Design of composite columns under high temperatures with special consideration of imperfections

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Outlining

- Introduction
- Thermal Analysis
- Mechanical Analysis
- Imperfections
- Conclusion
Advantages of composite columns

- Small dimensions at high load level
- Uniform dimension in multi-storey building
- High fire resistance because of the insulation properties of concrete
- No additional fire proofing
Introduction

- Advantages
- Types
- Heating and load behaviour
- Calculation of fire resistance

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- Mechanical analysis
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Advantages of composite columns

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- Uniform dimension in multi-storey building
- High fire resistance using the insulation properties of concrete
- No additional fire proofing
Types of composite columns

- Introduction
  - Advantages
  - Types
  - Heating and load behaviour
  - Calculation of fire resistance
- Thermal analysis
- Mechanical analysis
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Heating and load behaviour

- Temperature distribution after 90 minutes of standard fire exposure
Calculation of fire resistance

- Divided in two independent steps
  - Thermal analysis
    - Calculation of the temperature distribution over the cross section
  - Mechanical analysis
    - Calculation of the axial buckling load
    - Considering thermally induced stresses
    - Including geometrical Imperfection
## Thermal properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Steel</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity $\lambda$ (20°C)</td>
<td>53 W/m K</td>
<td>2 W/m K</td>
</tr>
<tr>
<td>Heat capacity $c$ (20°C)</td>
<td>440 J/kg K</td>
<td>900 J/kg K</td>
</tr>
<tr>
<td>Convection coefficient $\alpha_c$</td>
<td>25 W/m² K</td>
<td>25 W/m² K</td>
</tr>
<tr>
<td>Emissivity coefficient $\varepsilon_{res}$</td>
<td>0.56</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Standard fire ISO-834

- Introduction
- Thermal analysis
  - Thermal properties
  - Standard fire exposure
  - Natural fire exposure
- Mechanical analysis
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![Graph showing temperature in °C over time in minutes for a standard fire ISO-834. The graph shows an increase in temperature over time.](image-url)
Temperature distribution under standard fire exposure (90 min.)

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Temperature distribution under standard fire exposure (90 min.)
Natural fire exposure

Fire load: $q_{\text{fid}} = 1700 \text{ MJ/m}^2$; opening factor: $O = 0.14 \text{ m}^{0.5}$
Temperature distribution under natural fire exposure (90 min.)

Introduction

Thermal analysis
  ➤ Thermal properties
  ➤ Standard fire exposure
  ➤ Natural fire exposure

Mechanical analysis

Imperfections

Conclusion
Stress-strain relationship for steel at elevated temperatures

Introduction
Thermal analysis
Mechanical analysis
- Stress-strain relationship
- Calculation procedure
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Stress-strain relationship for concrete at elevated temperatures

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Introduction

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θ = 200°C

ε = 0.004

θ = 400°C

ε = 0.004

\[ N_{zentr} = \Sigma (\sigma_{ai,\theta,\varepsilon} A_{ai} + \sigma_{ci,\theta,\varepsilon} A_{ci}) \]

\[ N_{ki} = \frac{\Sigma (E_{ai,\theta,\varepsilon} l_{ai} + E_{ci,\theta,\varepsilon} l_{ci})}{s_k^2} \]
Resistance of the cross-section as a function of axial strain

Introduction

Thermal analysis

Mechanical analysis
  - Stress-strain relationship
  - Calculation procedure

Imperfections

Conclusion

\[
N_{pl} = -5607 \text{ kN}
\]

\[
\text{max } N_{zentr} = -5000 \text{ kN}
\]

![Graph showing the resistance of the cross-section as a function of axial strain.](image)
Euler buckling load as a function of axial strain

- Thermal analysis
- Mechanical analysis
  - Stress-strain relationship
  - Calculation procedure
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- Conclusion
Determination of the axial buckling load

- Introduction
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- Conclusion
Thermally induced stress

- Residual stress at a plane cross-section of a section:
  - Outside: compression ↔ inside: tension

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- Mechanical analysis
- Imperfections
  - Thermally induced stress
  - Effect of residual stress
  - Geometrical imperfection
- Conclusion
Effect of residual stresses on the axial buckling load

- Additional compressive stress at the outer range of the cross-section

- Decrease of stiffness

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Introduction

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  - Effect of residual stress
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Axial buckling load as a function of the buckling length

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Mechanical analysis

Imperfections

- Thermally induced stress
- Effect of residual stress
- Geometrical imperfection

Conclusion

Axial buckling load (z-axis)

Axial buckling load (y-axis)
Geometrical imperfection and eccentric loading

- Determination of the moment-curvature relationship
- Consideration of the unequal distribution of the stiffness along the column
  - Stiffness is dependent upon load
- Second-order analysis including geometrical imperfection
Conclusion

- The calculation of fire resistance of composite columns is divided in two steps
  - Thermal analysis calculates the temperature distribution over the cross section
  - Mechanical analysis with temperature dependent material laws
  - Thermal stress decreases the axial buckling load
Institute for steel structures and fractural mechanics
Thank you for your attention