Collapse of concrete columns during and after the cooling phase of a fire

Analysis of the effect of the additional loss in compressive strength during cooling

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Implementation in SAFIR

New material laws:

CALCONETCL, SILCONETCL

These laws are identical to CALCON_ETC, SILCON_ETC
except that the user can input the relative loss of compressive strength during cooling
(in CALCON_ETC, SILCON_ETC this relative loss is defined as 0.1 and cannot be modified)

If CMAT = CALCONETCL, SILCONETCL
PARACOLD(2,NM) Poisson ratio.
PARACOLD(3,NM) Compressive strength
PARACOLD(4,NM) Tensile strength
PARACOLD(5,NM) Relative loss of compressive strength during cooling

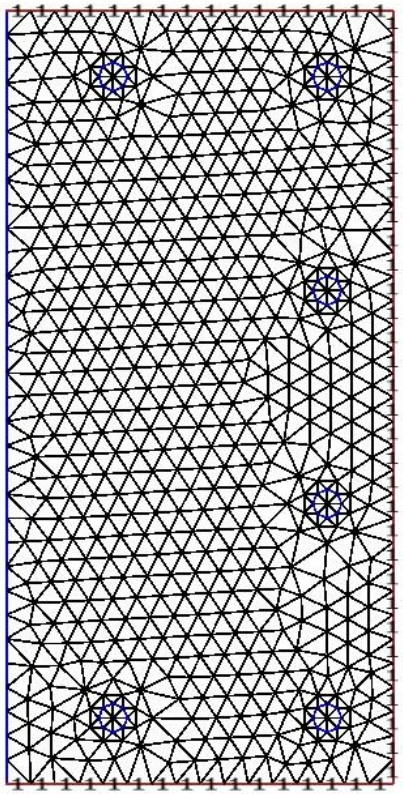
Note: if PARACOLD(5,NM) = 0.10, the law is identical to CALCON_ETC, SILCON_ETC

Case study 1

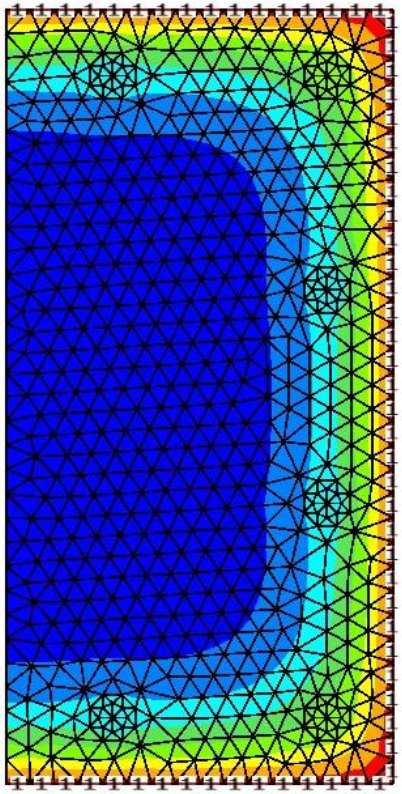
Reinforced concrete column:

- Square cross section 0.450 m side
- 12 reinforcement bars 16 mm in diameter
- Concrete cover 30 mm (to the edge of the bar)
- Heated on 4 sides
- Siliceous concrete

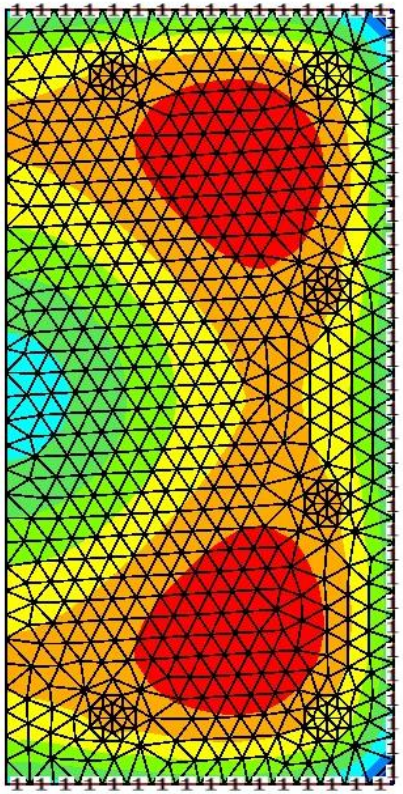
Mesh



Heating



Cooling
(change of scale)



Case study 1

Reinforced concrete column:

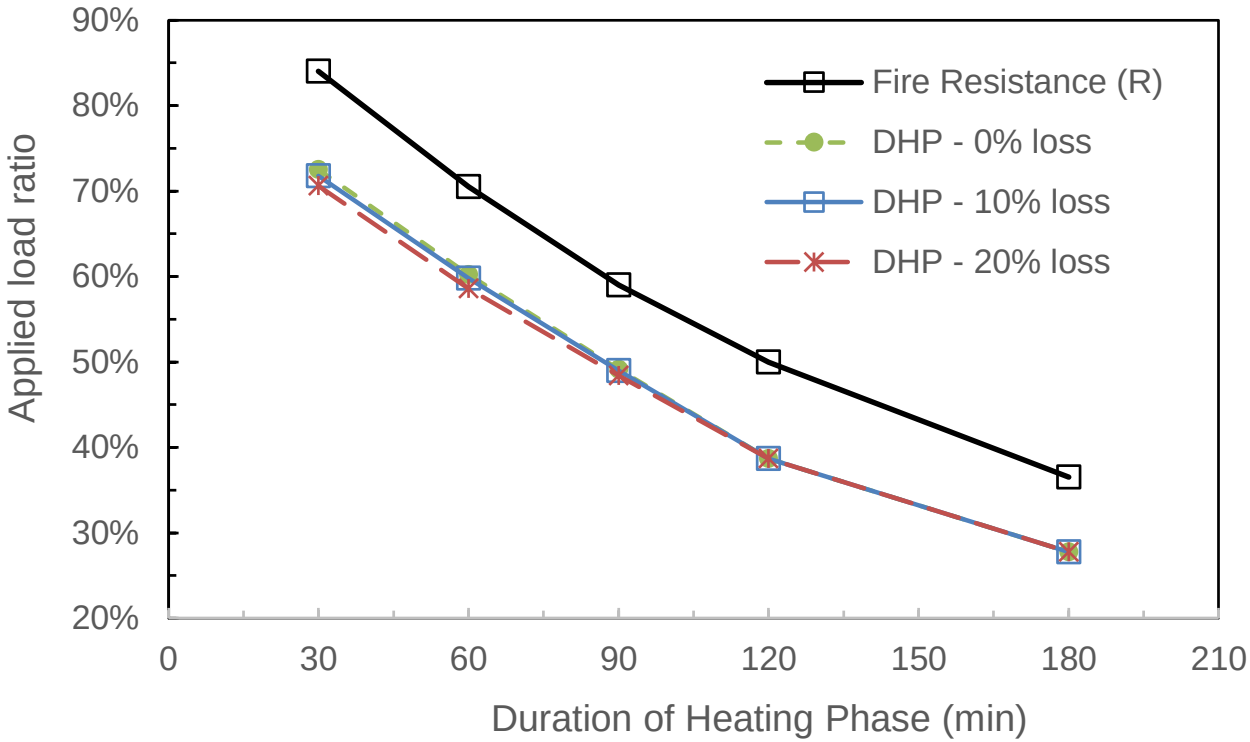
- Simply supported 4 m length
- Sinusoidal imperfection amplitude L/300
- Vertical load applied on top noad, centered (no eccentricity)
- Compressive strength 30 MPa; tensile strength 0 MPa
- Steel yield strength 500 MPa

- Ultimate load at ambient temperature (determined with SAFIR): 6338 kN
- Fire resistance of 120 min under load ratio of 50%

Results 1

Plot = relationship between *applied load ratio* and a *duration of fire that leads to failure*.

- **Fire Resistance (R)**: minimum exposure duration to a *standardized fire* (always heating) that leads to failure *at that time*.
- **Duration of the Heating Phase (DHP)**: minimum exposure duration to *a natural fire heating phase* that affects the component to such an extent that it will fail *later*.

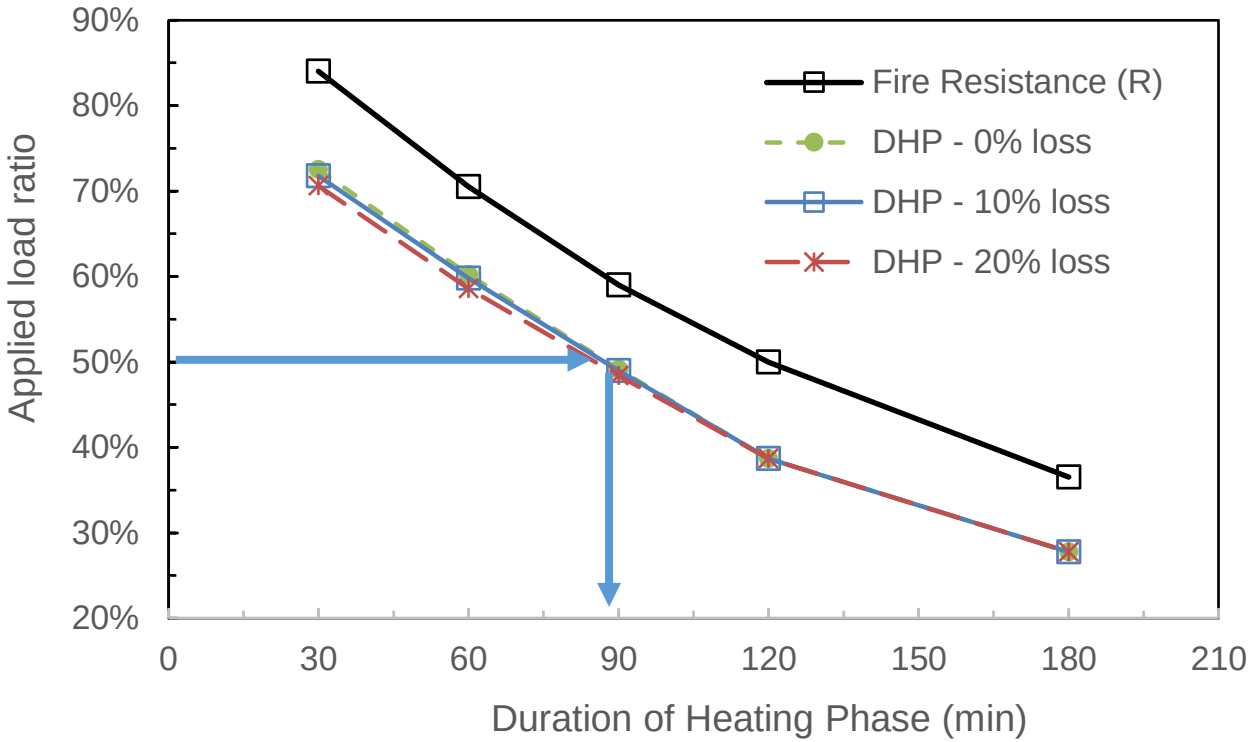


⇒ Very limited effect of relative loss of compressive strength during cooling

Results 1

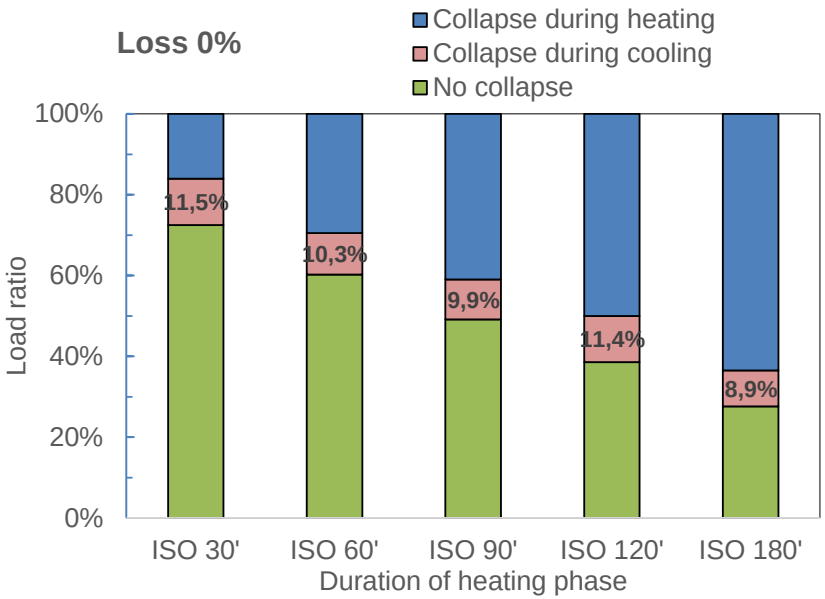
Example: Column loaded at 50% of its load bearing capacity at ambient temperature

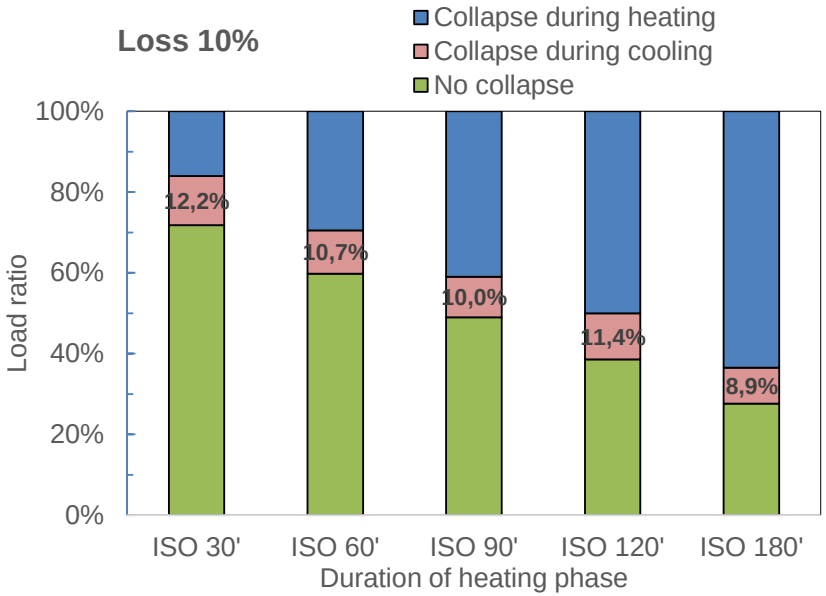
- R = 120 min → if heated by standard fire, fails after 120 min
- DHP = 89 min → if heated by natural fire with a heating phase > 89 min, will fail (when? During or soon after the cooling phase, but we cannot know exactly from DHP)

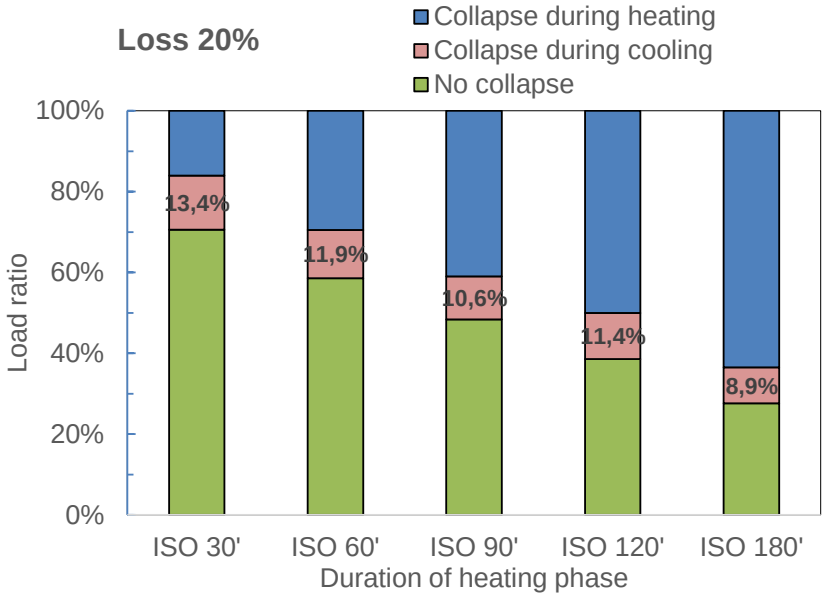


⇒ Very limited effect of relative loss of compressive strength during cooling

Results 1 Other plot showing the same results







$\Rightarrow$ The effect decreases with increasing DHP (even disappears for DHP $\geq$ 120 min)

Case study 2

Reinforced concrete column with same section as Case 1

- Simply supported **2 m length**
- Sinusoidal imperfection amplitude L/300
- Vertical load applied on top noad, centered (no eccentricity)
- Compressive strength 30 MPa; tensile strength 0 MPa
- Steel yield strength 500 MPa

- Ultimate load at ambient temperature (determined with SAFIR): **6860 kN**
- Fire resistance of **120 min** under load ratio of **60%** (4116 kN)

Duration of heating	Min load ratio for collapse in heating (R)	Min load ratio for collapse in cooling (DHP)		
		0% loss	10% loss	20% loss
ISO 60’	78%	69%	68%	66%
ISO 180’	48%	40%	40%	40%

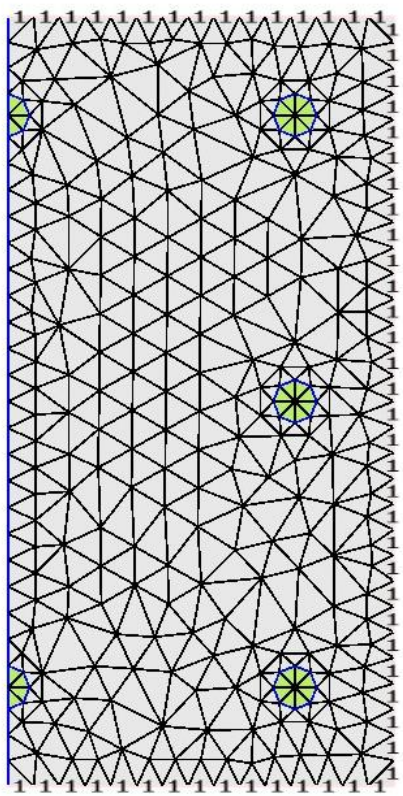
⇒ Limited effect of relative loss of compressive strength during cooling for “short” fires
No effect for long fires

Case study 3

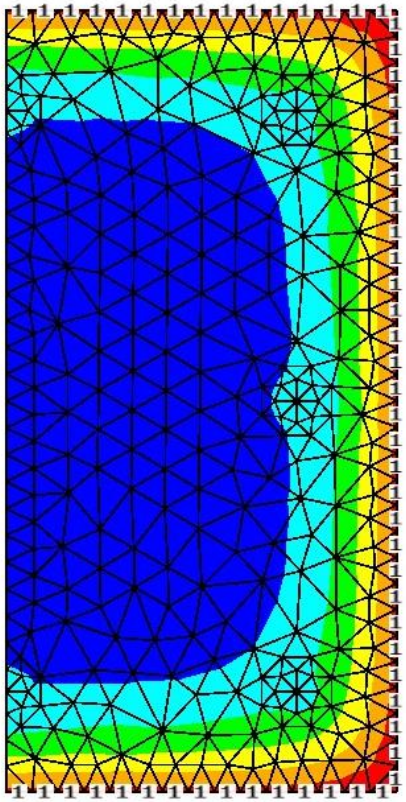
Reinforced concrete column:

- Square cross section **0.300 m side**
- **8 reinforcement bars** 16 mm in diameter
- Concrete cover 30 mm (to the edge of the bar)
- Heated on 4 sides
- Siliceous concrete

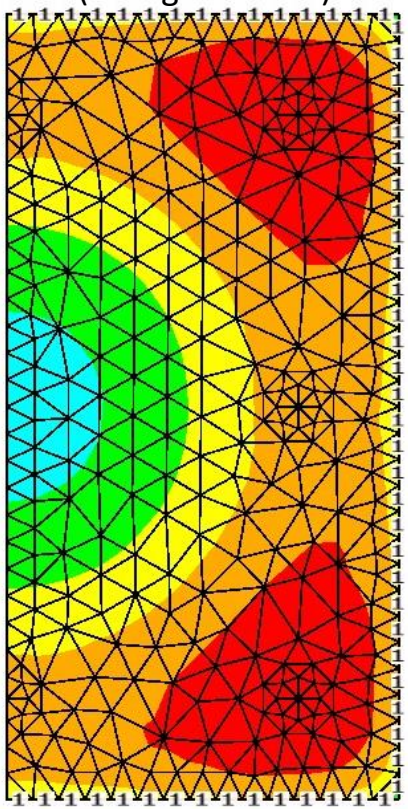
Mesh



Heating



Cooling
(change of scale)



Case study 3

Reinforced concrete column:

- Simply supported **3 m length**
- Sinusoidal imperfection amplitude L/300
- Vertical load applied on top noad, centered (no eccentricity)
- Compressive strength 30 MPa; tensile strength 0 MPa
- Steel yield strength 500 MPa

- Ultimate load at ambient temperature (determined with SAFIR): **2953 kN**
- Fire resistance of 120 min under load ratio of **26%**

Duration of heating	Min load ratio for collapse in heating (R)	Min load ratio for collapse in cooling (DHP)		
		0% loss	10% loss	20% loss
ISO 60’	54%	42%	42%	42%
ISO 120’	26%	16%	16%	16%

⇒ No effect of the relative loss of compressive strength during cooling

Case study 1

45x45 cm²
4 m length

Duration of heating	Min load ratio for collapse in heating (R)	Min load ratio for collapse in cooling (DHP)		
		0% loss	10% loss	20% loss
ISO 60’	71%	60%	60%	59%
ISO 180’	37%	28%	28%	28%

Case study 2

45x45 cm²
2 m length

Duration of heating	Min load ratio for collapse in heating (R)	Min load ratio for collapse in cooling (DHP)		
		0% loss	10% loss	20% loss
ISO 60’	78%	69%	68%	66%
ISO 180’	48%	40%	40%	40%

Case study 3

30x30 cm²
3 m length

Duration of heating	Min load ratio for collapse in heating (R)	Min load ratio for collapse in cooling (DHP)		
		0% loss	10% loss	20% loss
ISO 60’	54%	42%	42%	42%
ISO 120’	26%	16%	16%	16%

References

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