



2.11 Residual concrete strength after fire action (short version)

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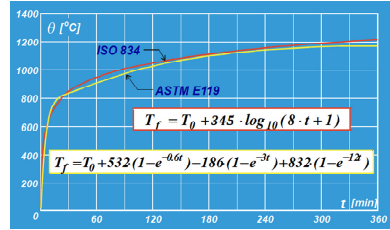

Integrated Fire Engineering and Response

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RESIDUAL CONCRETE STRENGTH AFTER FIRE ACTION

1

Standard fire test (ISO 834 / ASTM E119)




The standard fire test is used not only for determining the fire resistance of the elements but also for defining mechanical and physical properties of the materials at higher temperatures

recommended by EC2, Part 1.2

2

Visual inspection of structure



Change of color and structure of the concrete. Buff color indicate temperatures round 900°C
 Change of color of the concrete. Red color indicate temperatures round 600°C
 White color of the surface concrete layers was caused by the chemical reaction between the water, used for extinguishing the fire, and the dehydrated carbonate aggregate

3

1. Experimental determination of the residual concrete strength




The specimen are taken without the destruction of reinforcement and divided in two slices. The deteriorated tested at the Testing laboratory of the (burned) slices had small height (3-6cm) Faculty of Civil Engineering in Skopje and rough surface

They are specially prepared by adding plaster layers, so the measured values for the compressive concrete strength are reduced with coefficients depending on the shape and height (h) of the deteriorated concrete specimens

4

1. Experimental determination of the residual concrete strength



This is necessary for testing with the hydraulic press only
 For point load test (PLT), plaster adding is unnecessary

5

2. Numerical determination of the residual concrete strength

Governing differential equation of heat transfer in conduction:

$$\frac{\partial}{\partial x} \left(\lambda_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda_z \frac{\partial T}{\partial z} \right) = \rho c \frac{\partial T}{\partial t}$$

where:

- $\lambda_{x,y,z}$ - is a thermal conductivity
- ρ - is a density of the material
- c - is a specific heat

Fire boundary conditions:

- convective heat transfer mechanism
- radiative heat transfer mechanism

6

2. Numerical determination of the residual concrete strength

Governing differential equation of heat transfer in conduction:

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The heat flow caused by convection:

$$q_c = \alpha_c (T_z - T_f)$$

where:

- α_c - is coefficient of convection ($\alpha_c = 25 \text{ W / m}^2 \text{ C}$)
- T_z - is the temperature on the boundary of the element
- T_f - is the temperature of the fluid around the element

7

2. Numerical determination of the residual concrete strength

Governing differential equation of heat transfer in conduction:

$$\frac{\partial}{\partial x} \left(\lambda_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda_z \frac{\partial T}{\partial z} \right) = \rho c \frac{\partial T}{\partial t}$$

The heat flow caused by radiation:

$$q_r = V \varepsilon \sigma_c (T_{z,a}^4 - T_{f,a}^4) = \alpha_r (T_z - T_f)$$

where:

- α_r - is coefficient of radiation
- T_z - is the temperature on the boundary of the element
- T_f - is the temperature of the fluid around the element

8

2. Numerical determination of the residual concrete strength

The solution of the differential equation in FEM is:

$$[C] \cdot \dot{\vec{T}} + ([K_1] + [K_2]) \cdot \vec{T} + [R] \cdot \vec{T} = \vec{P}$$

- $[K_1]$ - conductivity matrix (temperature dependent)
- $[K_2]$ convection matrix
- $[C]$ - capacity matrix (temperature dependent)
- $[R]$ - radiation matrix (temperature dependent)
- \vec{P} - vector of temperature loads
(convection and radiation included)
- \vec{T} - vector of unknown nodal temperatures
- $\dot{\vec{T}}$ - vector of temperature derivatives over time

9

2. Numerical determination of the residual concrete strength

The solution of the differential equation in FEM is:

$$[C] \cdot \dot{\vec{T}} + ([K_1] + [K_2]) \cdot \vec{T} + [R] \cdot \vec{T} = \vec{P}$$

Iterative procedure recommended by
Wilson and Nickell

$$\dot{T}_i = \dot{T}_{i+\Delta t} = \frac{T_{i+\Delta t} - T_i}{\Delta t}$$

$$[K_1]_{t+\Delta t} = [K_1]_t \quad [C]_{t+\Delta t} = [C]_t \quad [R]_{t+\Delta t} \neq [R]_t$$

$$\left([K]_{t+\Delta t} + \frac{2}{\Delta t} [C]_t \right) \vec{T}_{t+\Delta t} = \left(-[K]_t + \frac{2}{\Delta t} [C]_t \right) \vec{T}_t + \vec{P}_{t+\Delta t} + \vec{P}_t$$

10

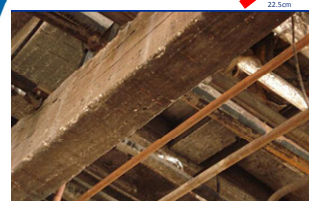
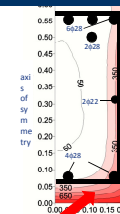
2. Numerical determination of the residual concrete strength

Following assumptions are made to determine the fire-induced thermal fields :

- A fire can be modeled by a single valued gas temperature history
- Temperature dependent material properties are known
- Two dimensional heat transfer is assumed
- No contact resistance to heat transmission at the interface between the reinforcing steel and concrete occurs
- The easier heat penetration, while cracks appear, or some parts of the cross section crush, is neglected

11

2. Numerical determination of the residual concrete strength



Values of concrete strength			
No.	D ₀ (mm)	f _{ck} [MPa]	f _{res} [MPa]
Deteriorated slices			
1	47.65	0.93	0.81
2	47.63	0.51	0.50
3	47.67	0.77	0.75
4	46.91	0.33	0.32
5	43.70	0.99	0.93
Average of f _{res} = 0.662 MPa			
Compact slices			
6	52.84	2.26	2.34
7	51.46	1.75	1.77
8	49.08	2.23	2.21
Average of f _{res} = 2.107 MPa			
k = 2.107 / 0.662 = 3.18			
Average strength of burned slices			
f _{bo} = f _{bo,k} = 29.375 / 3.18 = 9.24 MPa			

12