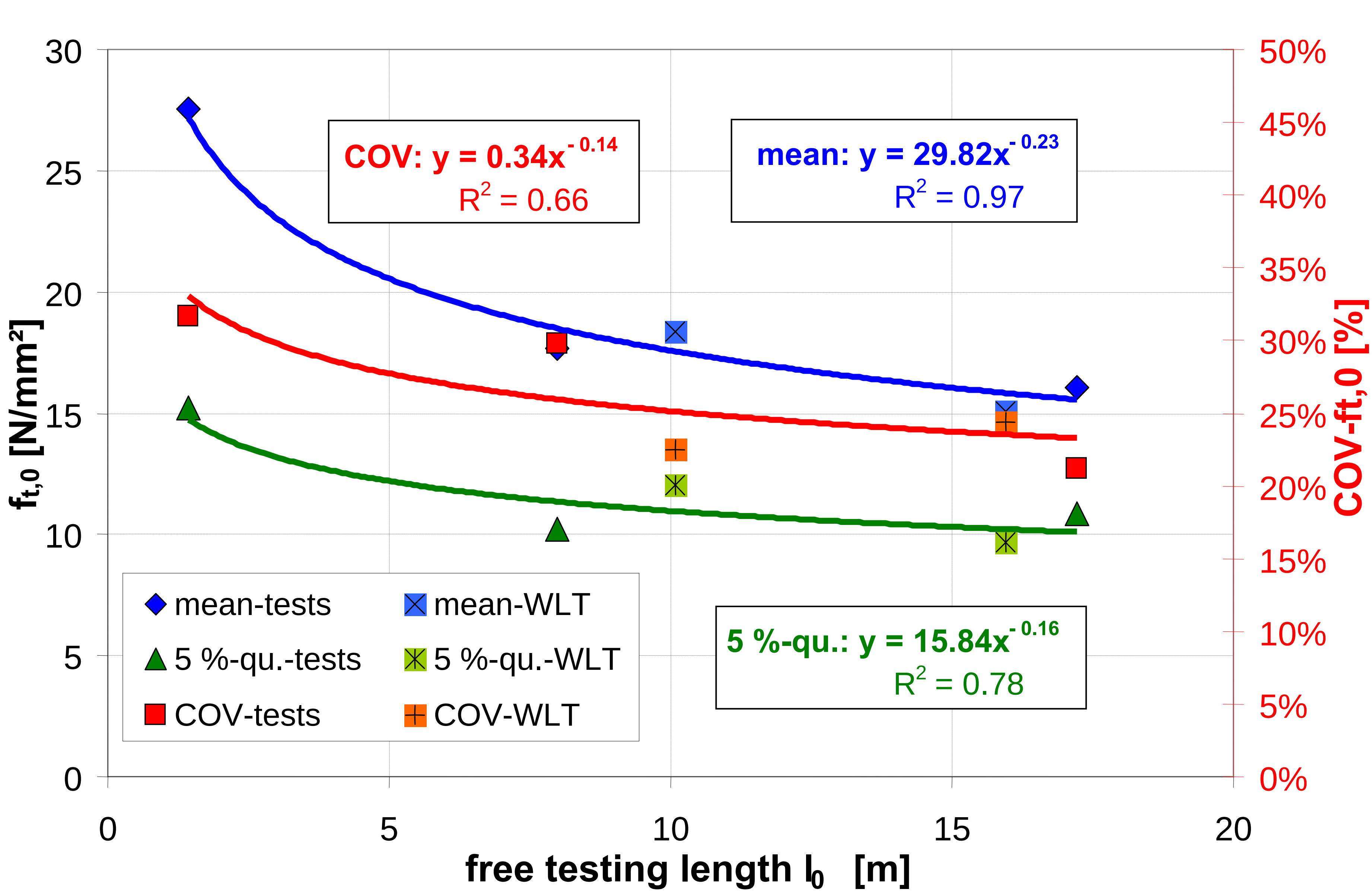
k_{length} –RVE's with $f_{t,0,l,LND,n=1}$

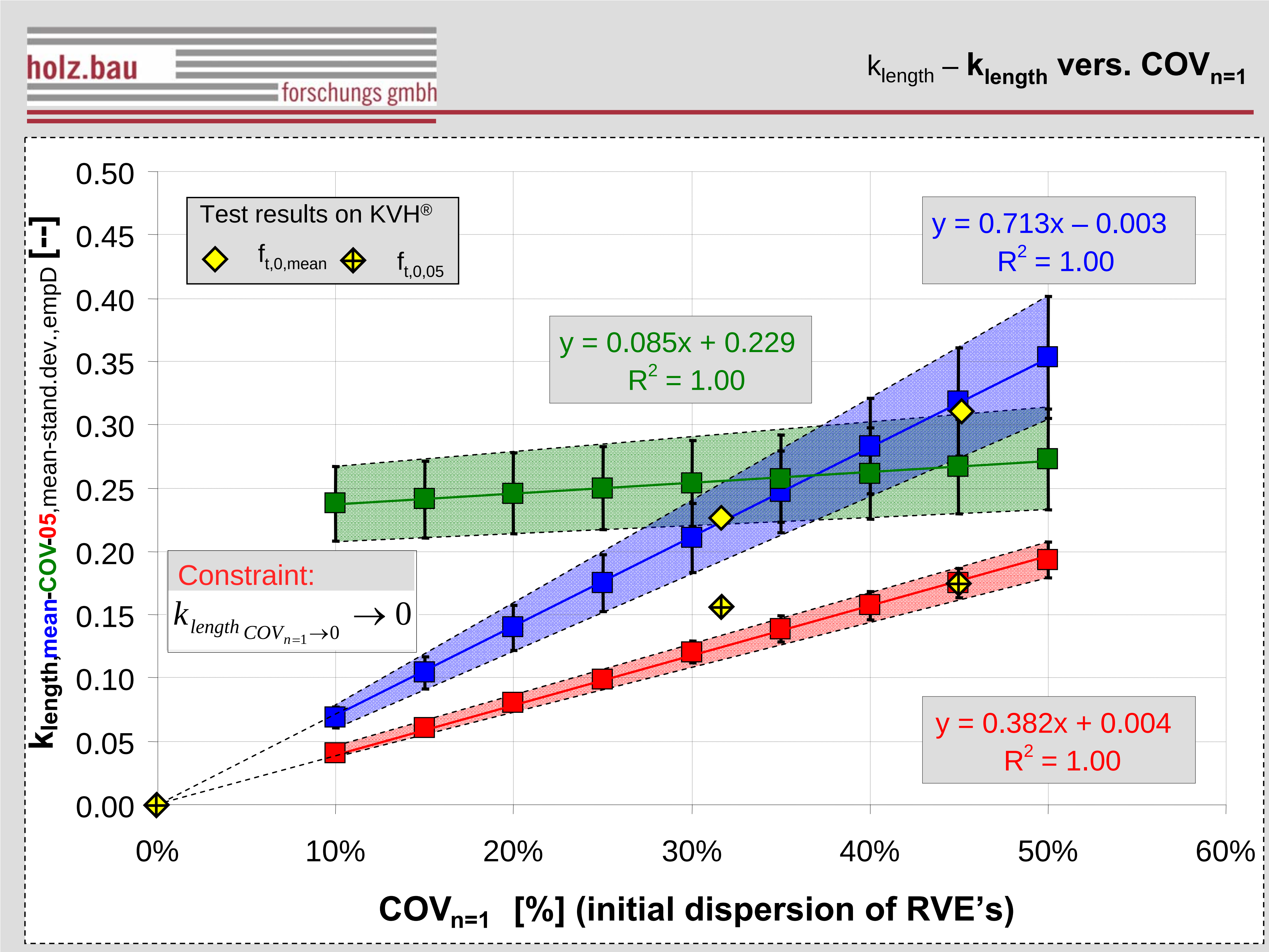


k_{length} –RVE's with $f_{t,0,l,WD,n=1}$



k_{length} – Practical test results

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k_length – k_length vers. COV_n=1
Test results on KVH®
f_t,0,mean
f_t,0,05
y = 0.713x – 0.003
R² = 1.00
y = 0.085x + 0.229
R² = 1.00
y = 0.382x + 0.004
R² = 1.00
Constraint:
k_length COV_n=1→0 → 0
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0%
10%
20%
30%
40%
50%
60%
k_length,mean,mean-COV-05,mean-stand.dev.,empD [--]
COV_n=1 [%] (initial dispersion of RVE's)

Conclusion concerning the ‘statistical size effect’ on $f_{t,0,LND}$:

Modelling:

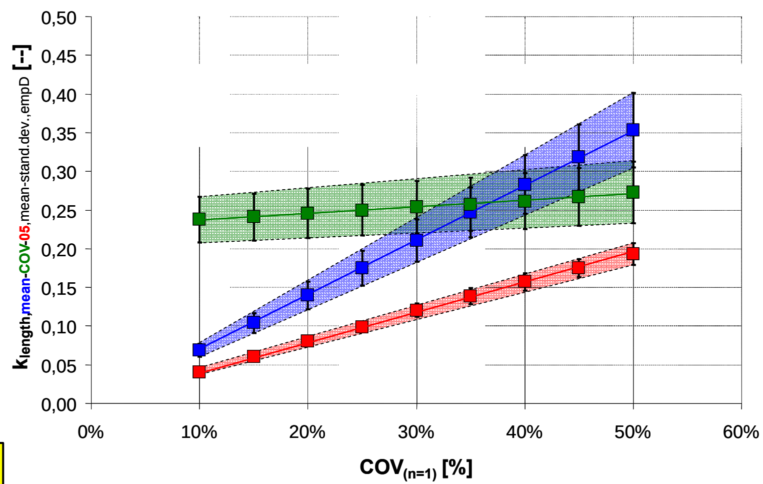
- **Constraint:**

$$k_{length\,COV \to 0} \to 0$$

- **Simplifications for RVE’s with $f_{t,0,LND}$:**

$$k_{length,mean,LND} \approx 0.7 \cdot COV_{n=1}$$

$$k_{length,05,LND} \approx 0.4 \cdot COV_{n=1} \to 0.6 \cdot k_{length,mean,LND}$$



Proposal (in regard to EN 14374 for LVL):

→ **Proposal for the regulation of $k_{length,t}$ for $f_{t,0,l,05,LND}$ even for $l > l_{ref}$!!!**

$$k_{length,t} = \left(\frac{l}{l_{ref}}\right)^{\alpha_t} \to \left(\frac{l}{9 \cdot w_{ref}}\right)^{\alpha_t} = \left(\frac{l}{1350}\right)^{\alpha_t}$$

$$\alpha \to f\left\{DM_{n=1}, COV_{n=1}\right\}$$

$$\alpha_{t,LND} = 0.4 \cdot COV_{n=1}$$

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