Department of Mechanics, Materials and Structures
English courses
Reinforced Concrete Structures
Code: BMEEPSTK601

Lecture no. 18:

DESIGN METHODOLOGY
FIRE RESISTANCE DESIGN

Content:

Introduction

Design methodology

1 The development of design methodology
2 The method of partial safety factors
3 Mathematical background of the determination of the design value of mechanical characteristics and of loads and actions

Fire resistance design

1 The aims of fore protection
2 Fire loading
3 Fire endurance requirements of buildings
4 Fire resistance limits
5 Methods of fire endurance design
6 Use of tables

DESIG METHODOLOGY

The development of design methodology

Traditional method: method based on experiences (occurance of catastrophs)

Ultimate stress method: $\sigma_{max} \leq \sigma_{allowable}$

Ultimate load method: $F_{max} \leq F_{allowable}$

Method of partial safety factors (at present)

Future: use of fully probabilistic methods

The method of partial safety factors

Both kinds of design input data (loads and strength) are

-statistically evaluated
-modified by use of *safety factors*, which are different depending of the level of reliability of the value of the action /strength of the structural material

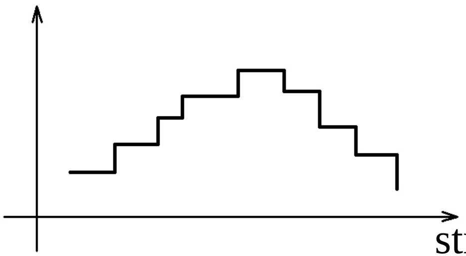
Examples:
For loads: value of a permanent load can more exactly be determined than that of a variable action (γ_G=1,35 γ_Q=1,5). These are factors (multiplicators)!
For strengths: mechanical properties of steel are more reliable then that of concrete (γ_s=1,15 γ_c=1,5). These are divisors!

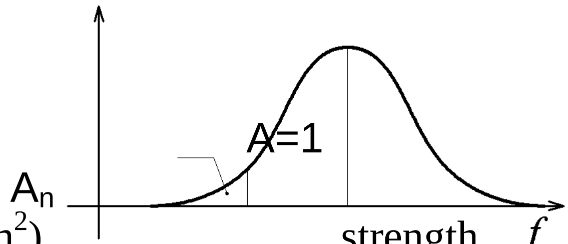
Mathematical background of the determination of the design value of mechanical characteristics and of loads and actions

Strength as probability variable

2.1 Statistical strength data

no. of occurance relative occurence





strength f (N/mm^2) strength f

Strength distribution diagram (histogram) Density function of strength distribution

The *probability* of not exceeding $f_{nom} = \frac{A_n}{A} = A_n$

Statistical evaluation of test results (Statistical strength evaluation)

Characteristics of the strength distribution

Mean value: $f_m = \frac{\Sigma f_i}{n}$ *n*: number of test data (min 10, if qualification is based on unknown scatter)

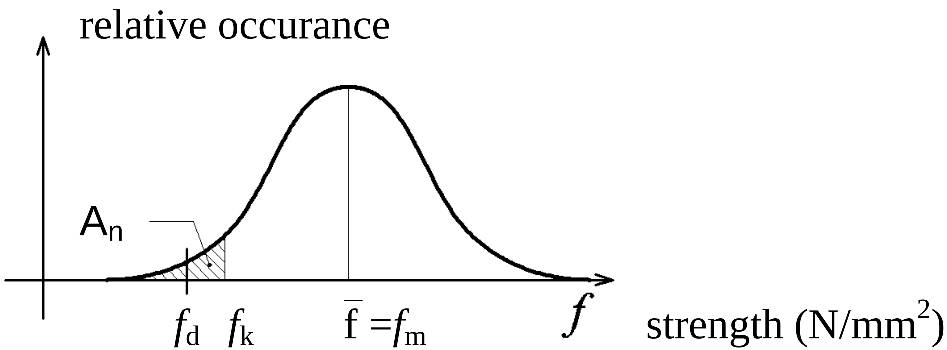
Scatter: $s = \sqrt{\frac{\Sigma (f_i - f_m)^2}{n-1}}$

Threshold value (characteristic or nominal value):

$$f_k = f_m - ts$$

where t is the so called Student factor, which, for n=10 and 5% risk is t=1,79 (5% threshold value: the probability of the occurence of a strength value smaller than f_k is 5%)

Relation of characteristic and design value



Design value: $f_d = \dfrac{f_k}{\gamma_m}$

The probability of f_d not being exceeded is $0{,}1\% = 10^{-3}$

γ_m for some important structural materials

1,15 for reinforcement (steel in reinforced concrete)

1,3 for timber

1,5 for concrete

Statistical evaluation of loads

The same evaluation method can be used for ti determine

-characteristic value of loads (F_k)

Here the upper extreme value of the load or action is determined, values higher than this, have a very limited probability to occure

-design value of loads: $F_d = \gamma_a F_k$

where γ_a is the safety factor of loads and actions

for live loads and meteorological loads (variable loads) $\gamma_F = \gamma_Q = 1,5$

for permanent loads $\gamma_F = \gamma_G = 1,35$

The probability of a load being greater then its design value is appr. 10^{-2}

The required safety level by designing structures for the ultimate limit states (ULS)

The probability of failure of a structure which was dimensioned for design value of loads and by use of design value of strength of the structural materials is equal to the product of the probabilities of occurance of the loads and strengths used during desin. that is:

$$p_{\text{failure}} = p_{\text{of smaller strength than } f_d} \cdot p_{\text{greater load than } F_d} = 10^{-3} \cdot 10^{-2} = 10^{-5}$$

that is in every 10 000th case a failure may occure.

The achievement of 100% safety is economically not viable.

FIRE RESISTANCE DESIGN

THE AIMS OF FIRE PROTECTION

(National Fire protection prescriptions of Hungary, 2008 (OTSZ)):

- Conserve the loadbearing capacity (during certain period of time)
- Reduce fire propagation and smoke formation
- Assure escape and rescue of people present in the building
- Safe work of the firemen

FIRE PROTECTION ADVANTAGES OF REINFORCED CONCRETE STRUCTURES

(when compared with steel structures)

Concrete is incombastible

Concrete protects steel (thermal insulation, cooling)

The role of steel is small in critical structures (columns, slabs)

In beams arrangement of reinforcement in several rows better

Smaller slenderness (smaller risc of stability failure)

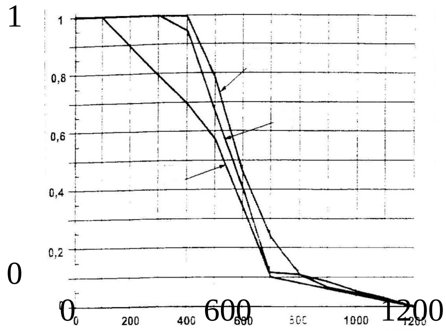
CHANGE OF MATERIAL CHARACTERISTICS IN FIRE

Reinforcement

- Partially reversable changes
- Rapid thermal expansion
- Strength reduction

$$f_{yk}(\Theta) = k_s \cdot f_{yk}(20°C)$$

$k_s - t$ diagram

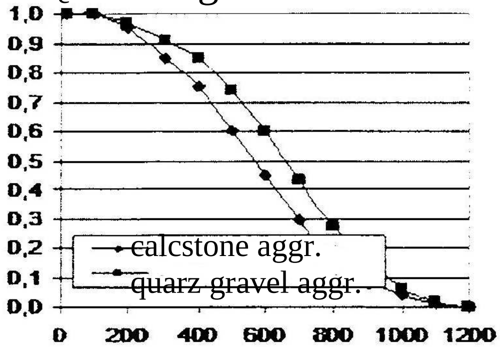


Concrete

- Irreversible physical and chemical changes (blast damages, splitting)
- Strength reduction

$$f_{ck}(\Theta) = k_c \cdot f_{ck}(20°C)$$

$k_c - t$ diagram



NORMATIVE FIRE CURVE (EN1991-1-2)

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

t: Time (Min.)	15	30	60	90	120	180	240
Θ: Temperature (˚C)	739	842	945	1006	1049	1120	1153

COMBINATION OF LOADS AND EFFECTS TO CONSIDER IN FIRE

Exceptional combination of effects

The reduced load intensity to consider in fire, approximately:

$$E_{d,fi} = \eta_{fi} \cdot E_d$$

where:

$$\eta_{fi} \approx \frac{G_k + \psi_{1,1} Q_{k,1}}{\gamma_G G_k + \gamma_{Q,1} \psi_{1,1} Q_{k,1}}$$

Safe upper value:

η_{fi} = 0,7

(Condition: $Q_{k,1} / G_k > 0{,}5$)

THE WAY OF FORMULATION OF FIRE ENDURANCE REQUIREMENTS OF BUILDINGS

according to the National Fire Protection Prescriptions of Hungary, 2008

- Ranging in **fire danger classes** (A to E)
- Ranging in **fire endurance grades** (I to V)
- Determining the fire endurance requirements and fire endurance limits (for ex.: REI 120**)**

FIRE SECTIONS, FIRE DANGER CLASSES OF ROOMS, BUILDINGS AND CONSTRUCTIONS

Fire danger class		**Examples**
sign	definition	
A	Fire and blast dang-erous in an increased degree	Rooms, places, buildings where fire and blast-dangerous materials in any state can be present (for ex.: great capacity accumulator charger rooms, presence of liquids with under 21˚C ignition point
B	Fire and blast dangerous	Powder forming blast dangerous mixture with the air, rooms, places or buildings where presence of liquids with ignition point between 21-50˚C can occure (for ex.: powder chamber)
C	Fire dangerous	Solid materials with ignition point under 300˚C , liquid mineral oil by-products with ignition points between 50-150˚C (for ex gas oil, petroleum), rooms, places and buildings where noncombastible but combustion nourishing gases can be present (for ex.: gasoline stations,

		communal building s above 500 people capacity)
D	Moderately fire dangerous	Solid materials with ignition point above 300˚C (for ex. hard coal), rooms, spaces, buildings where liquids of above150˚C flash point can be present;; offices, dwellings and buildings for animal keeping under 50 people capacity
E	Not fire dangerous	Rooms, spaces and buildings where exclusively non-combustible materials are present, where the temperature of the materials does not increase above 300˚C.

FIRE ENDURANCE GRADES

Function and details, height etc. of the building/fire section (characteristic types of buildings)	**The lowest fire endurance grade** that can be prescribed
Highrise buildings, medium high building designed for staying of masses, with pavement level above 13,65 m.	**I.**
Infant′s nursery, kindergarten, medium high building, multistorey cellars, more than two level high buildings for handycapped people	**II.**
Schools, dwelling and communal buildings more than two level high, with top pavement level under 13,65 m, max. two level high buildings for handycapped people.	**III.**
Roofed spaces without vertical space separations, cellar-ground floor+1 storey high (or with built-in attick) dwelling or rest-house,	**IV.**

single-storey communal building with 25 to 30 people capacity.	
Single storey rest-house, family house and public building of max.25 people capacity	**V.**

FIRE RESISTANCE LIMITS

The minimum time interval prescribed for the fulfilment of the given fire resistance requirement (for ex. R)

Such as: 15, 30, 60, 90, 120, 180, 240 Minutes

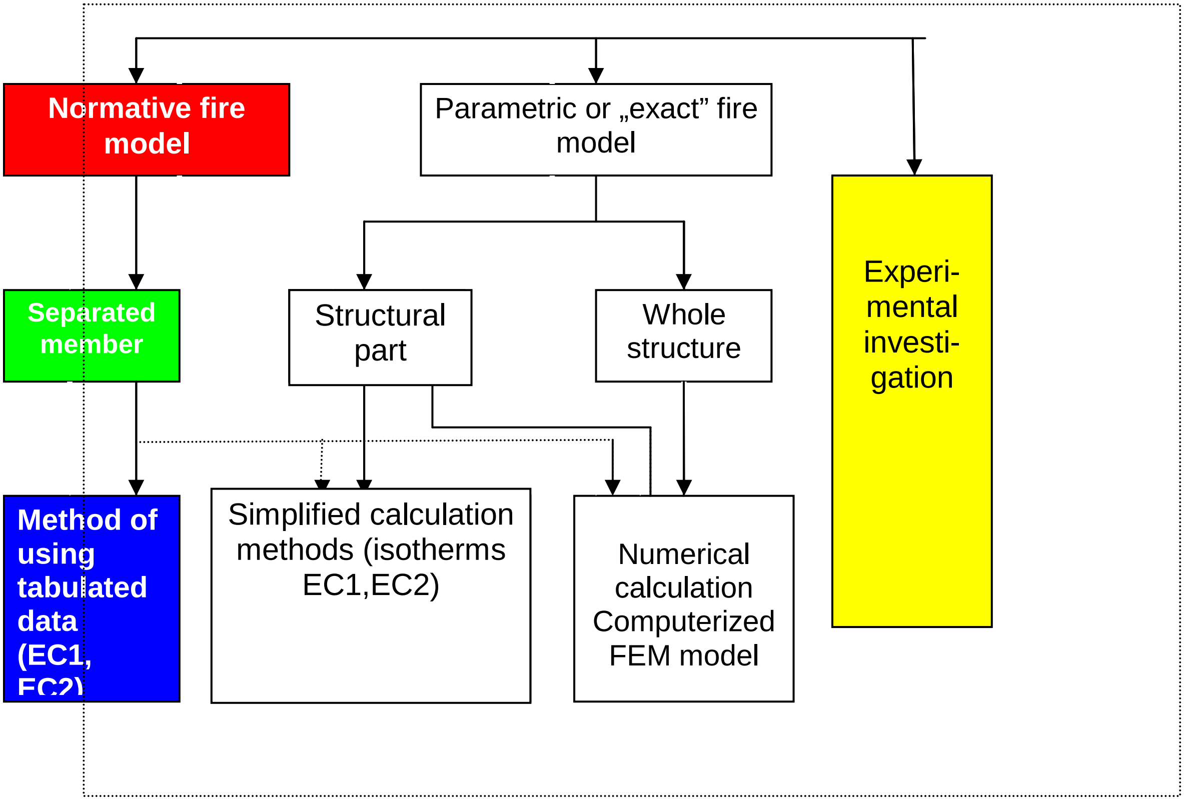
Examples:

- R 60 (beam, floor slab)
- REI 90 (wall)
- REI-M 240 (fire-wall)

- **R** : conserving the loadbearing capacity
- **E** : structural integrity (impeeding fire propagation)
- **I** : insulation (limited warming up)
- **M** : mechanical hitproof behavior

The requirement **REI-M** means : bearing capacity+integrity+insulation + hitproof behavior (fire-walls)

METHODS OF FIRE ENDURANCE DESIGN OF BUILDINGS



USE OF TABLES FOR FIRE RESISTANCE DESIGN

Input data is the prescribed fire resistance, for ex.:REI 90

To be checked / designed :

- Minimum dimension of the concrete cross-section (b_{min} or t_{min})
- Minimum distance between axis of bars and the surface (a_{min})
- Area of the reinforcement (by columns)

Elaborated tables in MSZ EN 1992-1-2:2005 for:

- Columns, pilars
- Walls (see next page!)
- Simple supported and continuous beams
- Slabs supported along the edges
- Flat slabs

Fire resistance requirement and limit (Min)	Reinforced concrete walls			
	Wall thickness/concrete cover to axis of bars			
	One side fire	Two side fire effect	One side fire effect	Two side fire
	Exploitation rate: $\mu_{fi}=N_{Ed,fi}/N_{Rd}$			
	μ_{fi}=0,35		μ_{fi}=0,7	
REI 30	100/10**	120/10**	120/10**	120/10**
REI 60	110/10**	120/10**	130/10**	140/10**
REI 90	120/20**	140/10**	140/25	170/25
REI 120	150/25	160/25	160/35	220/35
REI 180	180/40	200/45	210/50	270/55
REI 240	230/55	250/55	270/60	350/60
REI-M	In case of impact resistance requirement (M) the lower limit of t_{min} and a_{min} is 140 mm and 25 mm respectively			

** Authoritative is the *a* value according to EN 1992-1-1 (durability)

Re

See similar tables for columns and beams in the rc. design aids!

END