COMPARISON OF TEST RESULTS AND THE REDUCED CROSS-SECTION METHOD USING A ZERO-STRENGTH LAYER

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Summary.
The fire resistance of timber members has to be verified either by fire tests or by calculations. For timber members, the *Reduced Cross-Section Method* has been implemented in handbooks and *Eurocode 5* (EN 1995-1-2) to calculate the load-bearing resistance of structural timber in fire conditions.
Beside the reduction of the original cross-section by the char layer, the zero-strength layer is introduced to take into account losses in strength and stiffness of timber members.

***Figure 1**. The char layer provides an effective heat insulation to maintain the load-bearing resistance. However, heated timber exhibits less strength which has to be considered in calculation models [Image source: Fire Safety In Timber Buildings].*

As fire resistance testing is time and money consuming, it is needed to have sufficient verification models to predict the behaviour in standard fire tests or real fire conditions.

Design procedure.
The *Reduced Cross-Section Method* uses an effective cross-section to verify the load-bearing resistance. The idea is to consider the losses of strength and stiffness due to heat by means of an additional layer, the zero-strength layer. The method could be used for any fire exposure (standard or parametric fires) but the zero-strength layer d_0 implemented in *Eurocode 5* allows application for ISO 834 standard fire only.
The effective cross-section can be determined in two steps for any point of the standard fire exposure:

1) Reduction of the original cross-section by means of the char layer. The result is the residual cross-section at a certain point in time.
Wood exceeding 300°C is considered as char and non load-bearing. The charring depth may be calculated using fixed values or considering the density, initial moisture content or the species depending on the charring model used.
Some charring models take into account the corner roundings by a slightly increased notional charring rate to describe an equivalent section modulus.

2) Reduction of the residual cross-section by means of a fictive zero-strength layer. The result is the effective cross-section.
The second step is conducted instead of taking into account the reduced strength and stiffness properties in the depths exhibiting between 20 and 300°C.

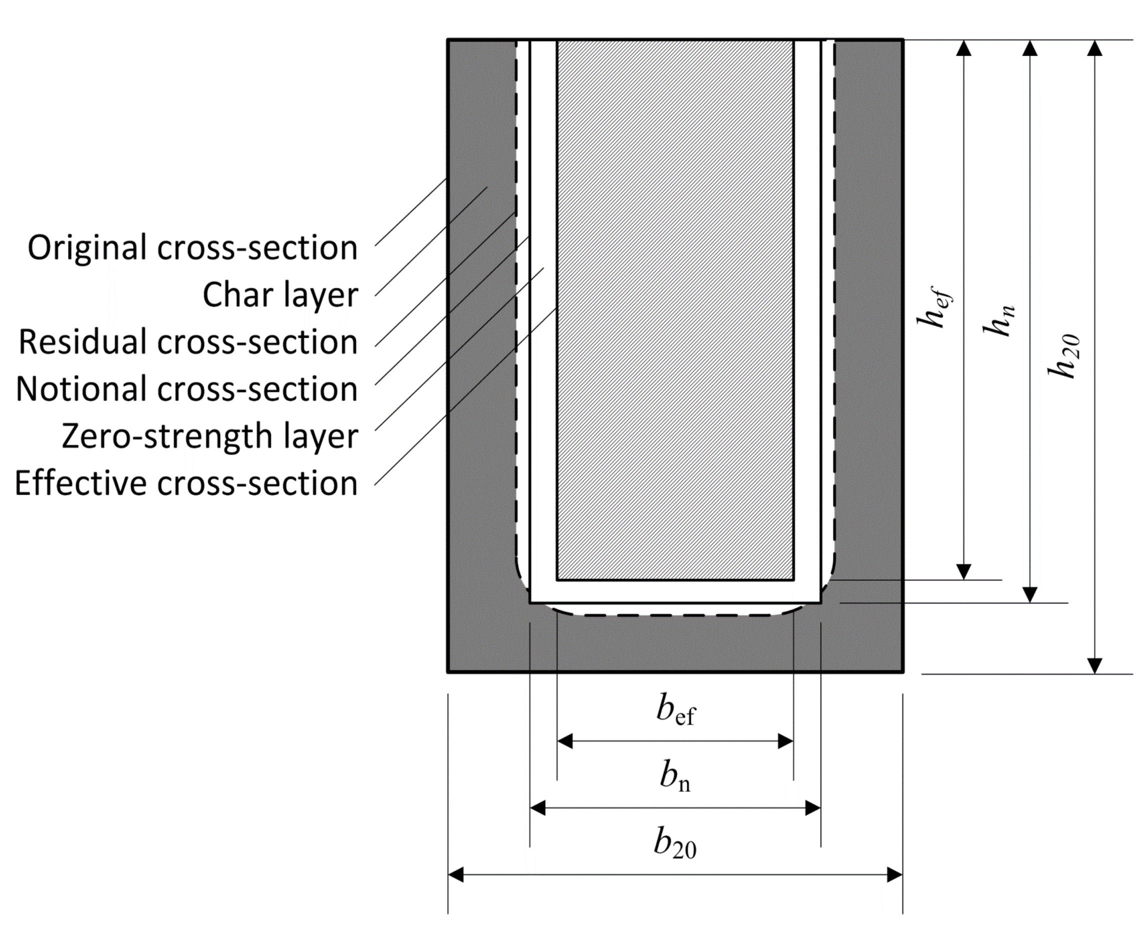


***Figure 2.** Original and fire exposed timber beam cross section exposed to fire on three sides.*

Limitations of the original model.
The original zero-strength layer was determined averaging strength and stiffness values and has some draw-backs:

- Using test-results from oven heated small-scale specimen may not represent material properties in non-steady state conditions where moisture movement occurs.
- Averaging strength for a brittle material in combination with a linear-elastic mechanical model might deliver wrong results.
- Using equal stiffness properties for fibers in compression and tension does not reflect the correct material behaviour.
- The determined zero-strength layer may be inappropriate for members in tension and compression since these characteristics are different in the fire condition.

Questioning.
The original method was developed studying a glulam beam (134 mm x 420 mm) with a reduction of the cross-section corresponding to 30 and 60 minutes; a 0.3 inch zero-strength layer was determined based on strength and stiffness losses of in small-scale specimens [Schaffer et al., 1986].
Later studies in Europe determined the bases for advanced calculations (Finite Element Modelling) which can be used for any cross-section exposed to standard fire; these material characteristics were implemented in the *Annex of Eurocode 5*.
Using this reduction curves, it can be shown that the 7mm zero-strength layer is valid only to a limited extent.

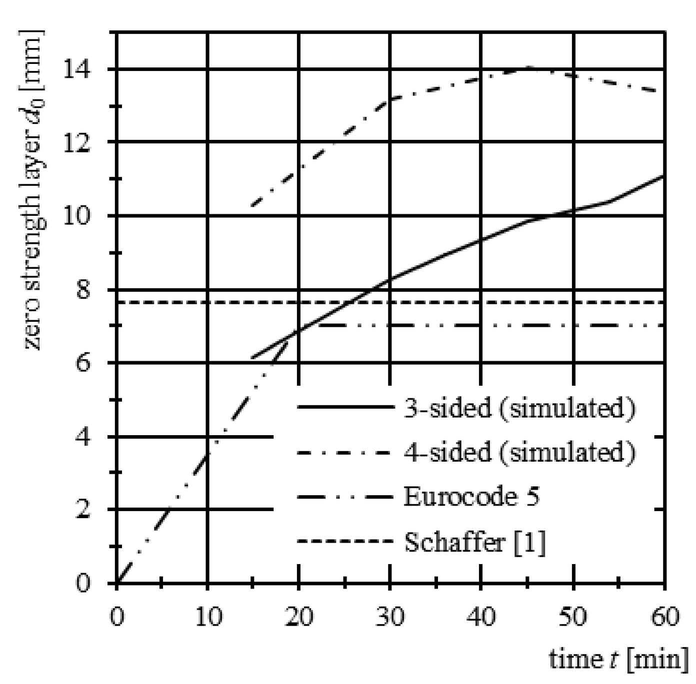


***Figure 3.** Zero-strength layer of timber beams according to the original RCSM (Schaffer), the RCSM in Eurocode 5 and advanced calculation based on Eurocode 5 [Schmid et al.,2014].*

Validity.
As the material reduction curves were developed with small cross-section (width 45mm) questions arose if the results are valid even for large cross-sections.
The comprehensive analysis of full-scale fire resistance tests was performed taking into account:

- 117 fire resistance tests in bending
- 107 fire resistance tests of buckling members
- Fire tests from 1961 to 2014
- Fire tests in Europe, US/CAN, China

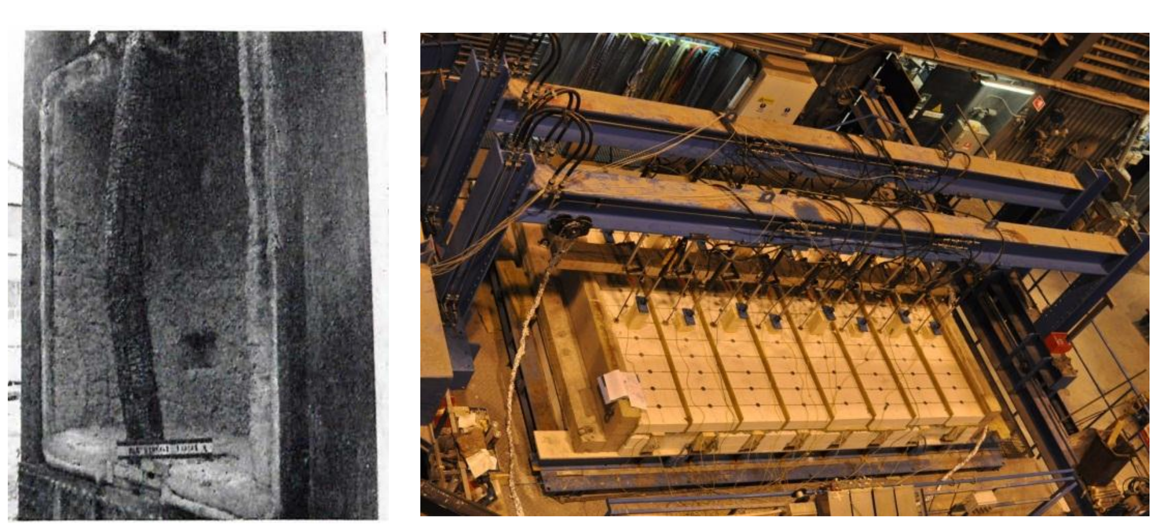


***Figure 4.** Fire resistance test of a timber column [Fackler, 1961] and glulam beams [Lange et al., 2014].*

Backwards calculation.
Using the RCSM, the design in the fire situation follows the design at normal temperature. All fire test results were analysed with respect to the material (strength, stiffness), the test condition (supports, extinguishing) and the time and type of failure. Many reports are of bad quality limiting the reliability of the direct test results and the possibility for the development of any design model.
Based on the reported residual cross-section and the failure time an appropriate zero-strength layer was calculated. The zero-strength layer for bending and buckling members was evaluated using the methodology of backwards calculation [Schmid et al., 2014].

Beams.
Bending members exposed on three and four sides were evaluated. Results between about -6 and 38 mm indicate that the prediction of the material characteristics (strength property) is challenging but further that these results do not verify a constant zero-strength layer of 7 mm as given in *Eurocode 5*.

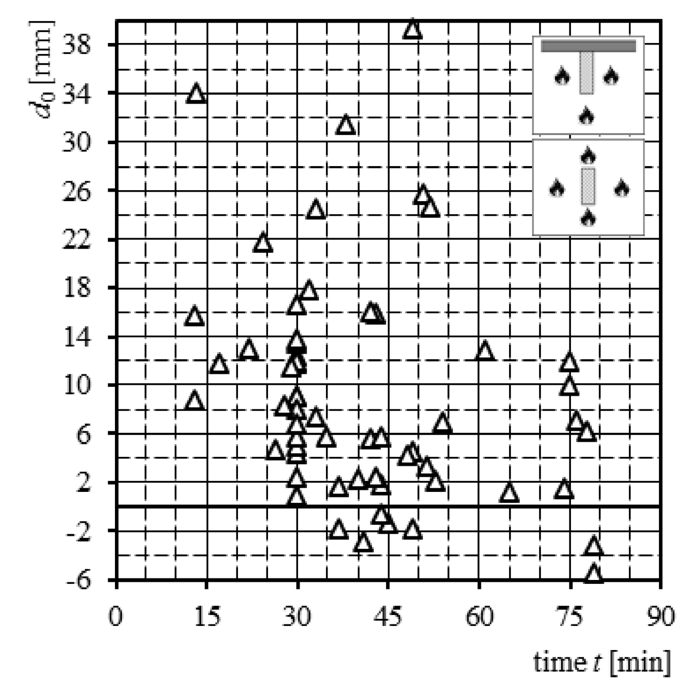


***Figure 5.** Zero-strength layer corresponding to full-scale fire resistance tests of timber beams [Schmid et al., 2014].*

Columns.
Even for columns results indicate problems with the prediction of the material properties; for a constant zero-strength layer (mean of all results) of 11mm a regression coefficient R^2 of 0,00 (d_0 vs. time) was achieved while a dependency of the cross-section depth (buckling about the weak axis) was observed.

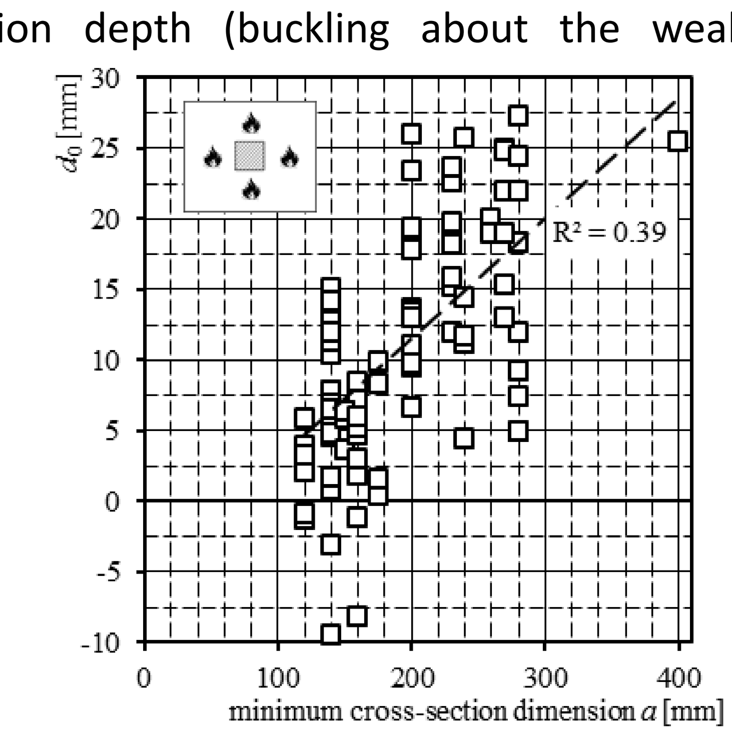
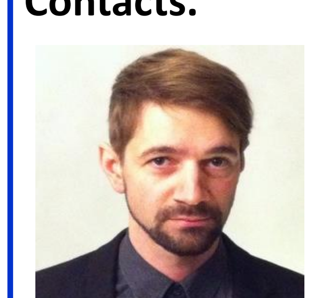


***Figure 6.** Zero-strength layer corresponding to full-scale fire resistance tests of timber columns [Schmid et al., 2015].*

Future work.
For the revision of the *Eurocode 5* a combined approach of testing and simulations is needed to develop a design model based on reliable fire tests. To describe all phenomena with one constant value seems to be impossible.

Contacts.



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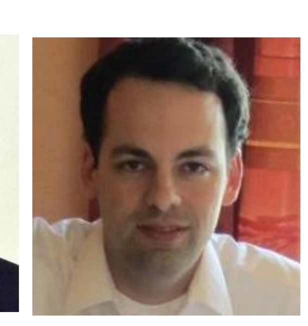

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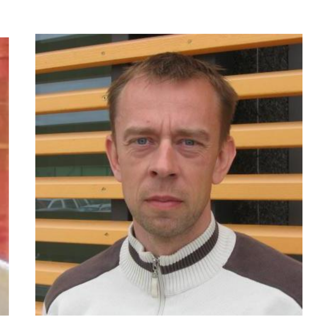

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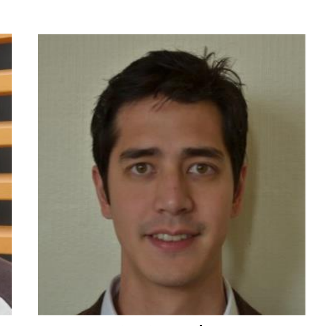

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