Fire Resistance of Timber Structures

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Use of timber as building material

- Combustible building materials like timber burn on their surface, release energy and thus contribute to fire propagation and the development of smoke in case of fire.

- The main precondition for the use of wood in buildings is adequate fire safety.

- The combustibility of wood is one of the main reasons for most building codes to strongly limit the use of timber as a building material and in particular of the number of storeys of timber buildings.
Critical points
## Research projects

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Fire regulations

- Many countries have liberalized the use of timber for multi-storey medium-rise buildings based on results of many research projects.
- Example: new Swiss fire regulations (2003) allow the use of timber structures in multi-storey residential buildings up to 6 storeys.
Steel behaviour in fire

Non combustible material; Steel heats up quickly
Temperature dependent reduction of strength and stiffness
Protection of steel elements against fire often required!
Concrete behaviour in fire

- Non combustible material;
- Concrete heat up slowly
- Temperature dependent reduction of strength and stiffness
- Spalling; Concrete performance after fire; Performance of new concrete mix designs
Timber behaviour in fire

- Pyrolysis: thermal degradation of wood producing combustible gases and accompanied by a loss in mass (starting from about 250°C)

- Charring rate $\beta$:
  Ratio between charring depth $d_{\text{char}}$ and fire time $t$ (in mm/min)

$$\beta = \frac{d_{\text{char}}}{t}$$

$$\beta = \frac{50\text{mm}}{63\text{min}} = 0.8\text{mm/min}$$

Fire time $t = 63\text{min}$

Residual cross-section

Char layer $d_{\text{char}} = 50\text{ mm}$
Timber behaviour in fire

- Char layer protects the residual cross-section from high temperatures

- “cold“
- load-bearing

Quelle: proHolz, Österreich
Intumescent coating systems on steel members

- Mode of action: intumescent systems expand at a temperature of about 200°C by a factor of 30 to 60 and form a compact insulating layer.
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Intumescent coating systems

“Modern manmade intumescent materials applied to steel structural elements are in essence an attempt to replicate what timber does naturally.”

From paper “Overview of design issues for tall timber buildings”, I. Smith, A. Frangi, Structural Engineering International SEI 2/2008
Fire resistance of timber elements

Basic strategies

- Use of massive cross-sections
- Increase of cross-sections by charring depth
- Protection of the timber elements with non-combustible materials
Design of timber structures in fire

Reduced cross-section method according to EN 1995-1-2

- char layer
- zero strength layer of maximum 7 mm
- effective cross-section

\[ k_{\text{mod,fi}} = 1 \]
Fire separating function of walls and floors

Fire spread after 50 minutes ISO-fire exposure by a nailed laminated timber slab without cladding on the fire unexposed side
Fire test on loaded timber-concrete composite composite slab
Influence of joint between timber hollow core elements

Residual cross-section after 60 minutes ISO-fire exposure
Fire separating function of walls and floors

Basic strategies

- Gaps, joints backed by other layers
- Cavities filled with non combustible materials like mineral wool
- Multi-layered timber elements
- Claddings, linings

Favorable timber elements

- Timber-concrete composite slabs
- Cross-laminated timber elements
Fire separating function of walls and floors
Calculation model

- New model based on component additive method (EN 1995-1-2)
- Calculation of the time $t_{\text{ins}}$ by adding the contribution to the fire resistance of the different layers $t_i$

$$t_{\text{ins}} = \sum_i t_i$$

$$t_i = t_{0,i} \cdot k_{\text{pos},i} \cdot k_{j,i}$$

Fire separating function of walls and floors
Connections with steel elements in fire

Fire test with a multiple shear steel-to-timber dowelled connection
Connections with steel elements in fire

Connections with side steel plates

Connection with side steel plates and annular ringed shank nails

Connections with slotted-in steel plates

Multiple shear steel-to-timber dowelled connection
Connections with steel elements in fire

Basic strategies

- Connections with slotted-in steel plates much better than connections with side steel plates
- Increase of the overall thickness of the timber members as well as the end distance of the dowels
- Fire protection of connections by boards (timber boards or gypsum plasterboards)
Fire design model for multiple shear steel-to-timber dowelled connections

Residual cross-section $A_r$

Effective cross-section $A_{ef}$

$t_1$: thickness of timber side member

$R_{d,t,fi} = A_{ef} \cdot f_{t,0,k} \cdot k_{fi}$
Natural fire tests

Tsukuba (Japan), March 6, 2007
Experimental investigations on fire safety concepts under natural fire conditions

- Swiss Expo02 temporary hotels
- 6 full scale tests

Objectives

- Efficiency of different fire safety concepts (structural, technical)
- Fire spread inside and outside the room hotel
- Influence of combustible surfaces in room hotel
- Efficiency of automatic extinguishing systems
Influence of combustible surfaces in room hotel

Fire after 7 minutes after fire ignition

Combustible surface in fire room

Non combustible surface in fire room

Natural fire tests
Fire compartmentation: no fire propagation from lower to upper room
Efficiency of automatic extinguishing systems: sprinkler

Natural fire tests
Project SOFIE

- Project SOFIE, Institute IVALSA, Trento, Italy
- Timber buildings with cross-laminated timber panels (XLam)
- Natural full-scale fire test on a 3 storey XLam timber building
Cross-section

Fire load density = 790 MJ/m²
Fire propagation: no fire spread to adjacent rooms

Tsukuba (Japan), March 6, 2007
**New Swiss fire regulations (2003)**

Fire requirements for structural safety concept

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<th>Since 1.1.2005</th>
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<tr>
<td>F 30bb</td>
<td>REI30</td>
<td>REI60</td>
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Zurich, Switzerland
New Swiss fire regulations recognize that the fire safety objective adopted for medium-rise buildings can be achieved with the given requirements despite the combustibility of the structural material used.
Examples
Project Holzhausen, Steinhausen, Switzerland

- 6 storeys residential building
- Timber structure (except staircase in concrete)
- Dimensions
  - Height: 20.00 m
  - Length: 29.75 m
  - Width: 13.80 m
  - Area: 410.55 m²
- Minergie-Standard
- Timber facade
Static system

2. Obergeschoss
Detailing

Connection of bracing walls

Fire stop barrier on timber facade
Fire safety plan

2. Obergeschoss

Symbol / Legende

- Feuerwiderstand RE180(ebb)
- Feuerwiderstand RE110/EE130(ebb)
- Feuerwiderstand RE80/EE130(ebb)
- Feuerwiderstand EE130
- Tür EE130

Fluchtrichtung
Fluchtreppe
Project school building, Baar, Switzerland

- 5 storeys school building
- Timber structure (except staircases in concrete)
- Dimensions
  - Height: 20,0 m
  - Length: 45,0 m
  - Width: 19,0 m
  - Spacing columns: 7.70 m x 6.50 m
- Minergie-Standard
Static system

- Timber beams
- Timber columns
- Timber-concrete composite slab
Detailing

Examples
Building service installation

- Cavity for building service installation
- Glulam timber beam 320x680 mm

Examples
Fire safety plan

Legende:
- Fluchtweg
- Fluchtbereich nichtbrennbare Mauer/Deckenverkleidung
- Feuerlöscher
- Verkleidung (€/€/€) in mmstärke
- Brandschutzsilizium
- Brandschutzsilizium in nichtbrennbarer Bauweise
- Brandschutzsilizium (E100) in nichtbrennbarer Bauweise
- Brandschutzsilizium (E100/E130) in Holzbauweise
- Brandschutzsilizium (E130) in Holzbauweise
- Brandschutzsilizium R(E100) in nichtbrennbarer Bauweise
- Brandschutzsilizium mit Flächentrennung
- Unterkernholz der Fassaden-Hinterlüftung oder Schornsteinlückung
- Tragwerk:
  - Treppenhaus: R60 (nbb)
  - Tragwerk EC: 3.OC: R60 Unterzüge Stützen
  - Tragwerk DG: R0
- Aussenwandverkleidung:
  - Gesamtgebäude S.3, Hinterlüftung alle 2Geschosse abgeschaltet

Examples
Quality of construction

- Fire safety plan with all fire safety measures
- Careful planning and detailing
- Professionally implementation of fire safety measures during the execution
- Periodic controls and maintenance
- The intensity of maintenance and controls must be set depending on the type of structures and the type and importance of the building
Conclusions

- Fire safety is not primarily a question of building material but of concept.
- Novel calculation models for fire resistance of timber structures were developed based on extensive element and full scale testing.
- Structural safety concept for timber structures with careful detailing and maintenance can provide same safety level as for buildings with non combustible structures.
- Great chance for increased use of timber in multi-storey buildings with new fire regulations and fire performance based design concepts.
Yes, we can...

London, 9 storeys (UK)

Steinhausen, 6 storeys (Switzerland)

Lugano, 6 storeys (Switzerland)

Bolzano, 7 storeys (Italy)