Repairing of timber and fire-damaged structures

Mon 02.05.2016
Introduction & Conservation

Repair methods of the roofing structures

Repair methods of the window and the door structures

Building information modelling BIM

The use of ICT for condition assessment of structures

Repair of fire damage

Repair methods for wooden structures

Strengthening of building structures

HVAC-renovation
Outlines

**Repair of timber structures**
- Introduction
- Deterioration of timber structures
- Condition inspection of the timber structures
- Repair of timber structures:
  - load-bearing timber structures
  - timber floors
  - timber grids
  - glued timber structures
  - wood damaged by rot and mould
  - Wood cladding

**Repair of fire damaged-concrete structures**
- Deterioration due to fire
- Assessment of fire damage
- Fire damage classification
- Repair methods of fire-damaged concrete structures
Repair of timber structures
Introduction

**Uses of timber in construction**
- Building construction
- Construction of house posts
- Construction of beams
- Construction of rafters
- Construction of bridges
- Construction of piles, poles and railway sleepers
Timber deterioration

Problems in timber structures can be defined in terms of three things:
- the timber material itself
- the way it's put together (connections),
- the way it is functioning

Wood deteriorating factors

• **Moisture**
  - influence on physical-mechanical properties of wood
  - creates favourable growing conditions for agents responsible for wood degradations.

• **Temperature**
  - When exposing wood to temperatures higher than 150°C, its strength will be affected

• **Loading stresses**
  - Bending moment, tensile, compressive and shear forces
  - Torsion, creep, fatigue

• **Biological agents**
  - Fungi and insects or, in some cases, by some marine borers

- Below the fiber saturation point, the wood will shrink when losing moisture and swallow when absorbing moisture
Damage to timber structures

Common damage are:
- Natural defects in timber elements
- Fungi (brown and white rot)
- Insects (termites etc.)
- Decay
- Delamination of glulam beams
- Fire
- Impact or collisions
- Abrasion or wear
- Overstress
- Weathering or warping
- Cracking (overload or shrinkage)
- Connections damage
Damage to timber structures

Voichita Bucur (2011) Delamination in Wood, Wood Products and Wood-Based Composites

Fig. 2.1.6  Natural Timber Defects

Fig. 17.4  Severe delamination in a glulam beam made of *Robinia pseudoacacia* after 34 years of service. Lamella thickness is 20 mm.
## Condition inspection of the timber structures

The inspection should include as a minimum the following:

1. Assessment of the condition of each timber member including:
   a) Significant checking
   b) Broken members
   c) Member splitting
   d) Water and decay damage
   e) Fire damage
   f) Member warping
   g) Other damage

2. Assessment of the condition of each timber connection.

3. Moisture content determination of representative members.

4. Assessment of all loads supported by timber members including:
   a) Roof dead loads
   b) Roof live/snow loads
   c) Ceiling dead loads
   d) Floor dead loads
   e) Floor live loads
   f) Mechanical unit loads
   g) Other applied loads

5. Assessment of timber member configuration and sizes
Repair of timber structures

1. Strengthening of load-bearing timber structures
   - Damaged load-bearing structures
   - Increasing the load bearing capacity of non-damaged structures
   - Strengthening the connections

2. Strengthening of timber floors
   - Adding additional beams

3. Strengthening of timber trusses
   - Supporting rods
   - buckling of the chords
   - Strengthening the connections

4. Repair of glued timber structures
   - Transverse tension
   - Cracking of the joint area

5. Repair of wood damaged by rot and mould
Strengthening of load-bearing timber structures

- Classical strengthening methods implying traditional materials:
  - **case of compressive loads**
    - reduce the deformations
    - enhance the rigidity of the member
  - **elements subjected to tension**
    - using cover plates made of wood
    - connected with rods
  - **elements subjected to bending**
    - stop crack propagation or to enclose it
    - use of metallic elements


Tension elements strengthening:
- \(a\) – using metallic tie rods,
- \(b\) – using cover plates and short inner plates;
- \(1\) – degraded area,
- \(2\) – metallic tie rods,
- \(3\) – L profile,
- \(4\) – wood cover plates,
- \(5\) – short inner plates,
- \(6\) – bolts.
Strengthening of load-bearing timber structures

Additional beams

- **wooden beams**
  - Timber glue wood
  - glued laminated beam
  - thin-web bed beam

- **Steel beams**
  - I-beams
  - Rectangular Hollow Sections (RHS) beams

Strengthening of load-bearing timber structures

Beam strengthening using external tie rods
1 – beam, 2 – anchorage, 3 – tension element, 4 – tie rod, 5 – spacing piece.

Strengthening of load-bearing timber structures

- Strengthening wood elements using **Fiber Reinforced Polymer** (FRP) composite materials

- Reinforcing the wood members with very thin FRP sheets bonded onto their **tension faces** has resulted in the increase of the elements strength, stiffness and ductility characteristics.

- Fiber reinforcements could also be very advantageous in regions of **stress concentration** (like bolted joints), as well as with tensile and flexural members.

![Columns strengthening using FRP composites](https://www.fhwa.dot.gov/publications/research/infrastructure/structures/04098/14.cfm)

- (0°/90°, −45° /+45°) FRP fabrics
- Spiral strips
- Parallel strips
- Straight strips
- Fabric confinement **FRP rods**
Strengthening of load-bearing timber structures

FRP strengthening of wood beams

- $a$ – resistance moment improvement using FRP plate,
- $b$ – prestressed FRP plate,
- $c$ – shear strength improvement,
- $d$ – shear strength and moment improvement using “U” jacketing.

1 – wood beam, 2 – FRP reinforcement.

Strengthening by using FRP rods

Beam strengthening using tie rods at the inferior part of the element

1 – FRP tie rod, 2 – beam, 3 – anchorage.

Strengthening of timber floors

Strengthening or repair of timber floor joists by the addition of steel sections

- As in the case of frames, the strengthening of wooden floors by the addition of steel sections is a suitable solution:
  - to reinforce damaged structures (rotten or worm-eaten),
  - to withstand increased loads.
- The strengthening sections are supported by the existing structure or a supplementary structure (walls, beams...)

http://www.constructalia.com/english/renovation_with_steel/iii_beam_reinforcement_techniques
Strengthening of timber floors (Video)

https://www.youtube.com/watch?v=2RJIJL9emY8
Strengthening of timber floors

a) Reinforcement of timber joist at supports
b) Braced timber joist reinforced above supports
c) Bracing of a timber joist using two UPN channels

http://www.constructalia.com/english/renovation_with_steel/iii_beam_reinforcement_techniques
Strengthening of timber trusses

Truss terms

Strengthening of timber trusses

- Strengthening of struts with bolted rigging rods
- Strengthening of joints with plywood
- Buckling support of the upper and lower chords (bracing)
- Adding new grids alongside the old truss
Strengthening of timber trusses

Buckling support: Bracing

Ympäristöministeriö, YM35/612/2006:
http://www.ymparisto.fi/download/noname/%7B53248464-F5C4-49BD-B319-DB59785EEF6E%7D/100789
Repair of glued-laminated (glulam) timber structures

- Glued-laminated timbers are made of wood laminations glued together to form a specific piece of wood for a specific load.
- Decrease product variability
- Less affected by natural growth characteristics like knots.
- Offers almost unlimited possibilities of shape and design for construction
- Widely used for load bearing structures in houses, warehouses, pedestrian bridges, etc.

http://publications.lib.chalmers.se/records/fulltext/40294.pdf
Repair of glued-laminated (glulam) timber structures

Repair of gluing surfaces
• The gluing surfaces on glulam beams can give way either:
  – under excessive loads
  – due to ageing
  – poor application of the glue.
• Resins reinjection of the surface
• Timber slats can be reassembled using glass or carbon fibre pins.
• By restoring the internal cohesion of the beam's structure, shearing stresses between slats are supported perfectly and the bearing capacity is restored.

Increasing the bearing capacity

• To increase the inertia of a glulam beam, and thus its bearing capacity, a wood prosthesis can be consolidated with the beam's soffit using timber resin.

• The wood prosthesis is linked to the original beam using glass fibre composite rods sealed with resin.

Repair of glued-laminated (glulam) timber structures

External prosthesis made of treated wood

- Rotting effects can often be observed at the bases of glued-laminated bearing arches or columns located outdoors.
- It is recommended to amputate the structure by sawing off the contaminated part and then replacing it with treated wood.
- The prosthesis shall be connected to the existing structure by a series of pinning sites sealed with glulam timber resin and carried out with composite rods (glass or carbon fibre according to the magnitude of stresses) that are insensitive to climatic changes and corrosion.

A wood preserving coating is then applied onto the restored external parts and a capping, such as a ventilated cap, is mounted to prevent condensation on contact with the timber.

Repairing wood damaged by rot and mould

- Repairing mold damage is not a lasting solution. If the conditions for mold to regrow exist (moisture, warmth, and a food source), mold will simply resume growing on your new wood over time.
- Before removing and replacing rotting wood, follow these steps:
  - Removing water leakage sources: (plumbing issues, groundwater leaking etc.)
  - Fix any grade line & gutter issues
  - Eliminate termites, carpenter ants, or other biological agents

Example rotting wood in crawl space

http://www.gothrasher.com/home-mold/repair-wood-damage.html
Repairing wood damaged by rot and mould

- Three main challenges when inspecting the damage:
  1. Determining which wood must be replaced
  2. Assessing where wood can be repaired
  3. Evaluating where repairs are not needed
- Crawl space supports are used to repair the wooden posts that are rotting
- Crawl space supports support the wooden posts that are sagging due to poor supporting soils
- An additional beam of new wood may be installed along the old rotten beam to add structural strength

Crawl space jack posts

http://www.gothrasher.com/home-mold/repair-wood-damage.html
Repair of wood cladding

- Wood cladding is typically used in residential and low rise buildings that have wood frame construction
- Maintenance and Repair:
  - **Re-Painting**
    - Re-painting and re-staining of wood siding is typically performed approximately once every five to seven years.
  - **Replacement**
    - Replace damaged boards
    - Replace the whole cladding
Repair of fire damaged-concrete structures
### Physical effects of temperature on concrete

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Color Change</th>
<th>Changes in Physical Appearance and Benchmark Temperatures</th>
<th>Concrete Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0 to 290 °C)</td>
<td>None</td>
<td>Unaffected</td>
<td>Unaffected</td>
</tr>
<tr>
<td>(290 to 590 °C)</td>
<td>Pink to red</td>
<td>Surface crazing: (300 °C); Deep cracking: (550 °C); Popouts over chert or quartz aggregate: (575 °C)</td>
<td>Sound but strength significantly reduced</td>
</tr>
<tr>
<td>(590 to 950 °C)</td>
<td>Whitish Grey</td>
<td>Spalling, exposing not more than 25% of reinforcing bar surface: (800 °C); Powdered, light colored, dehydrated paste: (575 °C)</td>
<td>Weak and friable</td>
</tr>
<tr>
<td>(950+ °C)</td>
<td>Buff</td>
<td>Extensive spalling</td>
<td>Weak and friable</td>
</tr>
</tbody>
</table>
Phases of deterioration due to fire

1. The concrete withstands temperatures of up to 650°C

2. The first part to break off is the concrete around the reinforcement, which is fundamental in protecting the rods

3. Once the reinforcement rods are exposed, heat propagates more quickly

4. If the structure is exposed to fire for a considerable time, the steel also loses its performance characteristics, causing the structure to collapse

http://www.mapei.com/public/GB/linedocument/Concrete_deterioration_GB.pdf
## Assessment of fire damage

<table>
<thead>
<tr>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Effects of high temperature on concrete strength and elastic modulus</td>
</tr>
<tr>
<td>- Mineralogical changes in concrete</td>
</tr>
<tr>
<td>- Cracking of concrete in fires</td>
</tr>
<tr>
<td>- Spalling of concrete in fires</td>
</tr>
<tr>
<td>- Residual thermal movement cracks</td>
</tr>
<tr>
<td>- Reinforcing and prestressing steel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing of fire damaged reinforced concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>- On-site inspection</td>
</tr>
<tr>
<td>- Non-destructive testing (NDT)</td>
</tr>
<tr>
<td>- Petrographic examination</td>
</tr>
<tr>
<td>- Thermoluminescence tests</td>
</tr>
<tr>
<td>- Core test</td>
</tr>
<tr>
<td>- Tests on samples of reinforcement</td>
</tr>
<tr>
<td>- Other laboratory tests</td>
</tr>
</tbody>
</table>

**Assessment of fire damaged structures**

- Assessment of fire severity
- Heat transfer

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Assessment of fire damage

Figure 1: The interior (left) and exterior (right) of a concrete framed structure shortly after a major fire during construction.

Assessment of fire damage

View of floor below the fire showing thermal expansion cracks on the slab soffit

Explosive spalling

Spalling of a slab soffit owing to fire-damage of embedded plastic reinforcement bar spacers.

### Assessment of fire damage

Table 5: A guide to the selection of test methods for fire-damaged reinforced concrete.

<table>
<thead>
<tr>
<th>Test location</th>
<th>Test type</th>
<th>Test method</th>
<th>Information gained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On-site</td>
<td></td>
<td>Colour changes, Lateral extent of damage, Depth of damage, Compressive strength of undamaged concrete, Tensile strength of reinforcement bars (damaged and undamaged)</td>
</tr>
<tr>
<td></td>
<td>Non-destructive</td>
<td>Visual inspection</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hammer soundings</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rebound Hammer</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ultrasonic Pulse Velocity</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Partially</td>
<td>Breakout/ drilling</td>
<td>✓</td>
</tr>
<tr>
<td>Laboratory</td>
<td>destructive</td>
<td>Petrographic examination</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermoluminescence</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Core Test</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reinforcement test</td>
<td>✓</td>
</tr>
</tbody>
</table>
## Fire damage classification

<table>
<thead>
<tr>
<th>Class of damage</th>
<th>Finishes</th>
<th>Colour</th>
<th>Features observed</th>
<th>Reinforcement bars</th>
<th>Cracks</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Decoration required)</td>
<td>Unaffected</td>
<td>Normal</td>
<td>None</td>
<td>None exposed</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>1 (Superficial repair required)</td>
<td>Some peeling</td>
<td>Normal</td>
<td>Slight</td>
<td>Minor</td>
<td>None exposed</td>
<td>None</td>
</tr>
<tr>
<td>2 (General repair required)</td>
<td>Substantial loss</td>
<td>Pink</td>
<td>Moderate</td>
<td>Localised</td>
<td>Up to 25% exposed</td>
<td>None</td>
</tr>
<tr>
<td>3 (Principal repair required)</td>
<td>Total loss</td>
<td>Whitish grey</td>
<td>Extensive</td>
<td>Considerable</td>
<td>Up to 50% exposed</td>
<td>Minor</td>
</tr>
<tr>
<td>4 (Major repair required)</td>
<td>Destroyed</td>
<td>Buff</td>
<td>Surface lost</td>
<td>Almost total</td>
<td>Up to 50% exposed</td>
<td>Major</td>
</tr>
</tbody>
</table>

### Colour change of heated concrete

![Image of concrete samples at different temperatures](http://mosenltd.com/wp-content/uploads/2011/01/Concrete-Structures-in-Fire.pdf)
Fire damage classification

Table 8: Initial repair classification.

<table>
<thead>
<tr>
<th>Class of damage</th>
<th>Repair classification</th>
<th>Repair requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Decoration</td>
<td>Redecoration if required</td>
</tr>
<tr>
<td>1</td>
<td>Superficial</td>
<td>Superficial repair of slight damage not needing fabric reinforcement</td>
</tr>
<tr>
<td>2</td>
<td>General repair</td>
<td>Non-structural or minor structural repair restoring cover to reinforcement where this has been partly lost.</td>
</tr>
<tr>
<td>3</td>
<td>Principal repair</td>
<td>Strengthening repair reinforced in accordance with the load-carrying requirement of the member. Concrete and reinforcement strength may be significantly reduced requiring check by design procedure.</td>
</tr>
<tr>
<td>4</td>
<td>Major repair</td>
<td>Major strengthening repair with original concrete and reinforcement written down to zero strength, or demolition and recasting.</td>
</tr>
</tbody>
</table>
Repair methods of fire-damaged concrete

For reinforced concrete, the main processes to be undertaken are as follows:

- Surface cleaning
- Removal of damaged or weakened concrete
- Replacement of weakened reinforcement
- Replacement of concrete both to reinstate the original form and to provide adequate structural capacity, durability and fire resistance.
- Reinstatement of special finishes and appearance.

Repair methods of fire-damaged concrete

Repairing methods
• Mortar / concrete – **patch repairing**
• Flowable **micro-concrete**
  – Flowable micro-concretes are self-levelling and self-compacting
• **Sprayed concrete**
• Overcladding
• **Resins**
  – often been used for repairs to lightly spalled areas
  – may perform quite satisfactorily in normal service
• **Strengthening** with fibre composites (FRP)

Repair methods of fire-damaged concrete (Video)

https://www.youtube.com/watch?v=XgKOSkqYAz4
Summary

Lecture summary
- Deterioration of timber structures
- Condition inspection of the timber structures
- Repair of timber structures
- Deterioration due to fire
- Assessment of fire damage
- Fire damage classification
- Repair methods of fire-damaged concrete structures

Next Lecture:
- 09.05.2016
- The use of ICT for condition assessment of structures