Korjauskonseptien kestävyyden näkökohtia ja suositukset rakennustesteollisuudelle

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Reference publications

- D2.2 Guidelines for the use of building physical modelling methods and tools in the development of sustainable refurbishment technologies for external walls.

- D4.2 General renovation concepts – Durability

- D7.2 Guidelines for building industry
D2.2 Guidelines for the use of building physical modelling methods and tools in the development of sustainable refurbishment technologies for external walls.

- Methods to calculate building physical performance of walls
  - Thermal performance
  - Moisture control
  - Durability (mould)
  - Indoor air

- Use of WuFi program

- Practical guideline on how to carry out the calculations
  - Inputs
  - Analysis of output
  - State of art in mould models
D4.2 General renovation concepts – Durability
Stresses of building envelopes
29.9.2011 - v12

Service load
- Wind
  - Bending
    - Cracks
    - Falling down
- Snow
  - Bending
    - Cracks
    - Falling down
- Thermal expansion
  - Bending
    - Cracks
    - Falling down
- Own weight
  - Bending
- Supported structures
  - Bending
    - Cracks
- Creep
  - Bending
    - Cracks
- Shrinkage
  - Bending
    - Cracks

Dead load
- Creep
- Bending
  - Cracks
- Shrinkage
  - Bending
    - Cracks

Climatic stresses
- Wind
  - Bending
    - Cracks
    - Falling down
- Snow
  - Bending
    - Cracks
    - Falling down
- Thermal expansion
  - Bending
    - Cracks
    - Falling down
- Own weight
  - Bending
- Supported structures
  - Bending
    - Cracks
- Creep
  - Bending
    - Cracks
- Shrinkage
  - Bending
    - Cracks

Biological factors
- Aesthetic aspects
- Loss of strength
- Rotting
- Insects
- Pests
- UV-radiation
- Fading
- Degradation
- Ageing
- Mould
- Rotting
- Salt migration
- Frost damages
- Corrosion
- Snow
  - Bending
    - Cracks
    - Falling down
- Rain
  - Moisture accumulation
    - Mould
    - Rotting
    - Salt migration
    - Frost damages
    - Corrosion

Health risks
- Air leakages
- Pests
- Indoor air moisture
- Mould
- Rotting
- Salt migration
- Frost damages
- Corrosion
- Peeling off
- Carbonation
- Carbon dioxide
- Air pollutants
- Weathering
- Fading
- Degradation
- Ageing
- Mould
- Rotting
- Salt migration
- Frost damages
- Corrosion
- Peeling off
- Carbonation
- Carbon dioxide
- Air pollutants
- Weathering
Deterioration mechanisms

Frost damage
- Concrete
- Peeling off
- Painting
- Rendering
- Cracking

Corrosion
- Steel bars
- Cracking

Overload
- Breakage
- Crash

Fire
- Burning
- Loss of strength
- Metals
- Cracking
- Concrete

Carbonation
- Cracking
- Concrete

Temperature changes
- Solar radiation
- Wetting - drying
- Freeze - thaw

Supporting structures
- Bending

Polymers
- Ageing
- Loss of strength
- Becoming fragile

Plastics
- Loss of strength
- Cracking

Concrete
- Cracking

Masonry
- Disintegration

Timber
- Cracking
- Shrinkage

Bricks
- Fretting

Concrete
- Cracking

Rendering
- Peeling off

Painting
- Peeling off

Coating damages

Moisture
- Bending

Supporting structures
- Cladding materials
- Cracking

Concrete
- Loss of strength

Polymers
- Loss of strength
- Becoming fragile

Plastics
- Loss of strength
- Cracking

Polymer
- Loss of strength
- Becoming fragile

Fire
- Burning
- Loss of strength
- Metals
- Cracking
- Concrete

Carbonation
- Cracking
- Concrete

Overload
- Breakage
- Crash

Wetting - drying
- Paint
- Rendering
- Cracking

Freeze - thaw
- Concrete

Frost damage
- Concrete
- Peeling off
- Painting
- Rendering
- Cracking

Deterioration mechanisms

2.10.2011 - v33
Tools available for durability assessment

- Moisture and heat transfer
  - Moisture sources:
    - Interior: diffusion, air leakages
    - Exterior: Driving rain
    - Built-in: construction moisture

- Mould growth analysis (all materials)

- Frost attack, carbonation and reinforcement corrosion (Concrete)
Calculation

Ort: Lund; LTH Data;

Puts på isolering

[W/m²]

[°C]

[mm/h]

[kg/m²]

al Plaster
Celplast expanderad

Gipsskiva utvändig

Mineral Wool

Gipsskiva invändig

Tväänitt [cm]

Rendering

Thermal insulation between wooden studs

Air and moisture barrier

Board
Calculation, 1% rain penetration

Ort: Lund; LTH Data;

Rendering on insulation + 0,2% rain leakage

WUFI Pro 4.2
Ei sadevuotoja

Viistosade vuoto 1%
Degredation models 1

Internal Frost Attack

Internal Frost attack was evaluated based on the theory of Göran Fagerlund (theory of Critical Degree of Saturation). The progress of frost attack depends on the factor $K_N$ (depending on the number of freeze-thaw cycles) and the excess of critical degree of saturation at each freeze-thaw cycle.

$RDM$ is degree of damage or relative dynamic modulus ($0 < RDM < 1$)

$N$ number of critical freezing events,

$S$ active degree of saturation at the moment of freezing,

$S_{cr}$ critical degree of saturation,

$K_N$ coefficient of degradation.

$A$, $B$ and $C$ are constants

$V_{cap}$ is volume of all capillary pores (and other water filled pores smaller than capillary pores),

$V_{air;tot}$ total volume of air pores,

$V_{air;cr}$ critical volume of (water filled) air pores

$$RDM = 1 - \frac{E_N}{E_0} = K_N \cdot (S - S_{cr})$$

$$K_N = \frac{A \cdot N^C}{B + N}$$

$$S_{cr} = \frac{V_{cap} + V_{air;cr}}{V_{cap} + V_{air;tot}}$$
Degredation models 2

Carbonation

Carbonation was evaluated using a modified carbonation coefficient. It depends on the relative humidity, temperature and possible internal cracking (RDM). The limit state of carbonation was the thickness of concrete cover.

\[ x_{ca} = \sum \Delta x_{ca} \]

\[ \Delta x = \frac{k_{ca} \cdot (1 + 0.64 \cdot (1 - RDM)^{1.32})}{x_{ca}} \cdot \Delta t \]

\[ k_{ca} = k_{ca,0} \cdot (3.221 - 3.172 \cdot \varphi)^{0.5} \cdot (T / 293)^{0.875} \]

- \( x_{ca} \) is depth of carbonation, mm
- \( \Delta x_{ca} \) increase of carbonation depth, mm,
- \( k_{ca} \) carbonation coefficient, mm/a^{0.5}
- \( \Delta t \) increment of time, a
- \( RDM \) degree of damage or relative dynamic modulus (0 < RDM < 1).
- \( \varphi \) relative humidity, %
- \( T \) temperature, °K,
Degredation models 3

Corrosion of reinforcement

Corrosion of reinforcement starts when carbonation reaches the depth of reinforcement. Corrosion rate depends on relative humidity and temperature. The limit state of corrosion is cracking of concrete cover (serviceability limit state) or critical depth of corrosion (ultimate limit state).

\[ s = \sum \Delta s \]
\[ \Delta s = c_T \cdot \left( 1 - 0.29 \frac{p_{bs}}{100} \right) \cdot \varphi^{1.67} \cdot \Delta t \quad \text{when } \varphi \leq 0.95 \]
\[ \Delta s = c_T \cdot 15 \cdot \Delta t \quad \text{when } 0.95 \leq \varphi \leq 1.00 \]

\[ c_T = 1.6 \cdot 10^{-7} \cdot (30 + T)^4 \]

\[ s_{ls:s} = 100 \mu m \cdot \frac{c}{d} \cdot (1 - RDM) \]
\[ s_{ls:u} = \frac{d}{5} \]

**s** is depth of corrosion, \( \mu m \)

**\( \Delta s \)** increase of corrosion depth, \( \mu m \),

**c** temperature corrector factor,

**\( \Delta t \)** increment of time, a

**\( \varphi \)** relative humidity, %

**T** temperature, °C,

\( p_{bs} \) is portion of blastfurnice slag from the total amount of binder, %,

**c** concrete cover, mm

**d** diameter of reinforcement, mm
Degradation models 4

Mould growth

Mould growth index $M$ can be determined by using the temperature and relative humidity histories of the subjected material surfaces.

$M$ is mould growth index
$\Delta s$ increase of corrosion depth, $\mu$m,
$\varphi$ relative humidity, %
$T$ temperature, °C, $p_{bs}$ is portion of blastfurnace slag from the total amount of binder, %,
c concrete cover, mm
d diameter of reinforcement, mm

\[
M = \sum \Delta M
\]
\[
\Delta M = \frac{1}{t_m} \cdot k_1 \cdot k_2 \cdot \Delta t
\]
\[
t_m = 7 \cdot 24 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 66.02) \text{ hours}
\]
\[
k_2 = \max \left\{ -\exp \left[ 3 \cdot (M - M_{\text{max}}) \right] \right\}
\]
\[
M_{\text{max}} = A + B \cdot \frac{RH_{\text{crit}} - RH}{RH_{\text{crit}} - 100} - C \cdot \left( \frac{RH_{\text{crit}} - RH}{RH_{\text{crit}} - 100} \right)^2
\]

<table>
<thead>
<tr>
<th>Sensitivity class</th>
<th>$k_1$</th>
<th>$k_2$ $(M_{\text{max}})$</th>
<th>$RH_{\text{crit}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very sensitive (vs)</td>
<td>1</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>Sensitive (s)</td>
<td>0.578</td>
<td>0.386</td>
<td>80</td>
</tr>
<tr>
<td>Medium resistant (mr)</td>
<td>0.072</td>
<td>0.097</td>
<td>85</td>
</tr>
<tr>
<td>Resistant (r)</td>
<td>0.033</td>
<td>0.014</td>
<td>85</td>
</tr>
</tbody>
</table>
Jyväskylä, Original structure, MW

- Temperature (°C) over time (days)
  - Temperature ranges from -40 to 60 °C
  - Front and back temperatures are shown for comparison.

- Water content (kg/m³) over time (days)
  - Water content ranges from 0 to 180 kg/m³
  - Critical water content is indicated.

- Corrosion (relative to limit state) over time (years)
  - Corrosion ranges from 0 to 1
  - Front and back corrosion rates are shown for comparison.

- Time of repair = 65 years
Jyväskylä, Concept E1, MW

Before repair:
relative to serviceability limit state

After repair:
Relative to ultimate limit state

Repair

Before repair:
relative to serviceability limit state

After repair:
Relative to ultimate limit state

Repair
Jyväskylä, Concept E1, PUR

Before repair:
relative to serviceability limit state

After repair:
Relative to ultimate limit state

Repair

Temporary mould problem
Interior refurbishment, I
Important considerations

- Air tightness
- Water vapour permeability decreases towards the outside surface
- Driving rain leakages are harmful
- Ventilated facade improves the drying potential of the wall
- Refurbishment Concept E1, E2 – additional insulation laid on the original outer core of the sandwich and covered by a layer of rendering.

- External added insulation - existing wall becomes warmer and drier
- Avoid structural layers between 2 vapour tight insulations (PUR, EPS)
- Frost attack
- **Refurbishment Concept I** – additional insulation laid on the interior side
  - Condensation risk if vapour tight layers are in the existing wall,
  - Thermal bridges are created between floor and wall junctions
Assessments of the refurbishment External insulation’s effect on the fire safety of the external wall and facade

<table>
<thead>
<tr>
<th>WALL TYPE</th>
<th>BUILDING TYPE</th>
<th>Type of external structure/layer</th>
<th>Type of insulation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2_Sandwich element; concrete panel + concrete panel</td>
<td>C</td>
<td>Concrete or similar</td>
<td>Non-combustible</td>
<td>0</td>
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<td>Thin non-combustible</td>
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<td>Combustible</td>
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**External insulation (E) - New outer service with retrofit insulation – effect on Fire Safety**

A = Small houses
B = Terraced houses
C = Multi storey

External structures/layers:
- Thin non-combustible = Metal, rendering, etc.
- Combustible = Wood, PVC, etc.

Non-combustible insulation = Mineral wool
Combustible insulation = EPS/XPS, PUR/PIR, cellulose based, etc.

E1 = Insulation fixed without air gap
E2 = Insulation fixed with air gap and wind protection
Recommendations

- Considering **durability** aspects of the wall, excessive moisture is harmful. Excessive moisture levels may cause mould to develop in the wall. This may be a risk considering also the indoor air quality.

- Considering **fire safety**, to reach the intended fire safety level for multi-storey buildings, it is recommended to use non-combustible (=A1 or A2-s1, d0 reaction to fire class) or at least B-s1, d0 class external boards/layers.

- Considering **structural stability** the assessment of the load bearing capacity of the existing walls must include a verification to ensure that it can withstand the mounting of fastening points.

- Considering **buildability**, the aspects which need to be checked are the needs of space, availability of materials, work force, quality of workmanship. These will depend on the project at hand and on the local conditions.