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Faculty of *Civil and Geodetic Engineering*

PROOF OF SAFETY OF PRESTRESSED HOLOW CORE SLAB UNDER FIRE CONDITIONS

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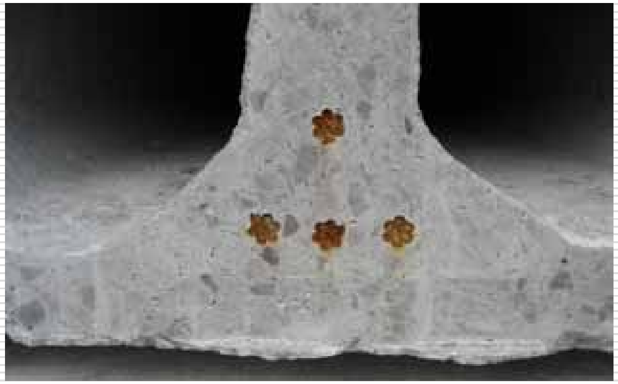
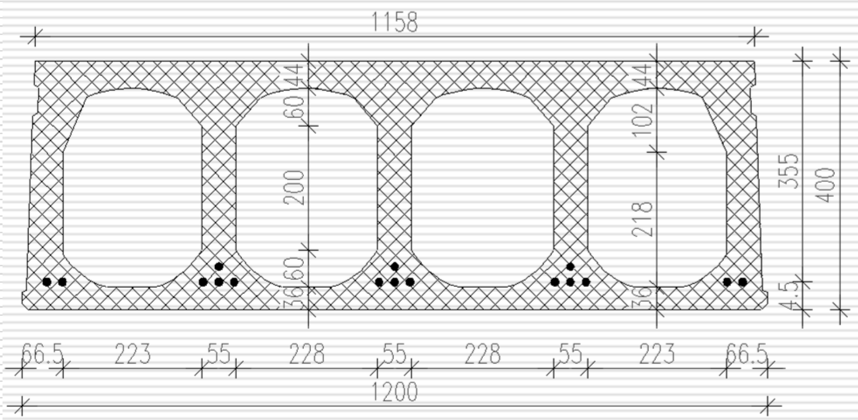
PRESTRESSED HOLLOW-CORE SLAB 400



- Precast prestressed concrete elements– transmission of prestressing force with adhesion
- Lower price compared to other systems
- Automated production
- Reduced consumption of material
- Longer span than conventional slabs of the same thickness
- Speed and ease of construction

PRESTRESSED HOLLOW-CORE SLAB 400



- Cross section: w/h = 120/40 cm
- Span L = 11.45 m
- 16 straight prestressing strands in 2 rows
- Concrete grade C 40/50
- High strength steel

  f_{pk} = 186 kN/cm^2
- Slab is used in shopping mall

PROOF OF SAFETY OF HOLLOW-CORE SLAB UNDER FIRE CONDITIONS

- In general:

  $E_{d,fi} < R_{d,t,fi}$
- The requirement of R,

  $t_{fi,requ} < t_{d,fi}$
- Methods of proof of safety:
  - Simple calculation models (500°C isotherm method)
  - Advanced calculation models (analysis of structural response in fire)
- Separated calculation of mechanical and thermal analysis of the slab

THERMAL ANALYSIS

- Finite element method
- Assumptions:
  - Slab exposed to fire from below,
  - standard temperature-time curve ISO 834
  - temperature field does not change along the slab ,
  - only one quarter of the cross section is considered,
  - strands are not taken into account for thermal analysis,
  - in a particular time step the temperature is constant in each hole,
  - inside the hole, heat transfer only by convection.
- Heat transfer across the slab by convection, radiation and conduction by so called Fourier's law:

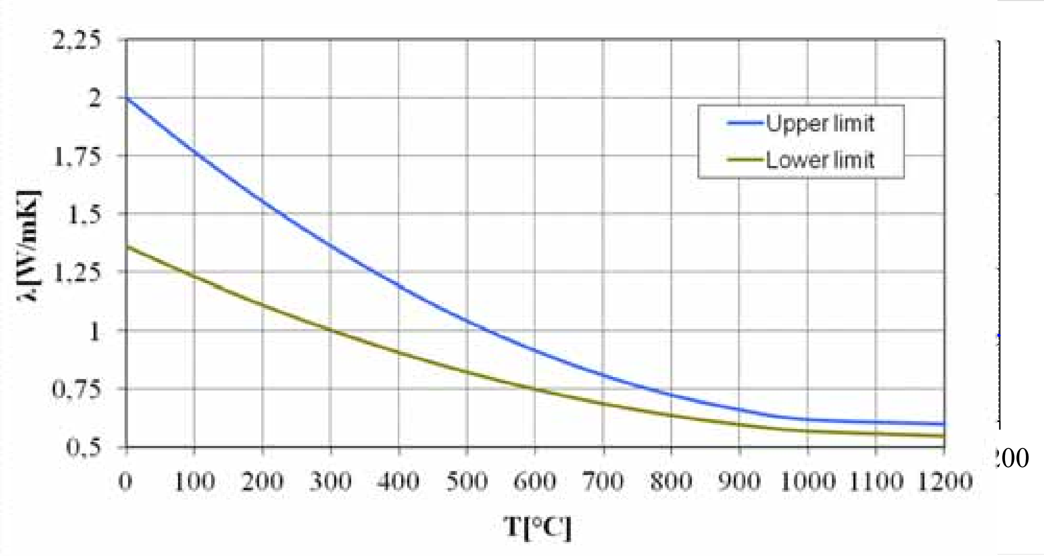
$$\left(k_{ij} \cdot \frac{\partial T}{\partial x_j}\right)\frac{\partial}{\partial x_i} + Q - \rho \cdot c \cdot \frac{\partial T}{\partial t} = 0, \qquad (i, j) = (y, z)$$

- Heat transfer through outer surface due to convection and radiation is considered with proper boundary conditions:

$$q^s = -k_{ij} \cdot \frac{\partial T}{\partial x_j} n_i,$$

THERMAL ANALYSIS

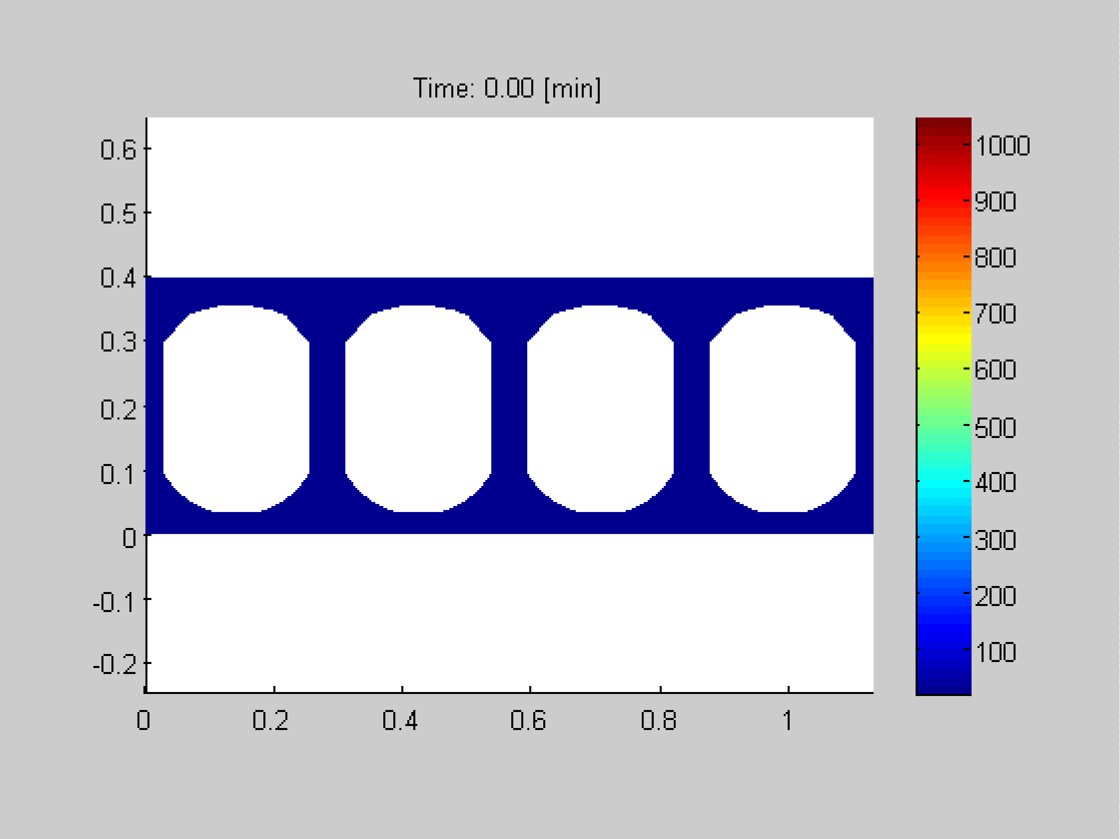
- Thermal and material properties of concrete at elevated temperatures



- The result of analysis – time dependent temperature distribution across slab cross section

THERMAL ANALYSIS

- Temperature development across the slab cross section (0-120 min)



MECHANICAL ANALYSIS

- Load combination for fire scenario in accordance with EN 1990:2004

  $$\sum_{j\geq 1} G_{k,j} + A_d + \psi_{1,1} \cdot Q_{k,1} + \sum_{i\geq 1} \psi_{2,i} \cdot Q_{k,i}$$

  $$q_{Ed,fi} = 17.91 \text{ kN/m}$$

- Design bending moment

  $$M_{Ed,fi} = 288.4 \text{ kNm}$$

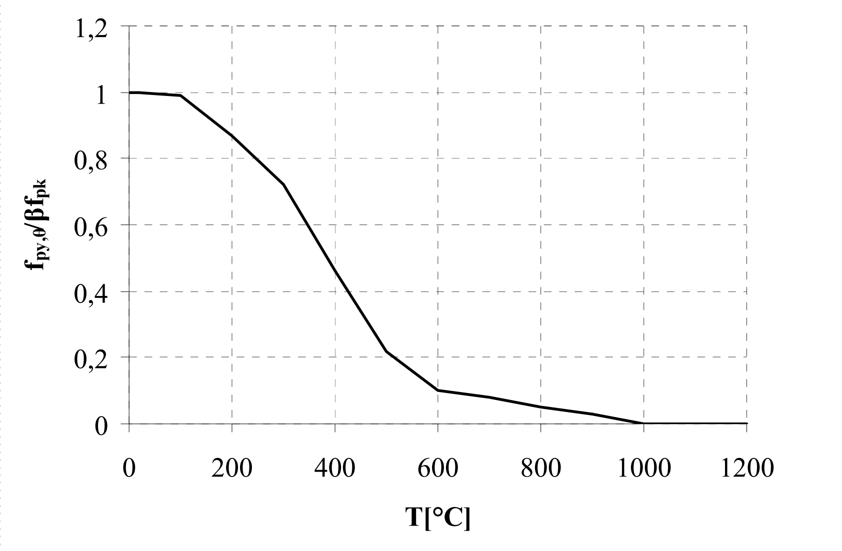
- Initial prestressing force in fire scenario

  $$P_{Ed,fi} = 1259 \text{ kN}$$

ISOTHERM 500°C

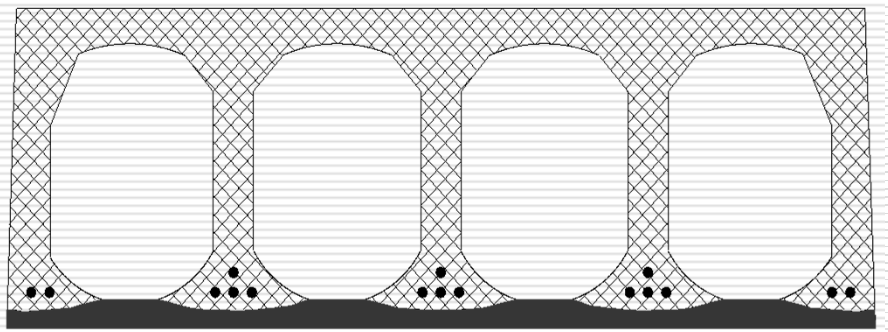
- Simple calculation model
- Concrete with temperature higher than 500°C does not contribute to bearing capacity of the cross section
- Reduced tensile strength of steel in accordance with EN 1992-1-2:2005

ted considering both reduced cross
of prestressed steel



ISOTHERM 500°C

- 60 minutes



- Temperature of strands

  $T_1 = 175°C$

  $T_2 = 285°C$

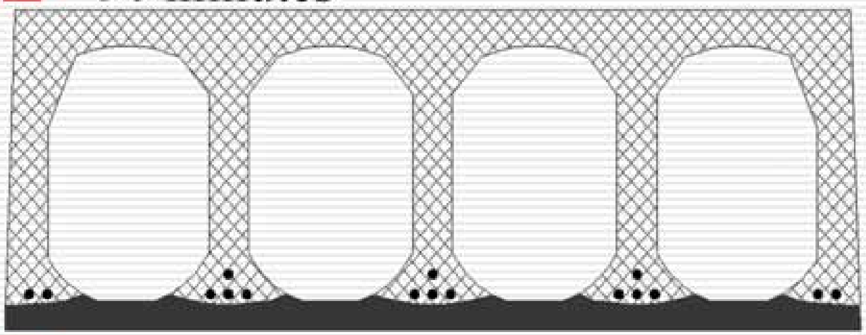
- Reduced tensile strength

  $f_{py,175} = 0.81\ f_{pk}$

  $f_{py,285} = 0.668\ f_{pk}$

ISOTHERM 500°C

- 90 minutes



- Temperature of strands

  $T_1 = 270°C$

  $T_2 = 390°C$

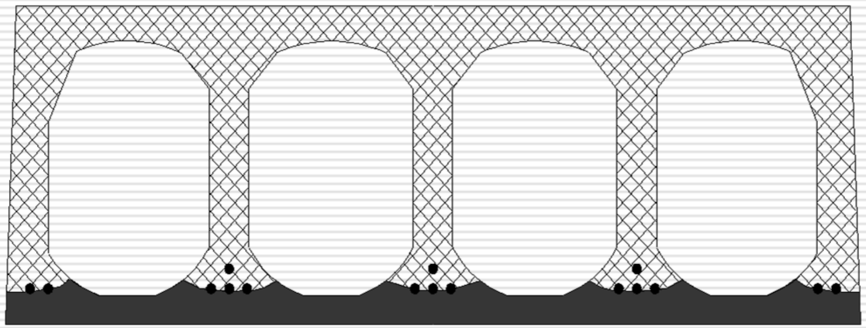
- Reduced tensile strength

  $f_{py,175} = 0.689\ f_{pk}$

  $f_{py,285} = 0.437\ f_{pk}$

ISOTHERM 500°C

- 120 minutes



- Temperature of strands

  $T_1 = 345°C$

  $T_2 = 480°C$

- Reduced tensile strength

  $f_{py,175} = 0.543\ f_{pk}$

  $f_{py,285} = 0.241\ f_{pk}$

ISOTHERM 500°C

- Results of analysis for slab cross section in mid-span

	t [min]		
	60	**90**	**120**
$M_{Ed,fi}$ [kNm]	288,4	288,4	288,4
$M_{Rd,t,fi}$ [kNm]	630	444	275
Cross section capacity	45,8%	65,0%	104,9%

In accordance with simple calculation model, hollow core slab classified as R90.

ADVANCED CALCULATION MODEL – NFIRA (Nonlinear fire analysis)

- Finit element method
- Reissnerjev 1-D beam model:
  - Bernoulli hypothesis,
  - deformation of the slab – membrane and bending deformations,
  - displacements, rotations and deformations are not limited by size,
  - short-term static load ,
  - bond stress-slip relationship between concrete and strands at elevated temperatures
  - explosive spalling is not taken into account.

ADVANCED CALCULATION MODEL

- Additive decomposition of total strain on elastic, plastic, temperature, transient and creep strain

  - Concrete:

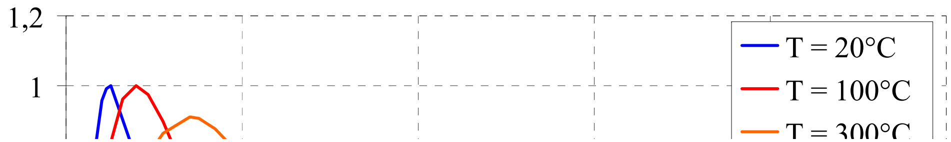
    $$\varepsilon_{c} = \varepsilon_{e,c} + \varepsilon_{pl,c} + \varepsilon_{th,c} + \varepsilon_{cr,c} + \varepsilon_{tr,c}$$

  - Prestressing steel:

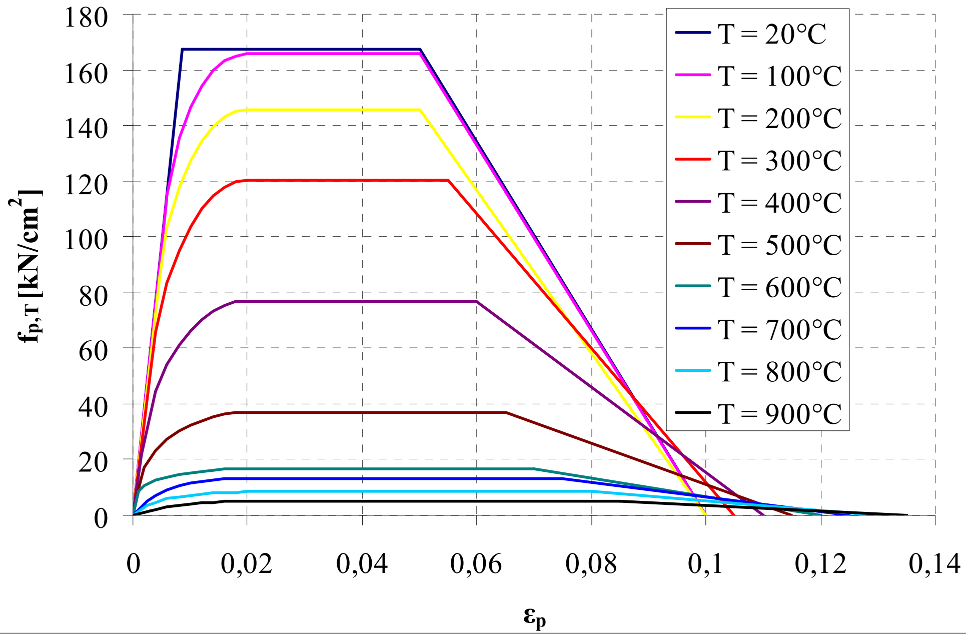
    $$\varepsilon_{p} = \varepsilon_{e,p} + \varepsilon_{pl,p} + \varepsilon_{th,p} + \varepsilon_{cr,p}$$

ADVANCED CALCULATION MODEL

- Stress-strain relationship for concrete under pressure at elevated temperatures

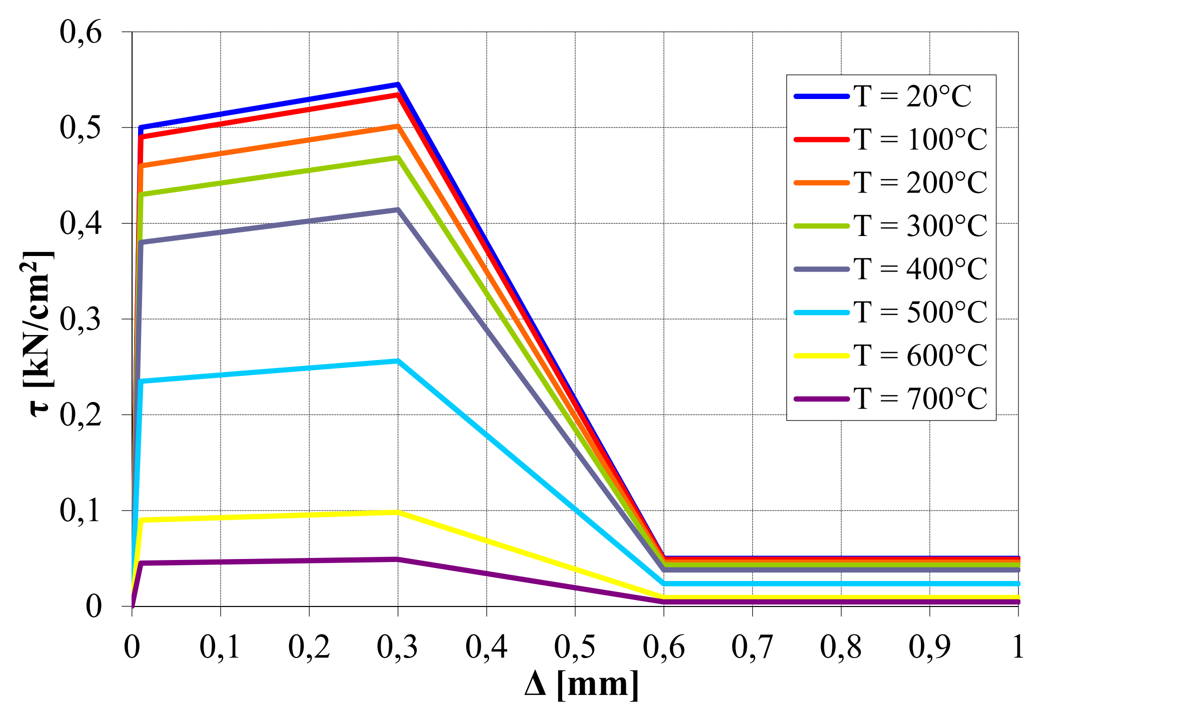


- … ng steel at elevated



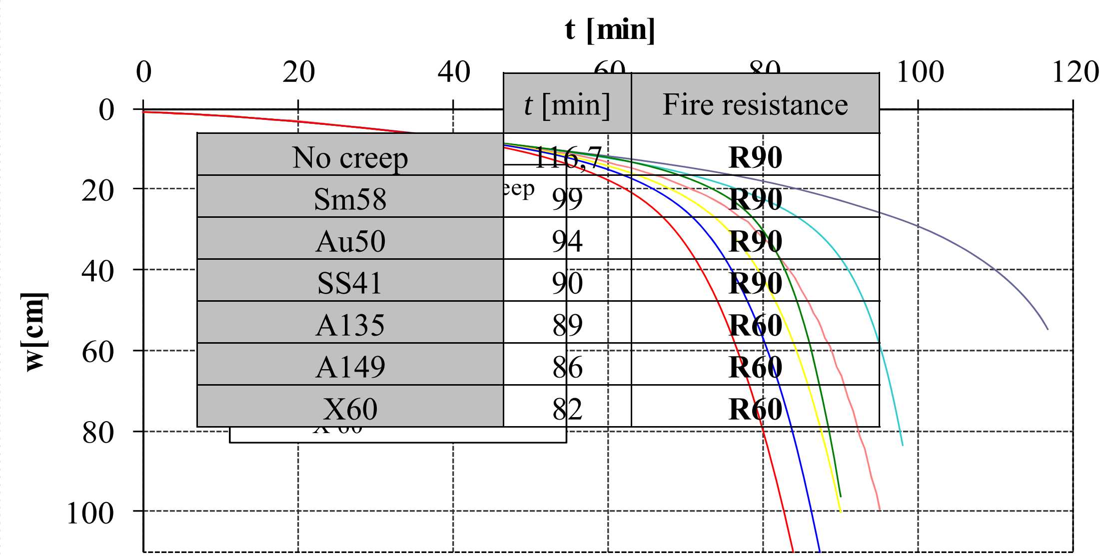
ADVANCED CALCULATION MODEL

- Bond stress-slip relationship betwen concrete and prestressing steel at elevated temperatures (Keuser and Mehlhorn,1983)



ADVANCED CALCULATION MODEL

- Parametric study of the influence of type of steel in a model of viscous creep of steel



	t [min]	Fire resistance
No creep	116,7	**R90**
Sm58	99	**R90**
Au50	94	**R90**
SS41	90	**R90**
A135	89	**R60**
A149	86	**R60**
X60	82	**R60**

Major influence of viscous creep of steel→ resistance classes R60 and R90

CONCLUSIONS

- Proof of safety in terms of fire:
  - Isoterm 500°C → class of resistance R90
  - Advanced calculation model (NFIRA) → class of resistance R60 and R90.
- Comparison if the two models:
  - Isoterm 500°C → failure due to decreased tensile strength of prestressing steel – yielding of strands
  - Advanced calculation model → significant impact has deformation of viscous creep of prestressing steel
  - Realistic response describes advanced calculation model, similarities betwen both model only if not taking deformation of viscous creep of steel into account.


THANKS FOR YOUR ATTENTION!
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