BACKGROUND IN FIRE ENGINEERING

Fire is a LOAD on Structures !

Caracas

Taipei

Los Angeles

Fire Engineering

I Fire load and fire scenarios

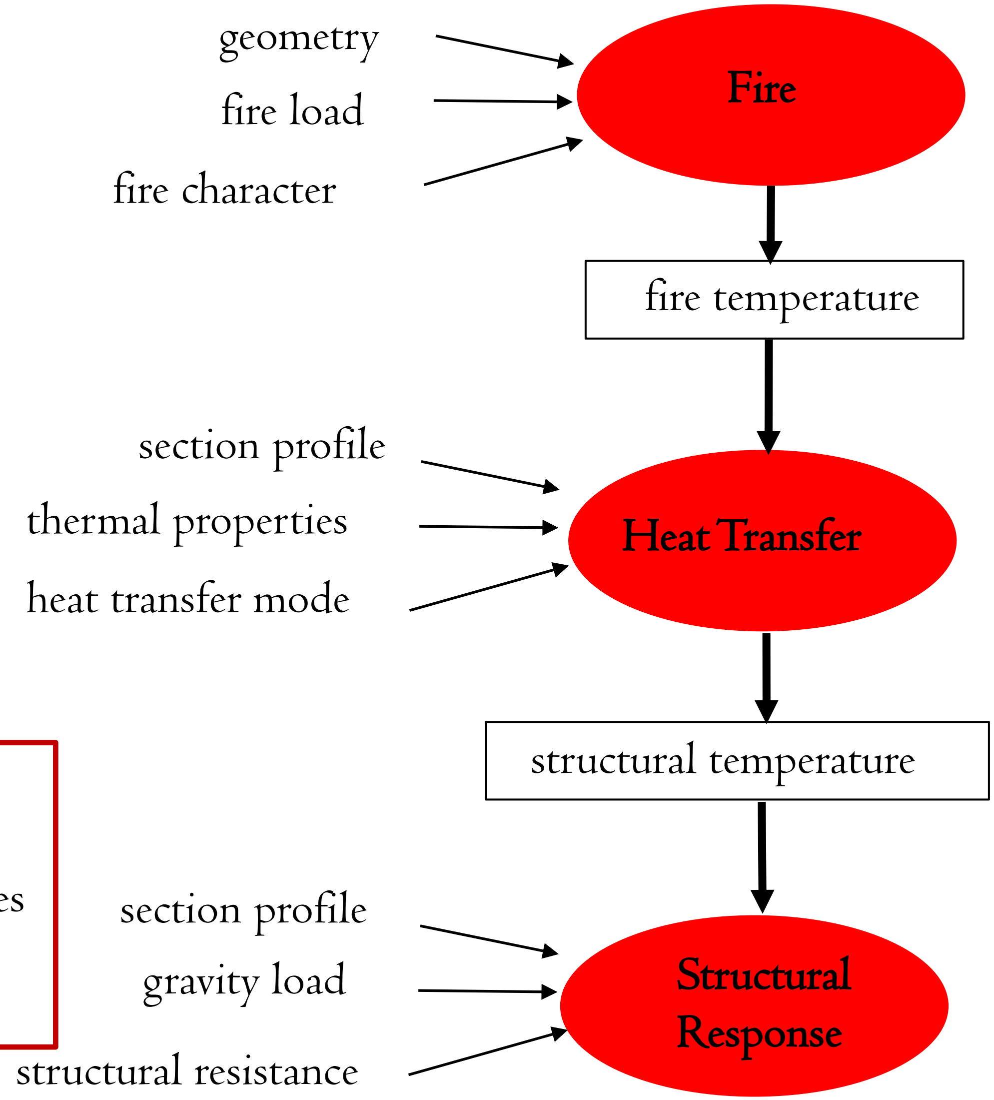
- Probability of fire initiation
- Fire growth models
- Fire location / fire spread
- Egress

II Heat transfer to structural members

- 1D analysis
- 2D and 3D analysis

III Thermo-mechanical analysis

- Material properties at elevated temperatures
- Behavior of isolated members
- System response



Building fires – Pre-flashover

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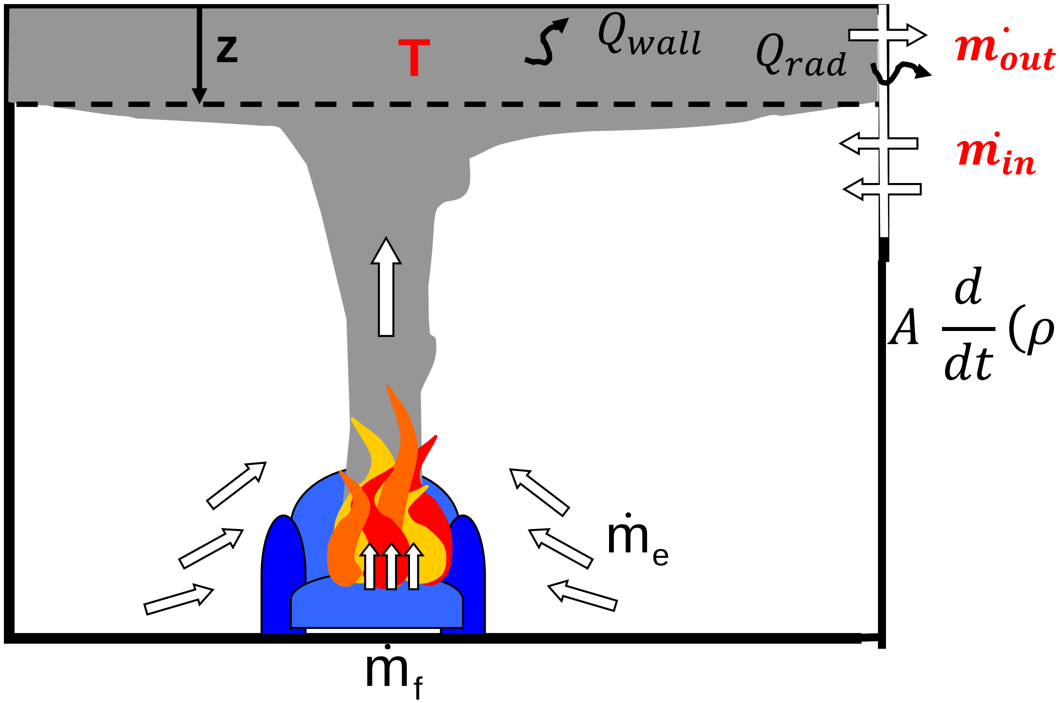
Building fires: Pre-flashover

Building fires: Pre-flashover

Building fires: Flashover

Compartment Fire Models



Mass balance

$$A\,\frac{d}{dt}(\rho\,z) + (\dot{m}_{out} - \dot{m}_{in} - \dot{m}_e - \dot{m}_f) = 0$$

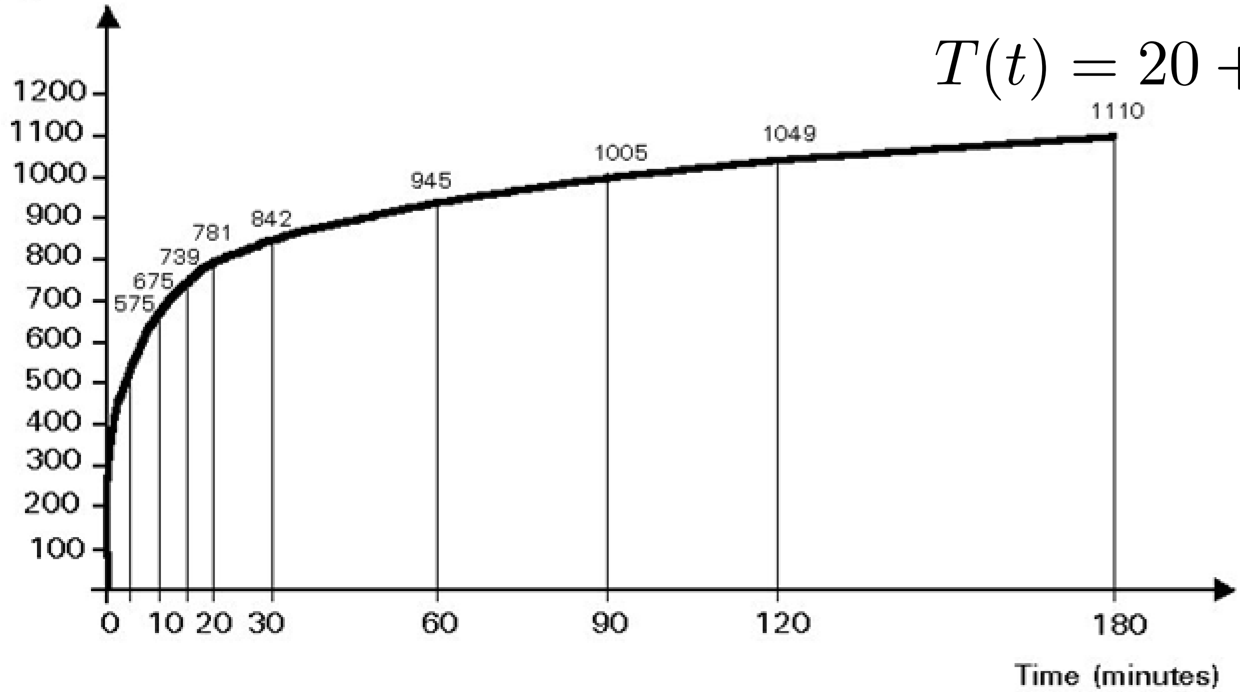
Energy balance

$$\underbrace{\rho\,c_p\,z\,A\,\frac{dT}{dt}}_{\text{change of internal energy}} - \overbrace{z\,A\,\frac{dp}{dt}}^{\text{work done}} + c_p\sum_{j=1}^{J}\dot{m}_j\,(T_j - T) = \dot{m}_f\,\Delta H_c - Q_{wall} - Q_{rad}$$

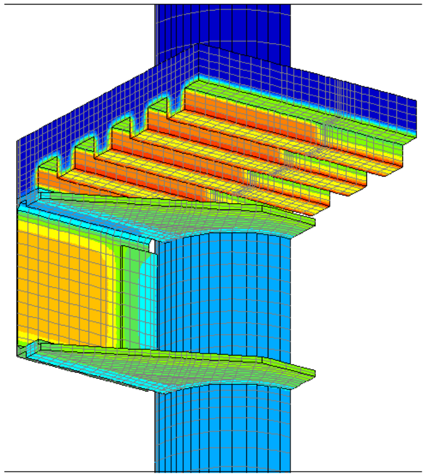
Standard Fire

- The time-temperature curve used in full-size fire resistance tests is called 'Standard Fire'. The most widely used ones are ASTM E119 (USA) and ISO834 (Europe).
- It is derived assuming that the bulk of the combustible material taken as **cellulosic** burns all together.
- Standard Fire is NOT a real fire, but it assumes to represent the fire load on a typical structural element. Standard Fire does NOT have a decay phase.

$$T(t) = 20 + 345\ log_{10}(8t + 1)$$



Heat Transfer



$$\nabla^2 T = \frac{\rho c}{k}\frac{\delta T}{\delta t}$$

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{\rho c}{k}\frac{\partial T}{\partial t}$$

HEAT EQUATION

$$-k\frac{\partial T}{\partial n} = \underbrace{\varepsilon\,\sigma\left(T^4 - T_{fire}^4\right)}_{\text{radiation}} + \underbrace{h\left(T - T_{fire}\right)}_{\text{convection}}$$

ON THE BOUNDARY

Thermal Properties of Steel:

k : conductivity [W/mK]

ρ : Density 7850 [kg/m^3] - constant with temp.

c : Specific heat [J/kgK]

Fire Protection

Board protection

Fire Protection

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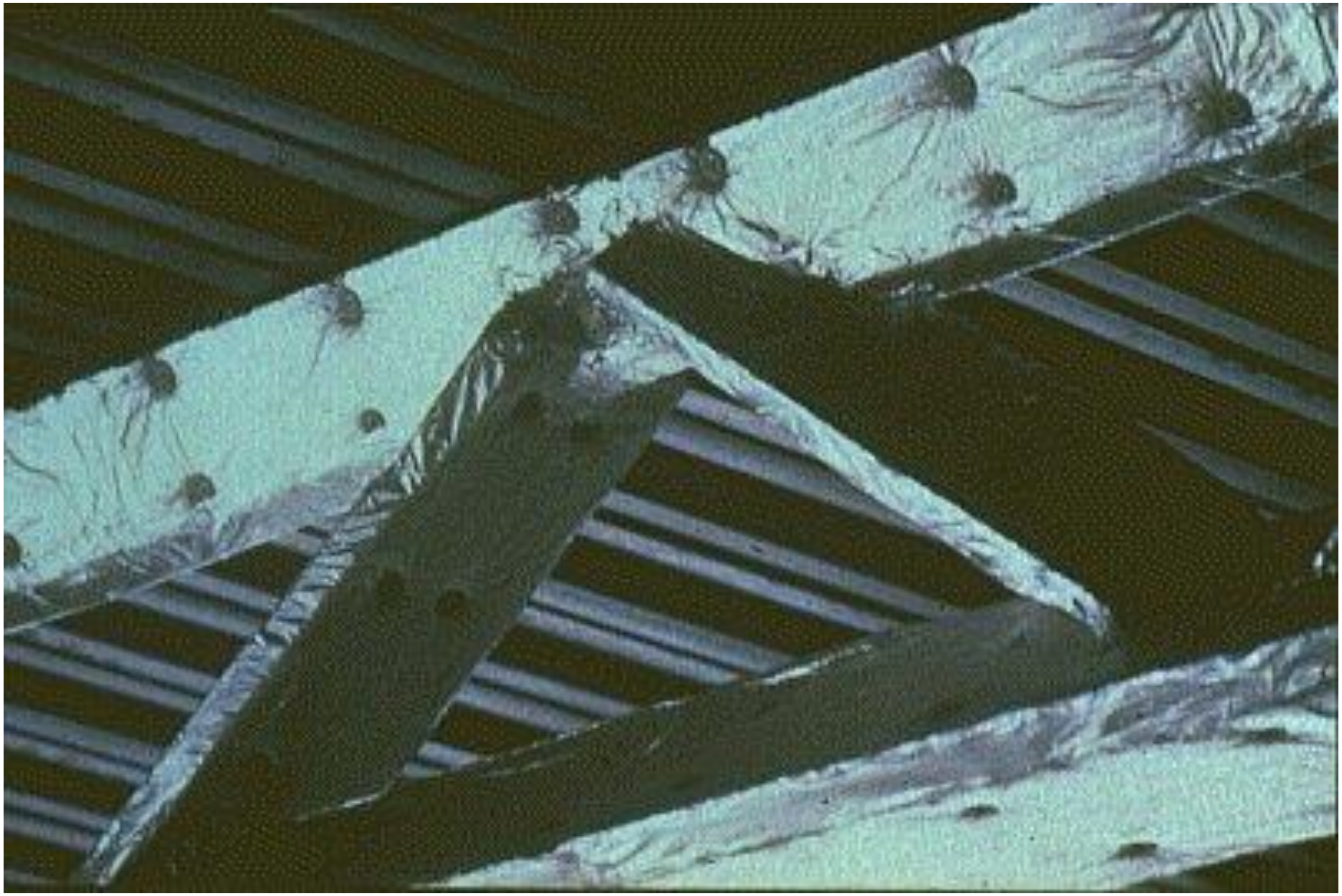
Spray protection

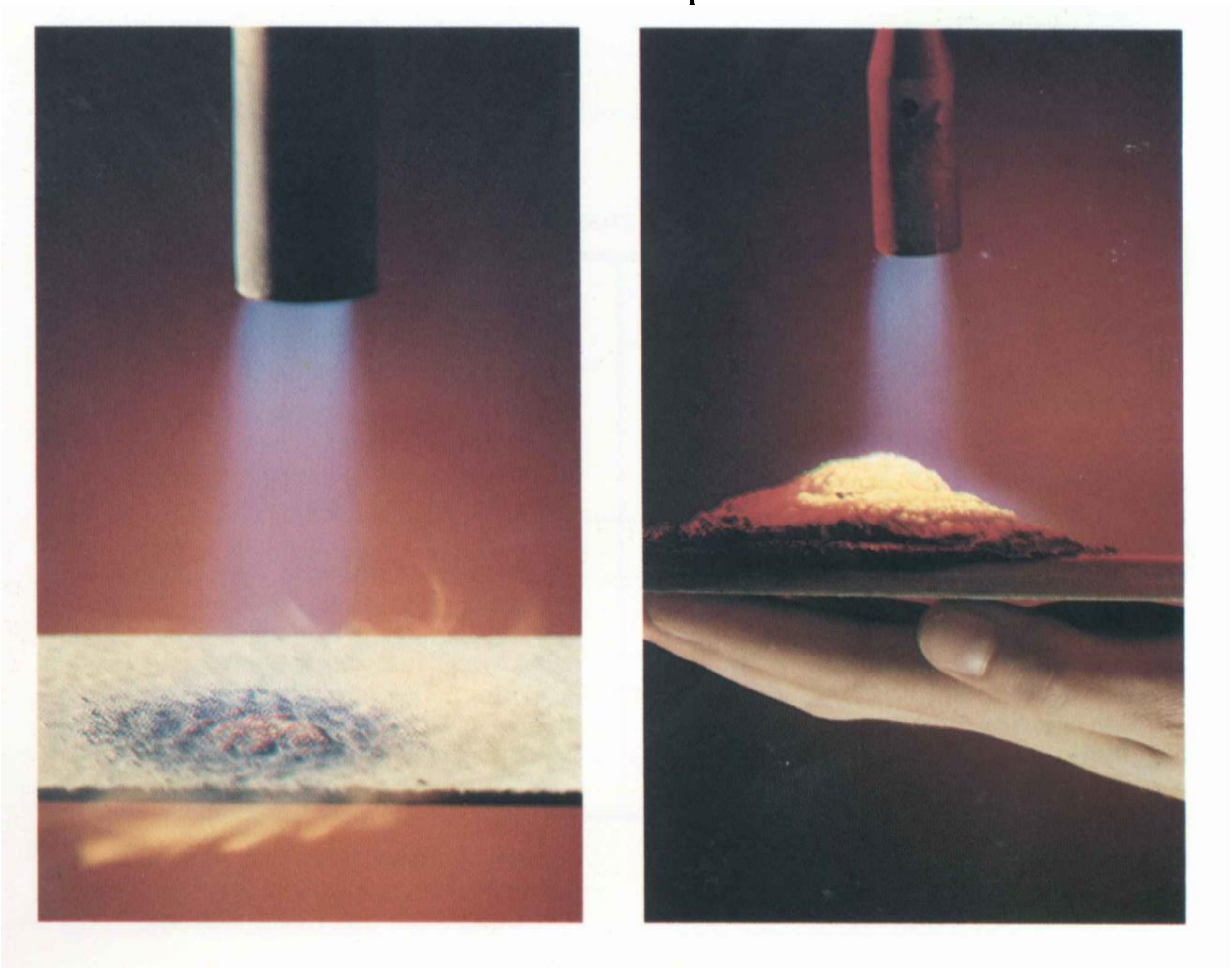
Fire Protection

Blanket Protection

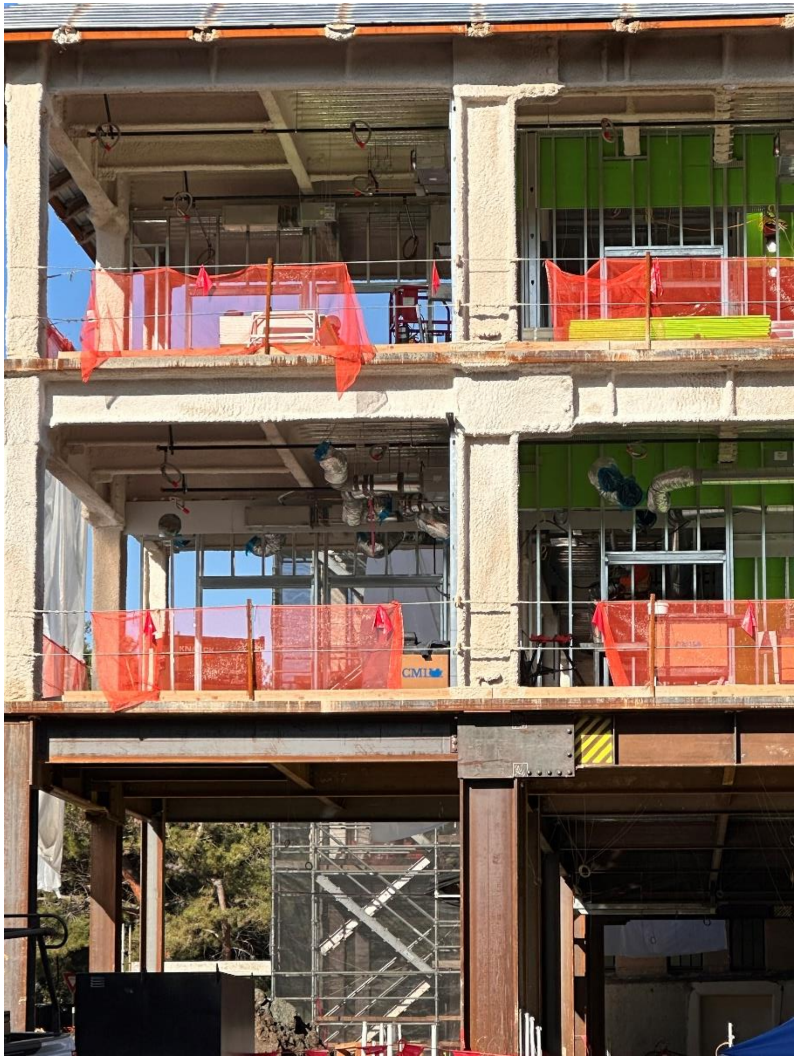


Fire Protection

Intumescent Paint protection



SFRM in Construction Site



III – Thermo-mechanical Analysis

Structural Fire Analysis

Structural analysis for fire design is essentially the same as structural analysis for normal temperature design, but it is complicated by the effects of elevated temperatures on the internal forces and the properties of materials.

- Nonlinearity in material – direct consequence of high temperatures
- Composite behavior – direct consequence of nonuniform temperature distribution
- Nonlinearity in geometry (2nd order effects σ') – direct consequence of elongation / contraction
- Varying internal forces (thermally induced stress σ_T) – direct consequence of axial and rotational restraint (time-history analysis)
- smaller safety factors (especially for live loads) can be used because of low probability of a fire event

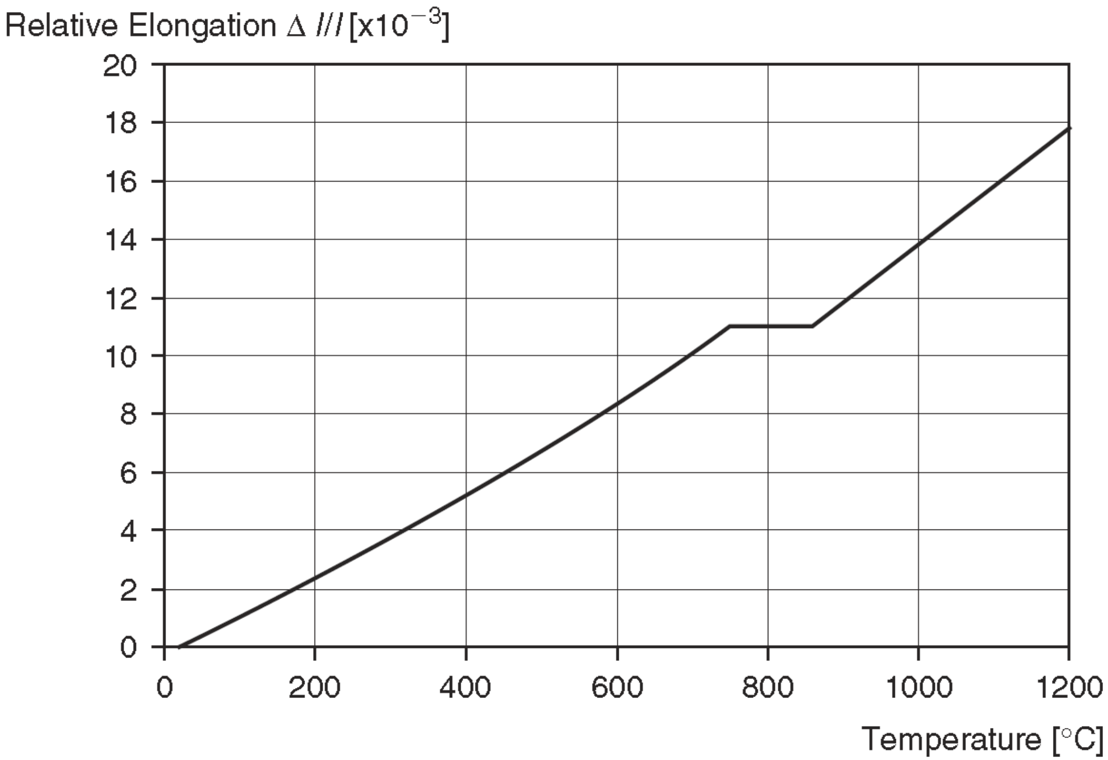
$$\sigma_{total} = \sigma_m + \sigma_T + \sigma' \qquad \varepsilon_{total} = \varepsilon_m + \varepsilon_{th} + \varepsilon'$$

Thermal Elongation of Steel

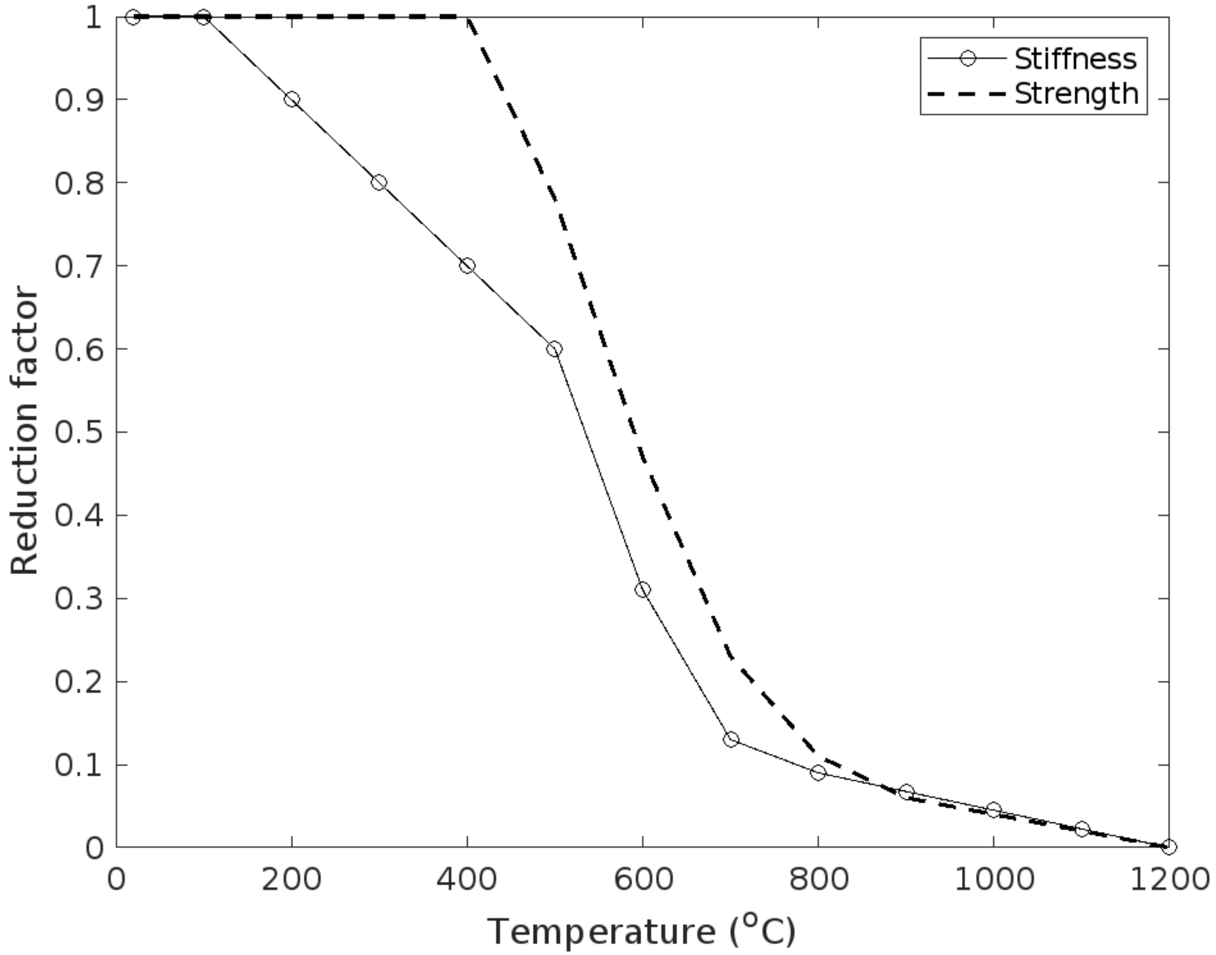
$$\varepsilon_{th} = 1.2x10^{-5}T + 0.4x10^{-8}T^2 - 2.416x10^{-4} \qquad 20^\circ C \le T \le 750^\circ C$$

$$\varepsilon_{th} = 1.1x10^{-2} \qquad 750^\circ C \le T \le 860^\circ C$$

$$\varepsilon_{th} = 2x10^{-5}T - 6.2x10^{-3} \qquad 860^\circ C \le T \le 1200^\circ C$$



Reduced Stiffness / Strength



Stress-Strain Curve (Steel)

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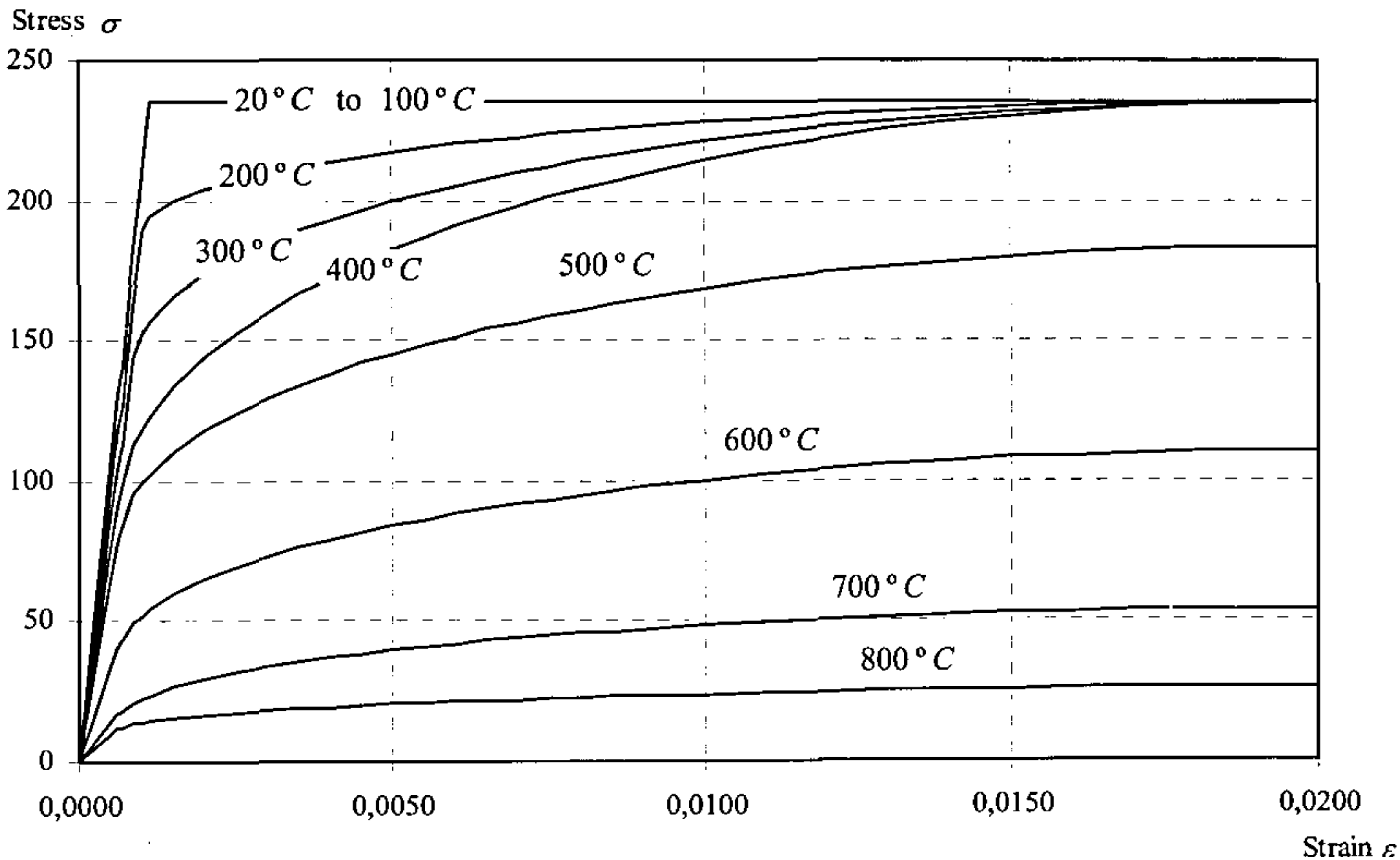
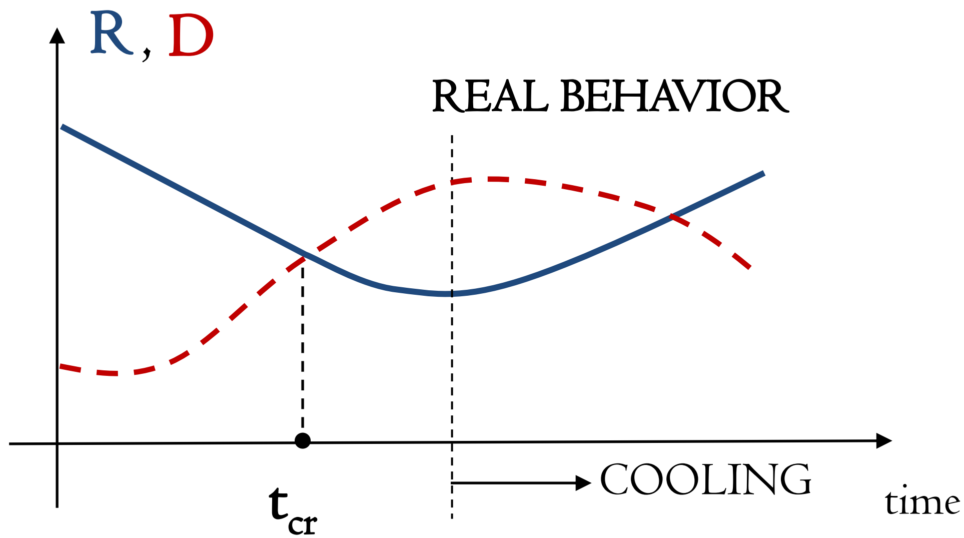


Demand vs Capacity



Capacity (R) reduces with decreasing stiffness and strength during heating.

Demand (D) increases with restraint to thermal elongation. As the yield strength reduces, the demand drops. During cooling, the thermal contraction causes the demand to change as well.

$$Demand = D_{Gravity} + \Delta D$$

$$f(A, I, E, \sigma_Y, \Delta T, \nabla T, boun.)$$