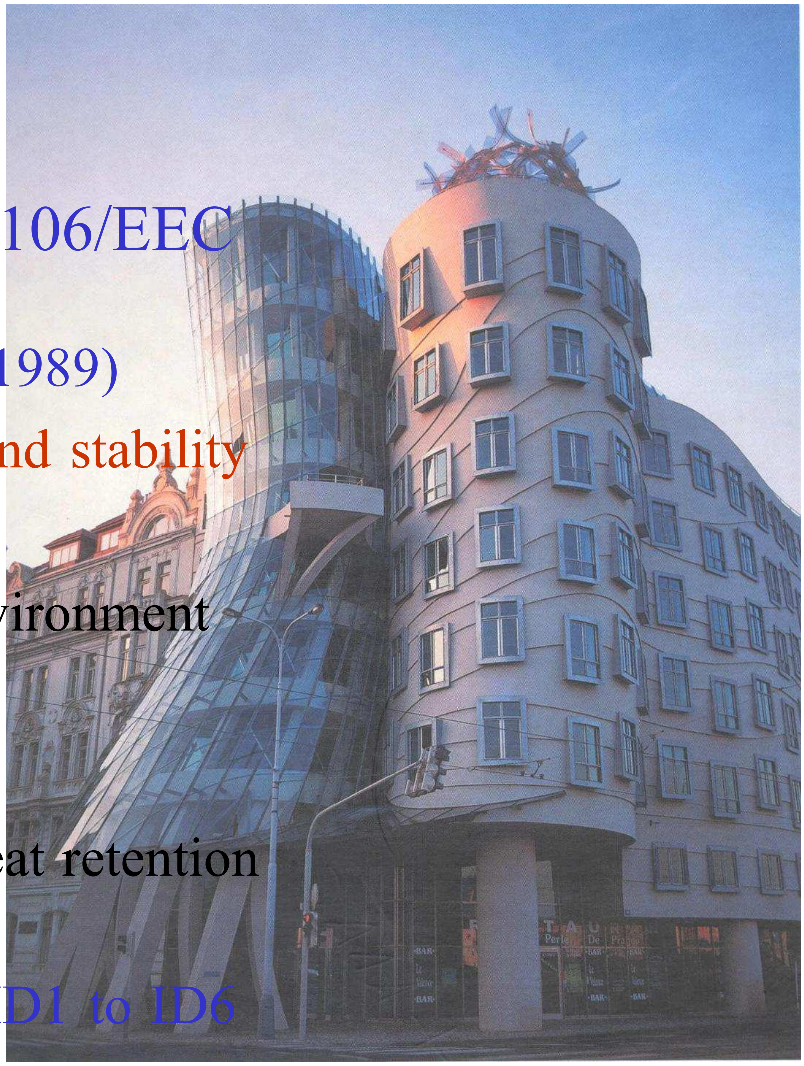
Basic concepts

Council Directives 89/106/EEC

Essential Requirements (1989)

- Mechanical resistance and stability
- Safety in case of fire
- Hygiene, health and environment
- Safety in use
- Protection against noise
- Energy economy and heat retention

Interpretative documents ID1 to ID6

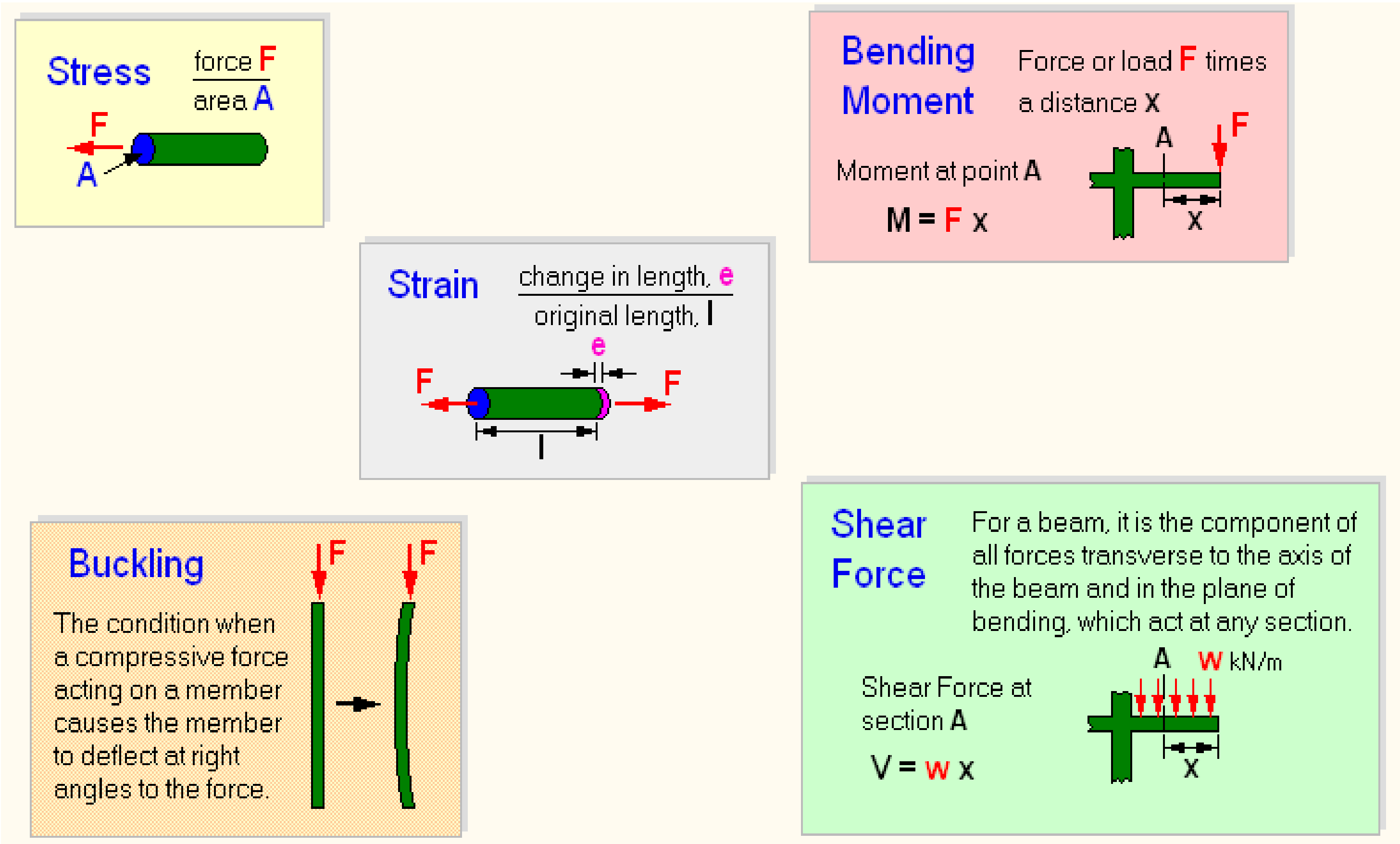


EUROCODES

Name	Publishing
EN 1990: Basis of Structural design	2002
EN 1991: Actions on structures	2002
EN 1992: Design of concrete structures	2004
EN 1993: Design of steel structures	2004
EN 1994: Design of composite structures	2004
EN 1995: Design of timber structures	2004
EN 1996: Design of masonry structures	2004
EN 1997: Geotechnical design	2004
EN 1998: Design of structures for earthquake	2004
EN 1999: Design of aluminium structures	2004

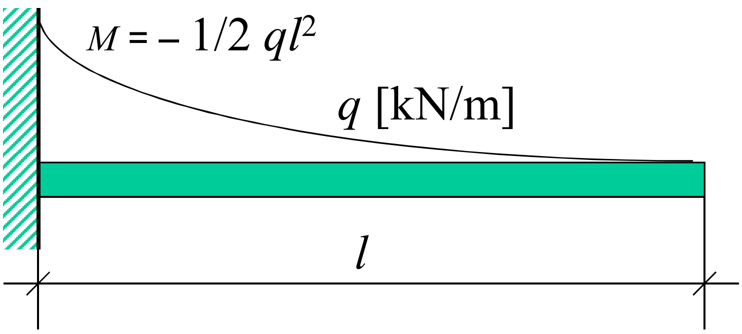
DAV: EN 1990, DAV: 2002-04-24
EN 1991-1-1, DAV: 2002-04-24
EN 1991-1-2, DAV: 2002-11-20
EN 1991-1-3, DAV: 2003-07-16

Some basic definitions

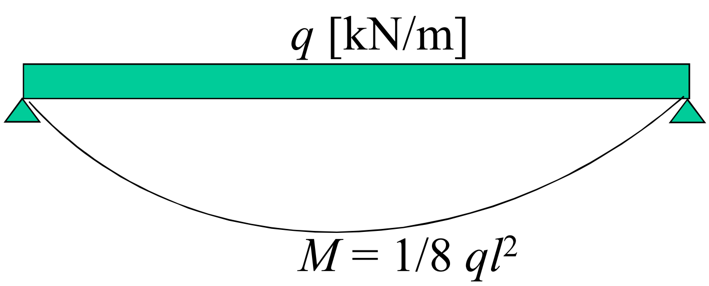


Bending moments M [kNm] on a beam

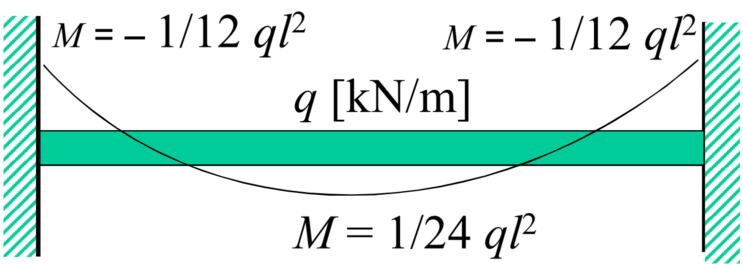
Cantilevered beam



Simply supported beam

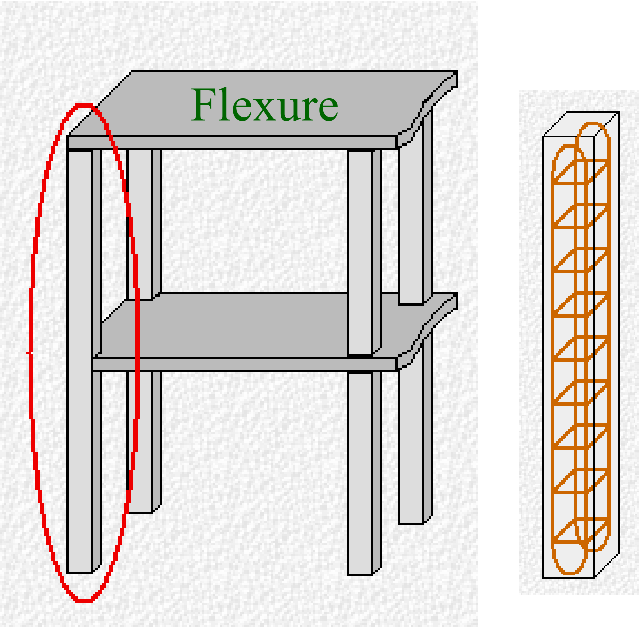


Fixed beam

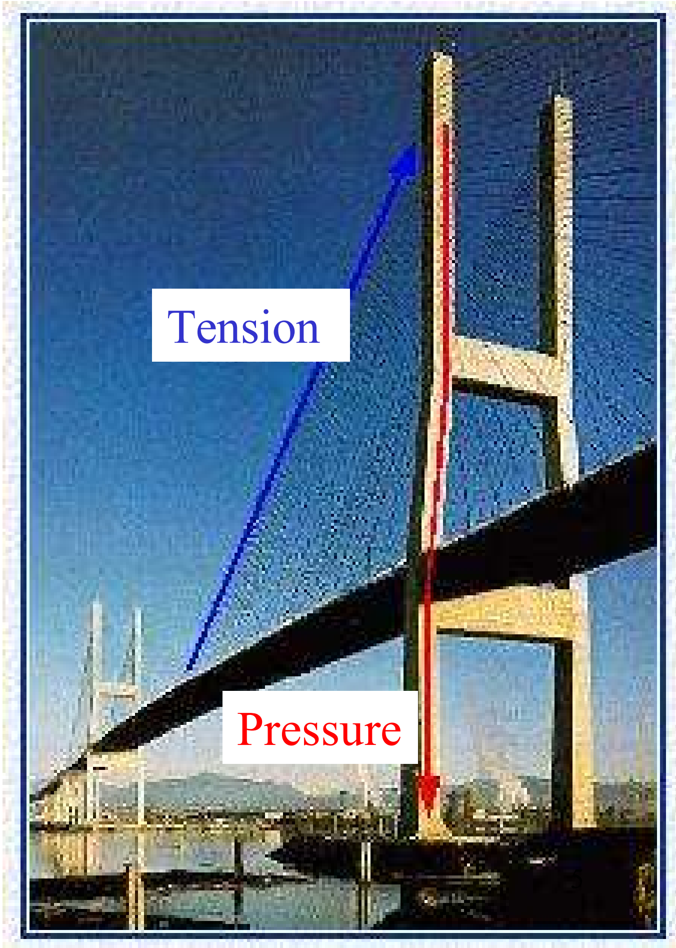


Fundamental load bearing members

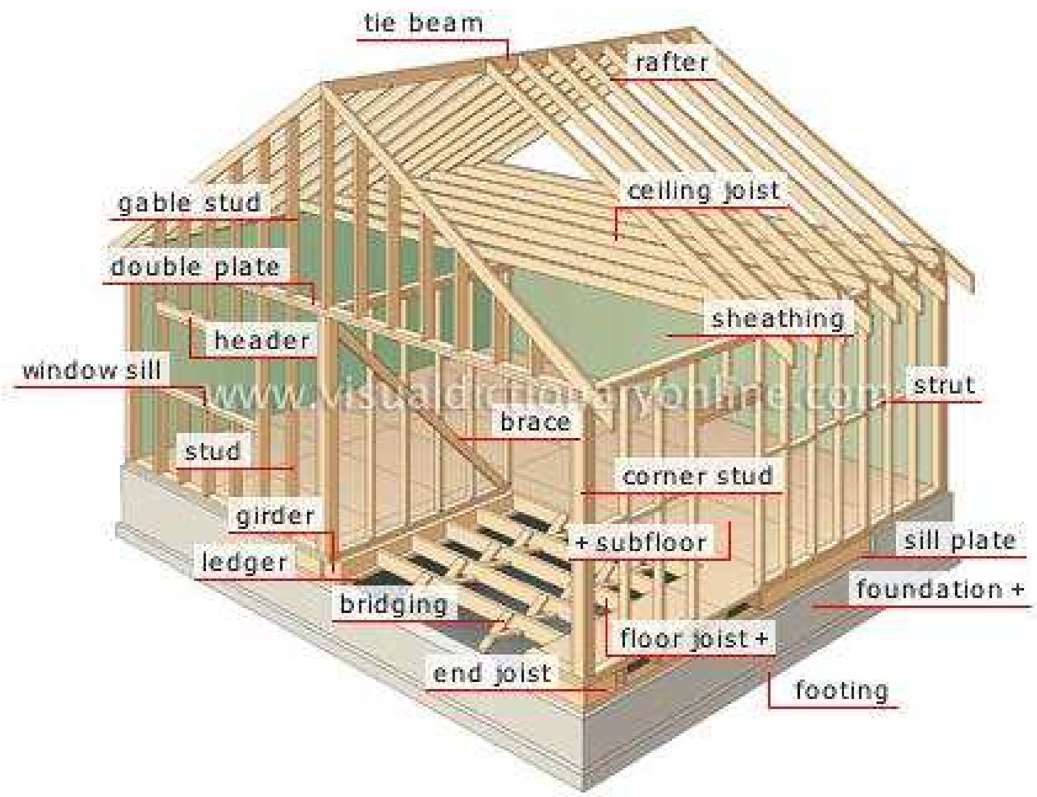
Pressure – reinforced concrete
Tension – steel
Flexure – reinforced concrete, steel



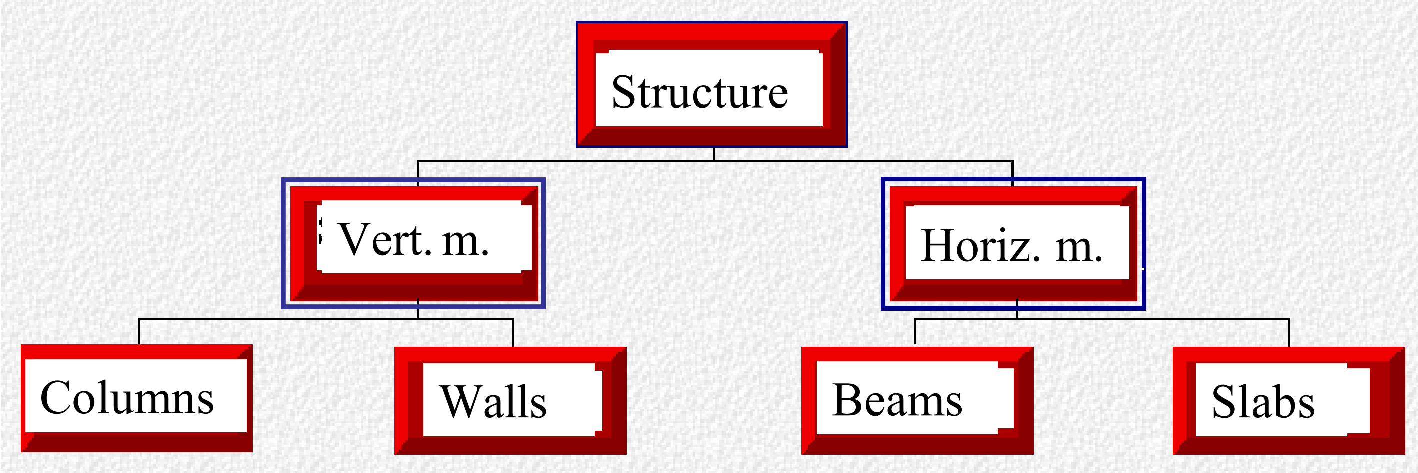
Reinforced concrete column



Structure of a house



Basic structural members



- Structure is a set of different members arranged in such a way that it can resist to all kind of actions without inadequate deformations.

-Vertical members support horizontal members and trasmit all actions to fundaments.

- Horizontal members enable the use of the structure and transmit all actions to vertical members and fundaments.

Reliability of load bearing structures

•**Reliability** - property (probability) of a structure to fulfil required functions during a specified life time under given conditions

- reliability – survival probability $P_s = 1 - P_f$
- functional (performance) requirements
- design working life T
- given conditions

•**Failure probability P_f or the reliability index β** - is the most important measure of structural reliability

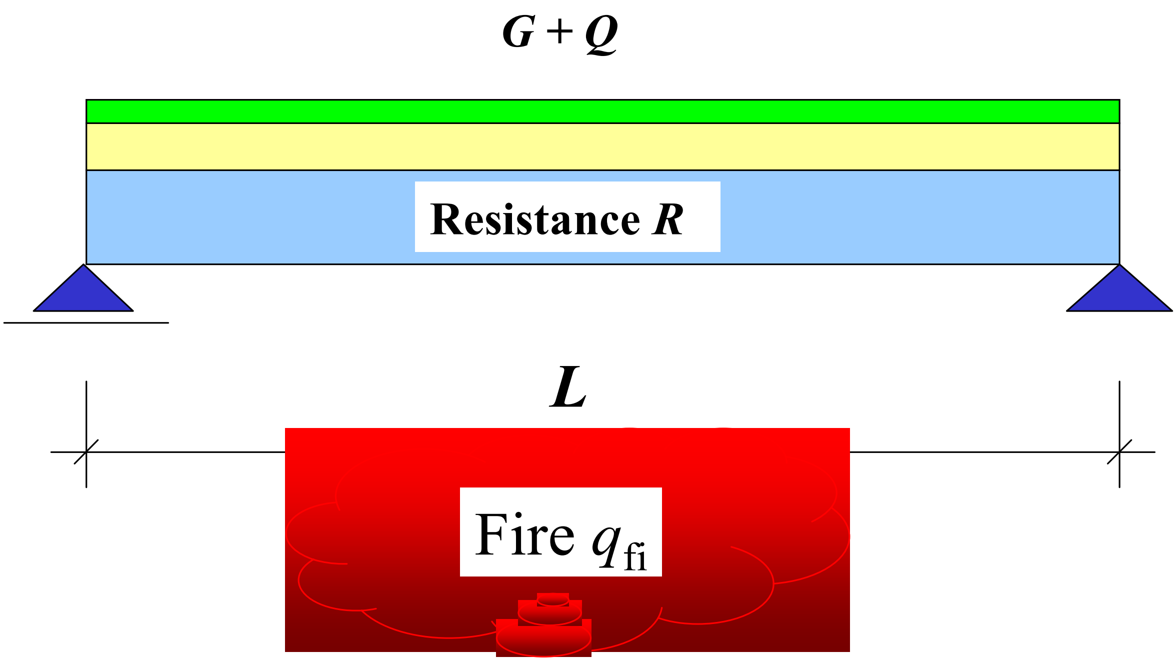
$$P_f < P_{f,t} ; \beta > \beta_t \qquad \beta = -\Phi_N^{-1}(P_f)$$

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	1,28	2,32	3,09	3,72	4,27	4,75	5,20

Basic concepts of current codes

- Design situations
  - Persistent - normal use
  - Transient - execution, repairs
  - Accidental - explosion, impact
  - Seismic - seismic events
- Design working life
  - Replaceable parts 1 to 5 years
  - Temporary structures 25 years
  - Buildings 50 years
  - Bridges, monuments 100 years

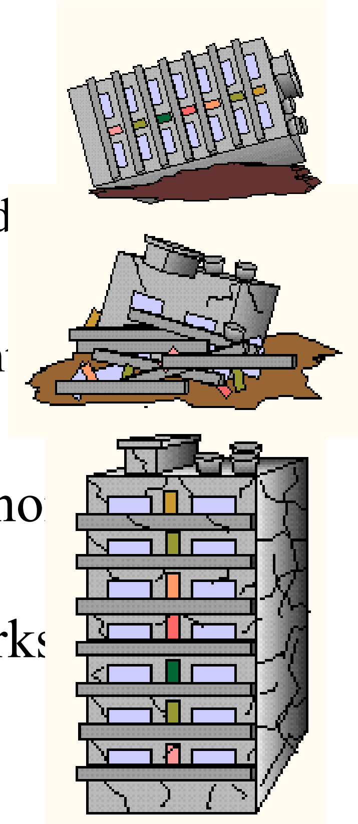
Accidental Design Situation - Fire



$t_d > t_{d,regu}$, $E_d < R_d$, $\Theta_d < \Theta_{cr,d}$ | fire

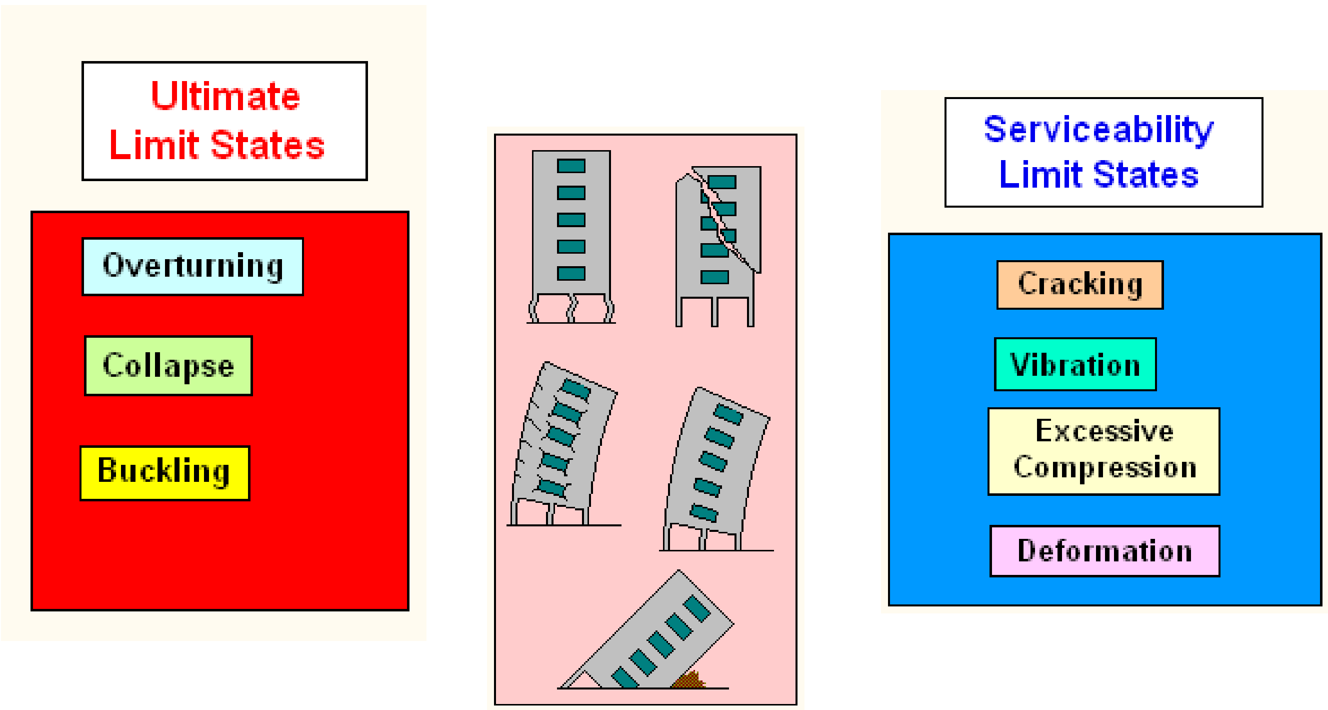
Limit states

- Limit states - states beyond which the structure no longer fulfils the relevant design (performance) criteria



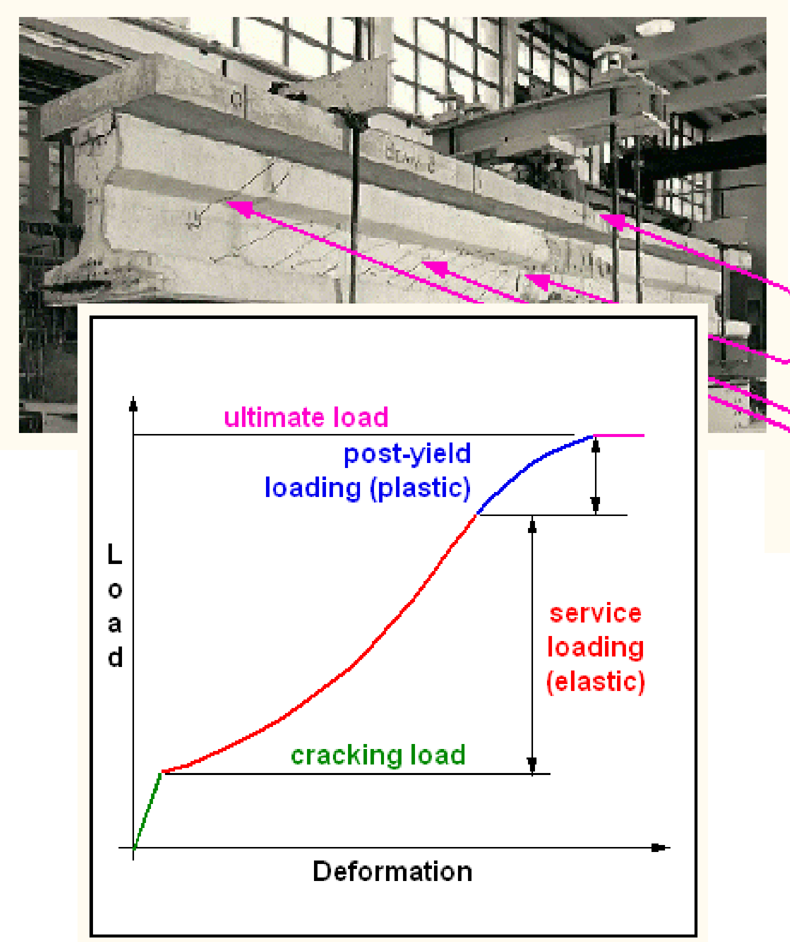
- Ultimate limit states
  - loss of equilibrium of the structure as a rigid bod
  - failure, collapse, loss of stability
  - failure caused by fatigue or other time dependen
- Serviceability limit states
  - the functioning of the structure under no
  - the comfort of people
  - the appearance of the construction works

Ultimate and serviceability limit states

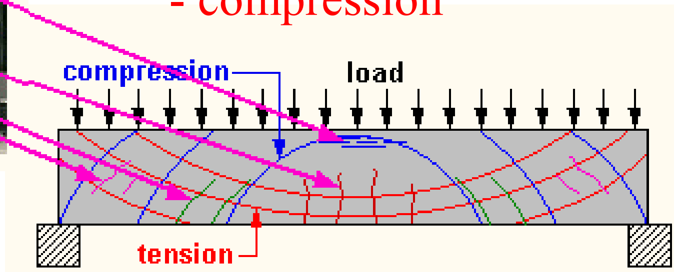


Deformations are generally limited to span/250 vertically and height/500 horizontally.

Behaviour of a reinforced concrete beam



Cracks
- tensile vertical
- tensile inclined
- shear
- compression



The beam may have several possible modes of failure:
- cracking
- deflection
- shear
- bending

Robustness – structural integrity

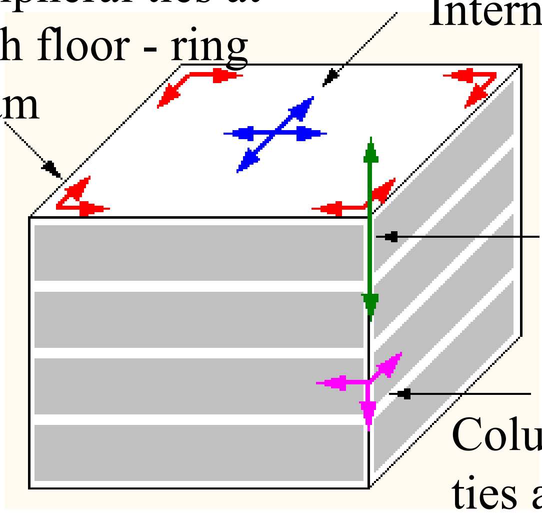
Structures should be designed in such a way that they exhibit robustness to the effect of impact or explosion.

Ronan point 1967 – explosen on the 20th storey

The measures – bonds, ties

Peripheral ties at each floor - ring beam

Internal ties



Continuous vertical ties In columns and walls

Columns and wall ties anchored into structure at each floor

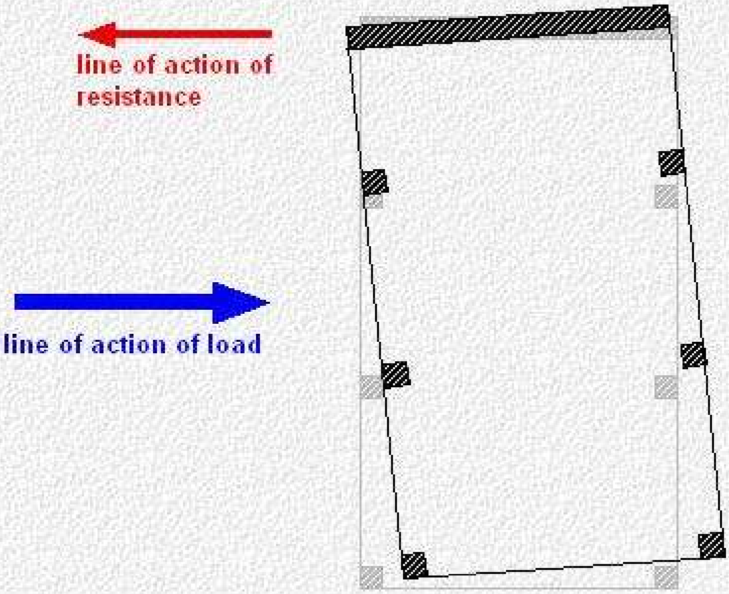
Overall stiffness

There are other factors which can lead to structures which are not robust. Consider this structure, seen from above, with a horizontal force acting on it (wind or earthquake).

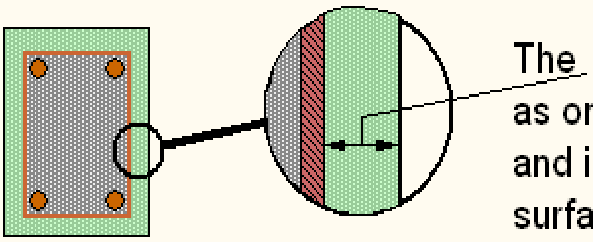
The wall which will resist the horizontal load does not line up with the load.

Consequently the structure will twist.

This is not a robust layout



Durability – concrete cover



The cover to the reinforcement is generally regarded as one of the governing factors controlling durability and is defined as the distance between the outer surface of the reinforcement (including links) and the nearest concrete surface.

Correct cover is required to ensure ....

adequate bond between the concrete and the reinforcement,
fire resistance, and
protection of the reinforcement against corrosion,
to prevent spalling of the concrete.

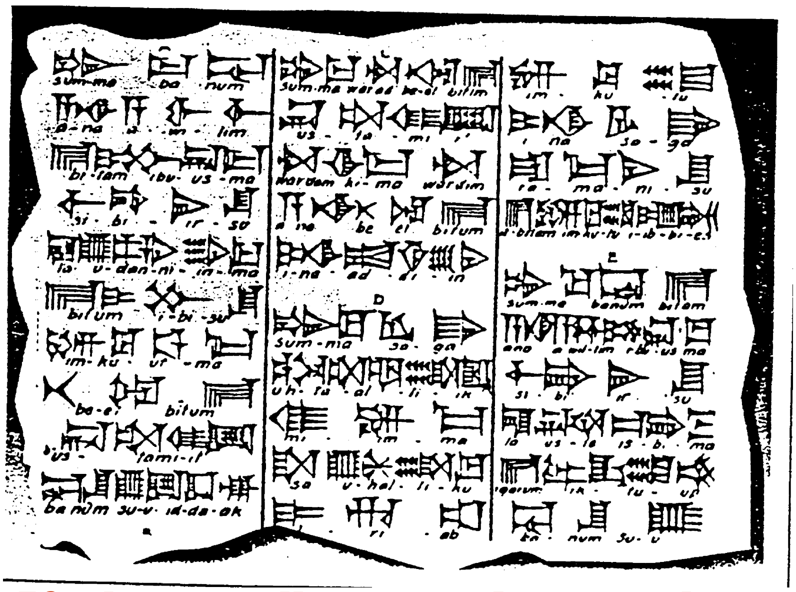
Methods of reliability verification

- Historical and empirical methods
- Permissible stresses
- Safety factor methods
- Partial factor methods
- Probabilistic methods
- Risk assessment

Increasing demands on design procedure

The Oldest Building Law

Hammourabi, Babylon, 2200 BC



If a house collapses and causes the death of the owner - the builder of that house shall be put to death

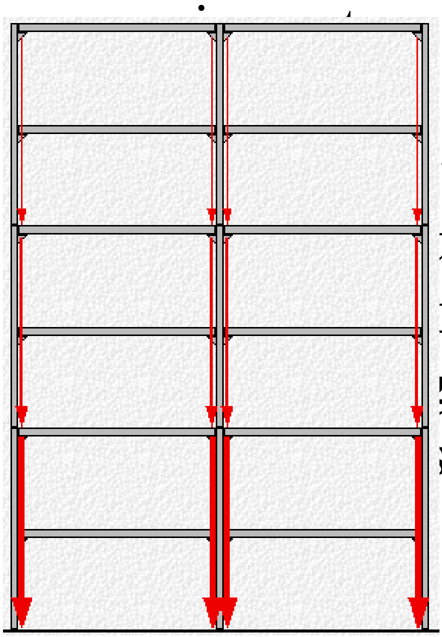
Variables

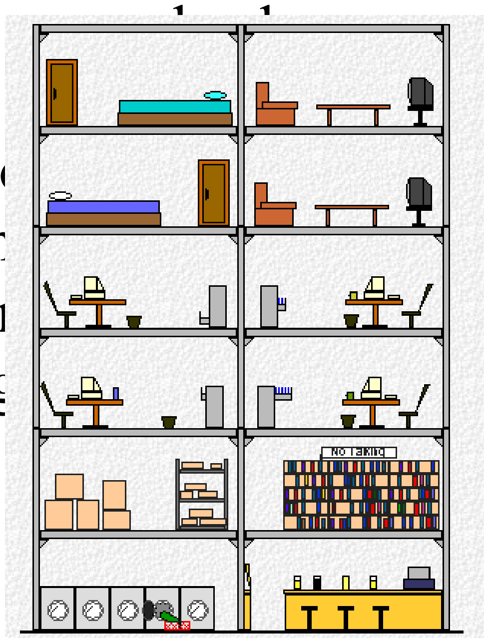
- Basic variables – in general random variables
  - actions *F*
  - properties of materials *f*
  - geometric data *a*
- Cumulative variables – random variables
  - load effect *E*(*F*, *f*, *a*)
  - structural resistance *R* (*F*, *f*, *a*)
- Model uncertainties
  - uncertainty of load effect *E* (*F*, *f*, *a*)
  - uncertainty of resistance *R* (*F*, *f*, *a*)
  - uncertainty of semi resulting variables

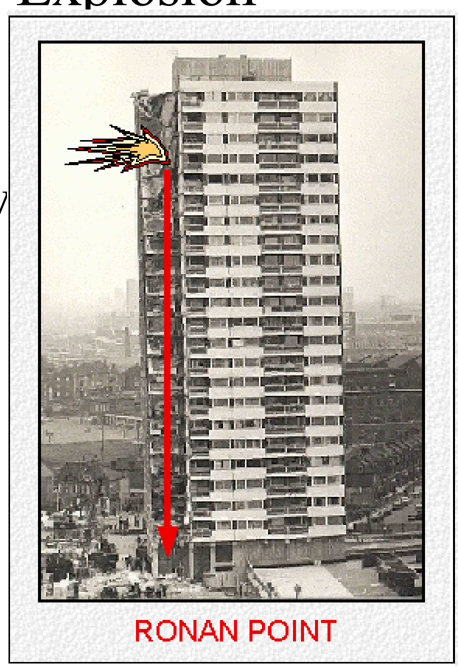
All variables may be time invariant (permanent load, geometric data) or time variant (variable actions, material properties) - then time *t*

Classification of actions *F*

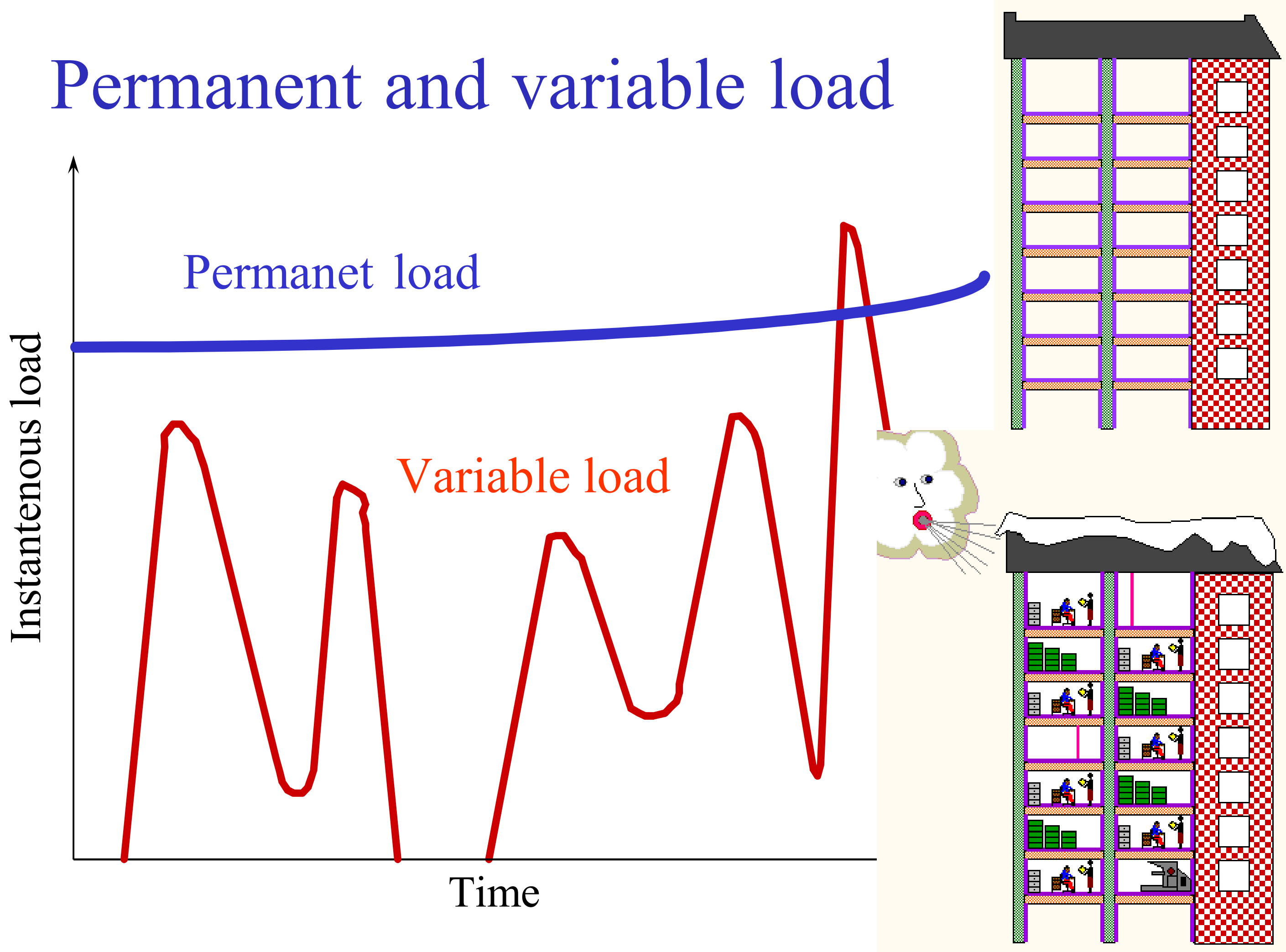
Permanent *G*	Variable *Q*	Accidental *A*
- Self-weight, fixed	- Imposed	- Explosion







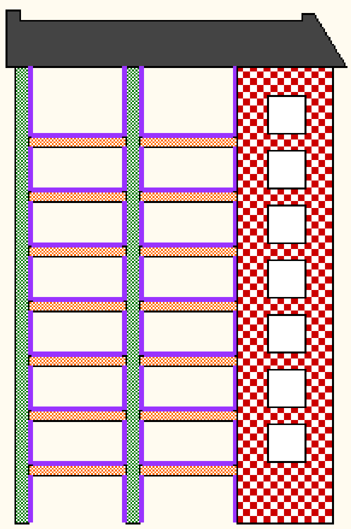
Permanent and variable load



Permanent load

2 Characteristic Permanent Loads

Permanent loads are loads due to the weight of the structure and include the weight of all :-



- Walls and columns
- Floor slabs and beams
- Roofs
- Finishes - plaster - screeds etc
- Cladding

The characteristic permanent load is denoted by G_k, but in situations where the permanent loads are likely to vary during the lifetime of the structure, two characteristic values are used -

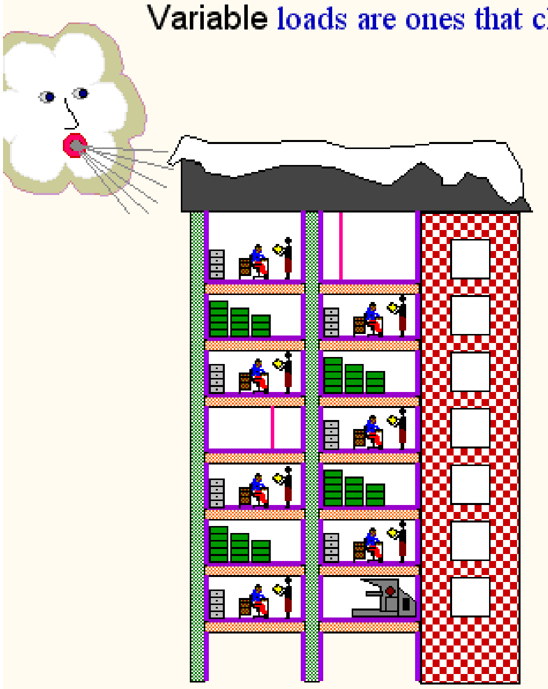
an upper $G_{k,sup}$

and a lower $G_{k,inf}$.

Variable load

3 Characteristic Variable Loads

Variable loads are ones that change in magnitude with respect to time, and include :-

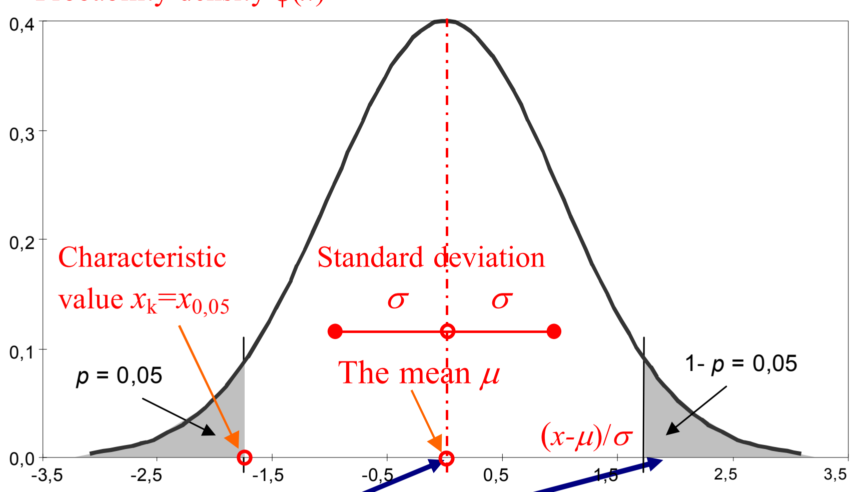


- imposed loads, such as :
  - occupants and furniture
  - stored materials
  - movable partitions
  - movable machinery
- wind loads
- snow loads

The characterisic values of actions

Actions F:

G, Q, P, g, q, p



The characteristic values F_k: G_k, Q_k, P_k, g_k, q_k, p_k

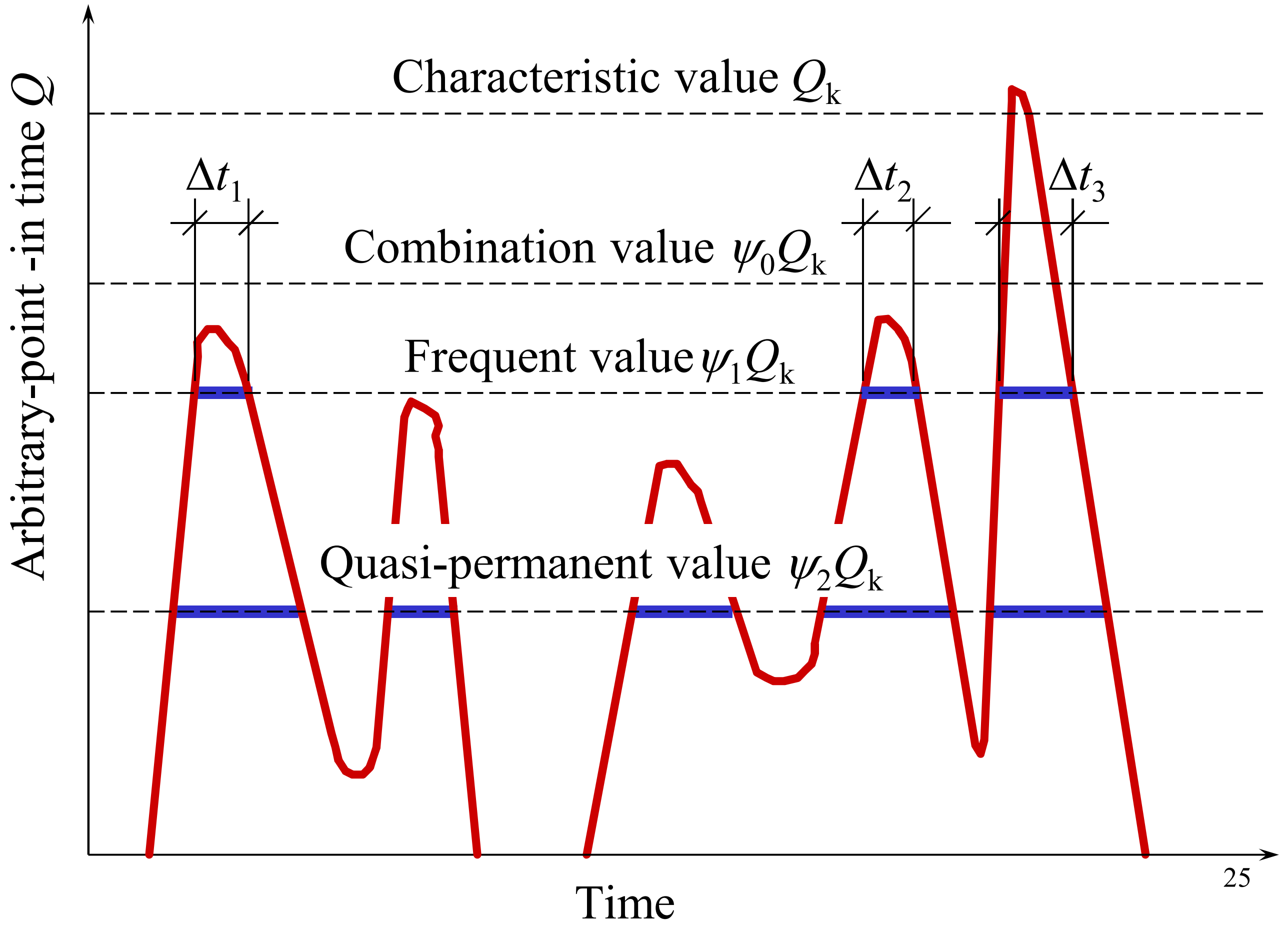
The design values: $F_d = \gamma_F F_k$

The design values of parmanent atcions: $G_d = \gamma_G G_k$

- variable actions: $Q_d = \gamma_Q Q_k$ nebo $Q_d = \gamma_Q \psi_i Q_k = \gamma_Q Q_{rep}$

where $Q_{rep} = \psi_i Q_k$ denotes representative value of Q

Representative Values of Q



Design Values of Actions

The load effect E_d

- exceeded with the probability $\Phi(-0{,}7 \times \beta)$

- Permanent loads $G_d = \gamma_G\, \xi\, Q_k$, reduction factor ξ
- Variable actions $Q_d = \gamma_Q\, \psi_\iota\, Q_k$, factors ψ_ι

-- Combination value $\psi_0 Q_k$

- exceeded by with the increased probability $\Phi(-0{,}7\times 0{,}4 \times \beta)$

-- Frequent value $\psi_1 Q_k$

- exceeded during 0,01 of a reference period

-- Quasi-permanent value $\psi_2 Q_k$

- exceeded during 0,5 of a reference period

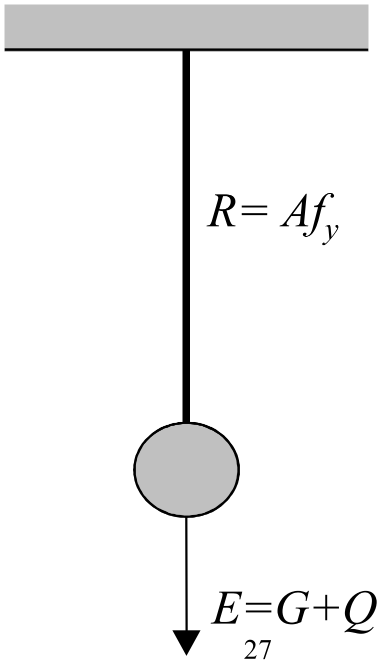
Partial safety factor method

- Actions - design values $F_d = \gamma_F F_k$
- Properties of materials - d. v. $f_d = f_k / \gamma_f$
- Dimensions - design v. $a_d = a_k \pm \Delta a$

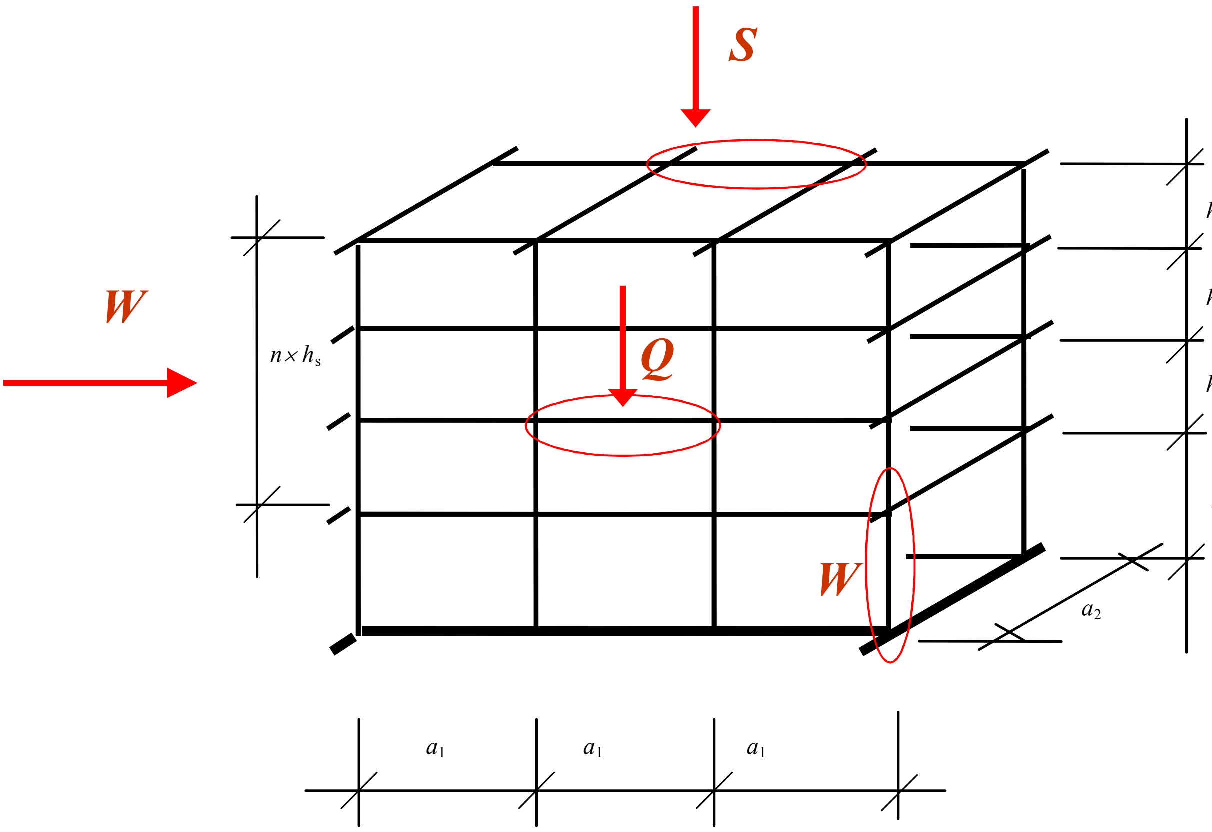
$$E_d(F_d, f_d, a_d) < R_d(F_d, f_d, a_d)$$

- Example

$$E_d = \gamma_G G_k + \gamma_Q Q_k < R_d = A f_{yk} / \gamma_M$$



Leading variable action

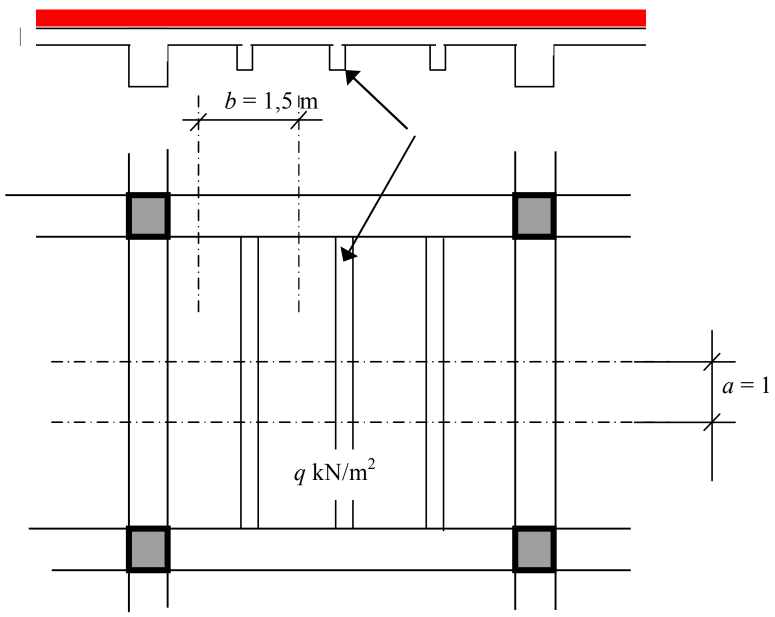


Factors γ_G and γ_Q

EN 1990, 24.04.2002

Limit state	Load effect	γ_G	γ_Q
A-EQU	Unfavourable	1,10	1,50
	Favourable	0,90	0,00
B-STR/GEO	Unfavourable	1,35	1,50
	Favourable	1,00	0,00
C- STR/GEO	Unfavourable	1,00	1,30
	Favourable	1,00	0,00

Assignment 1 - actions



Determine action on the beam for verification of the ultimate limit state. Axial distance of the beams is 1 to 2 m, cross section dimensions 0,45 × 0,20 m (including the slab thickness), slab thickness is 0,1 m. Consider the permanent load due to slab (volume weight is 25 kN/m3) and imposed load q_k = 1,50 kN/m². Partial factor for the permanent and imposed loads are γ_G = 1,35 and γ_Q = 1,5.

Solution of the assignment 1

The axial distance of the beams is assumed: 1,5 m

The characteristic loads:

Permanent from the slab $g = 1,5 \times 0,1 \times 25 = 3,75$ kN/m

from the beam $g_k = (0,45\text{-}0,1) \times 0,2 \times 25 = 1,75$ kN/m

Permanent total $g_k = 5,5$ kN/m

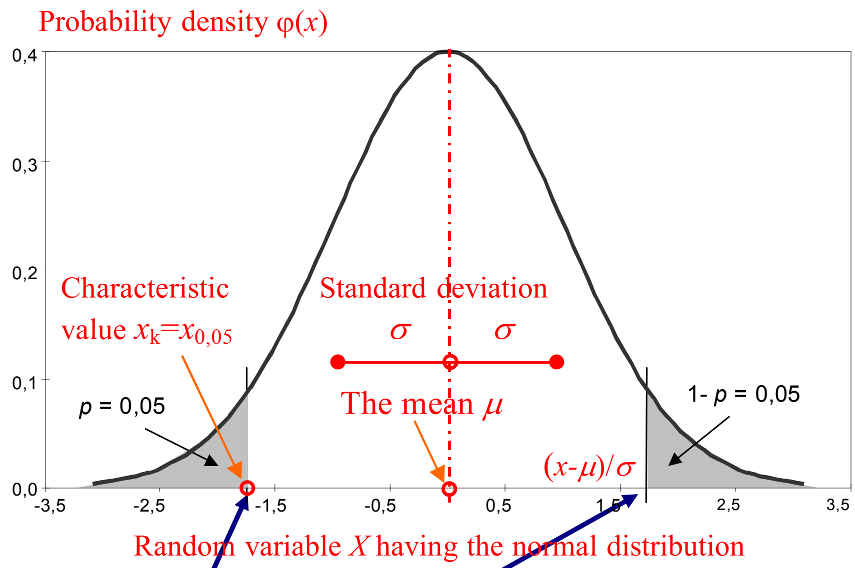
Imposed load $q_k = 1,5 \times 1,5 = 2,25$ kN/m

Design load total:

$$p_d = g_k \times 1,35 + q_k \times 1,5 = 5,5 \times 1,35 + 2,25 \times 1,5 =$$
$$= 7,425 + 3,375 = 10,8 \text{ kN/m}$$

The characterisic values of strength

Actions f:



The characteristic strenght f_k

Partial factors for materials

Material properties are specified in terms of their characteristic values which correspond to a defined fractile (usually the lower 5%) of the assumed distribution of the property considered.

Design values are then obtained by dividing these characteristic values by an appropriate partial safety factor thus,

$$\text{Design value} = \frac{\text{Characteristic value}}{\gamma_m}$$

γ_m = γ_c for concrete
= γ_s for steel

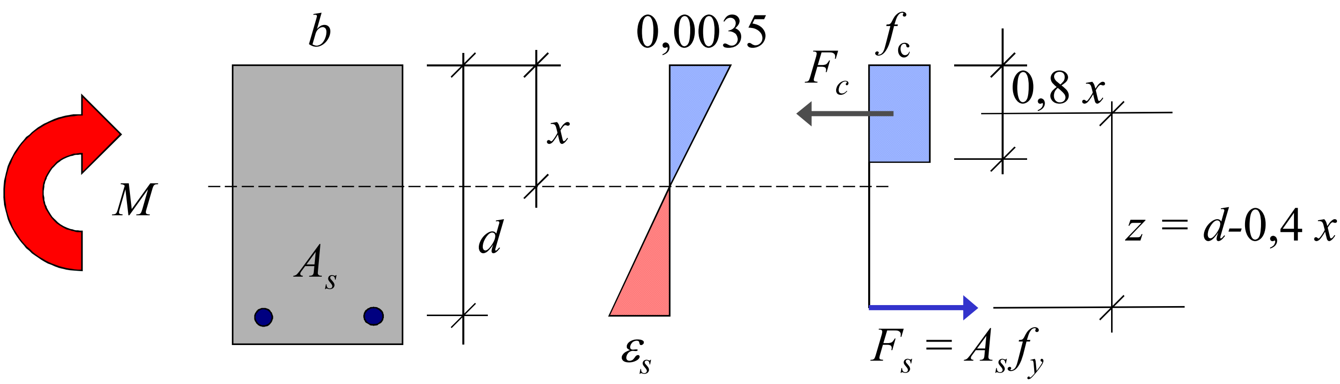
Partial safety factors for materials allow for :-

- Differences between specified strengths and actual strengths.
- Inaccuracies in the assessment of the resistance of sections.
- The importance of the limit state being considered.

The values specified by The Code are :-

Partial safety factors for material properties		
Combination	γ_c	γ_s
Fundamental	1.5	1.15
Accidental (not earthquakes)	1.3	1.0

Reinforced concrete section under bending – basic assumptions



Design values of internal forces:

$F_{cd} = 0{,}8\, x\, b\, f_{cd}$ $\qquad f_{cd} = \alpha f_c / \gamma_m,\ \gamma_m = 1{,}5$

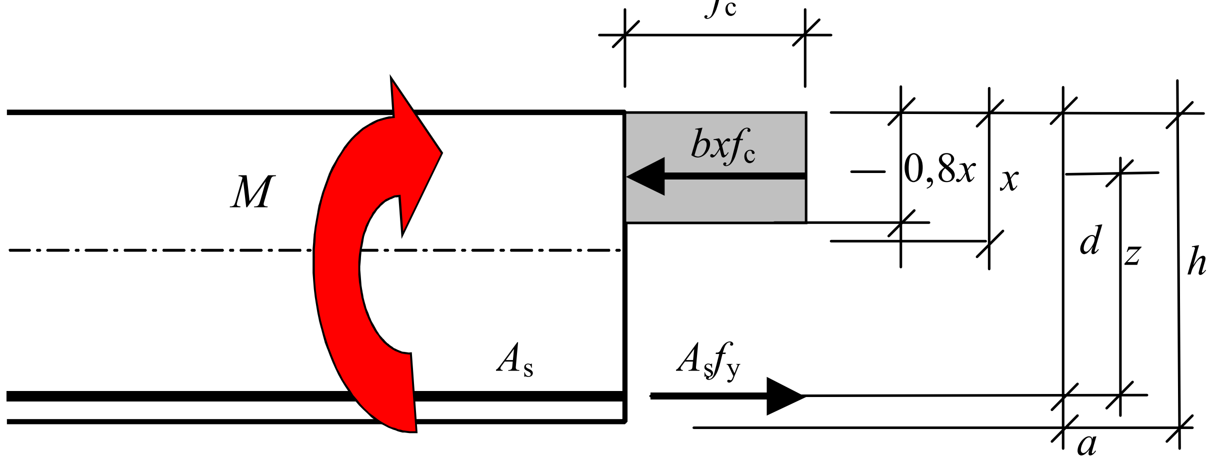
$F_{sd} = A_s f_{yd}$ $\qquad f_{yd} = f_{yk} / \gamma_s,\ \gamma_s = 1{,}15$

Equilibrium conditions:

$$F_{cd} = F_{sd} \Rightarrow x = \frac{A_s f_{yd}}{0{,}8 b f_{cd}},\ z = d - \frac{A_s f_{yd}}{2 b f_{cd}}$$

$$M_d = z F_{sd} \Rightarrow \quad M_d = A_s f_{yd}\left(d - \frac{A_s f_{yd}}{2\, b\, f_{cd}}\right)$$

A reinforced concrete beam or slab



$$A_s = b\frac{f_c}{f_y}\left(h-a-\sqrt{(h-a)^2 - \frac{2M}{f_c b}}\right) \qquad A_s \approx M/(z\,f_y) \qquad z \approx 0{,}9\,d$$

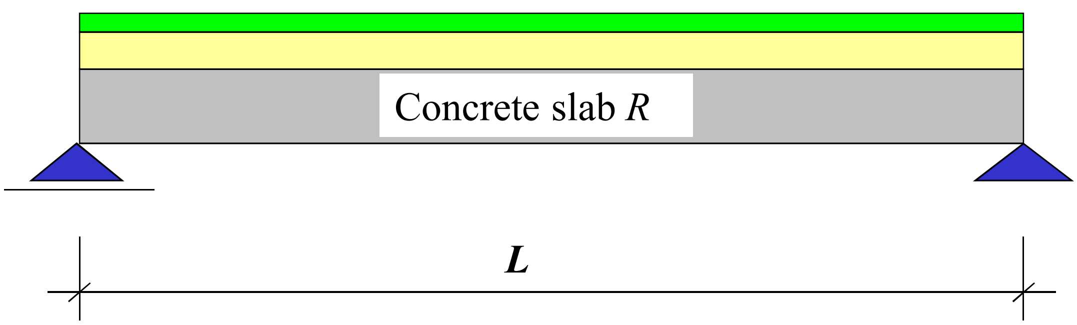
Example:

M_d = 0,1 MNm, d = 0.42 m, steel S500⇒f_{yk}=500 MPA, γ_s=1,15

f_{yd} = 500/1,15 = 435 MPA, z = 0,9d = 0,378 m,

$A_s \approx$ 0,1/0,378/435 = 6,08 10^{-4} m^2 = 608 mm^2

Assignment 2 – concrete slab



(1) Determine the maximum bending moment M_{Ed} of the simply supported reinforced concrete slab of the span L = 3 to 5 m exposed to permanent load due to own weight of the slab having the thickness $h \sim L/20$ m and imposed load 5 kN/m^2. Consider 1 m width of the slab (volume weight is 25 kN/m3), partial factor for the dead load γ_G = 1,35, for imposed load γ_Q = 1,5.

(2) Estimate reinforcement area A_s required for 1 m width of the slab using approximate formula $A_s \sim M_{Ed}/(z\,f_{yd})$, where $z \sim$ 0,9 d and $d = h$ – 0,03 m. Consider steel S 500 (the characteristic strength 500 MPa) and the partial factor for steel γ_s = 1,15.

Solution of the assignment 2

Assuming span L = 3 m:

(1) $M_{ed} = (25 \times 0{,}15 \times 1{,}35 + 5 \times 1{,}5) \times 3^2/8 = 14{,}13$ kNm

(2) $f_{yd} = f_{yk}/\gamma_s = 500 / 1{,}15 = 435$ MPa,

$d = h - 0{,}03 = 0{,}12$

$z \cong 0{,}9\ d = 0{,}9 \times 0{,}12 = 0{,}108$ m

$A_s \cong M_E/(z \times f_{yd}) = 0{,}01413/(0{,}108 \times 435) = 0{,}0003\ m^2$

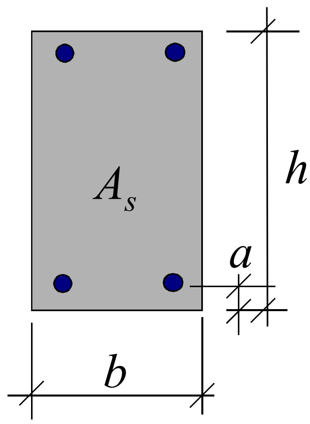
$\rho \cong A_s / (b \times d) = 0{,}0003/(1 \times 0{,}12) = 0{,}0025 = 0{,}25\ \%$

The minimum reinforcement area is about 0,0015 $b\ d$

A short column with centric load

For a very small eccentricity, for fixed column for $h > l/10$

$$N_d = 0{,}8\ A_c f_{cd} + A_s f_{yd}$$
$$= 0{,}8\ b\ h\ f_{cd} + A_s f_{yd}$$



Design of the column dimensions:

$b^2 = h^2 = (N_d - A_s f_{yd}) / (0{,}8\ f_{cd})$

chosen $A_s \sim 0.01\ b\ h$ *rho ´= As/(b h)*

$b^2 = h^2 = N_d / (0{,}01\ f_{yd} + 0{,}8\ f_{cd})$

$b > 0{,}20$ m, commonly 0,30 až 0,50 m

Condition for reinforcement area: 0,003 < *rho*< 0,08

An example

Design load effect

$N_d \approx 1000$ kN = 1 MN

Design strengths

$f_{yd} = 500/1{,}15 = 435$ MPa , $f_{cd} = 20/1{,}5 = 13{,}3$ MPa

Chosen reinforecement area

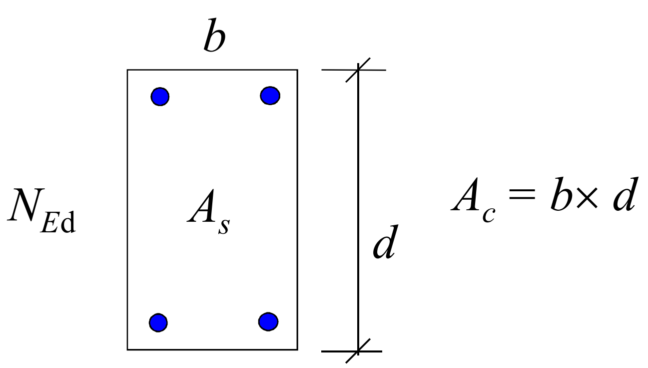
$A_s \sim 0.01\, b\, h < 0{,}08\, b\, h$

$b^2 = h^2 = N_d \,/\, (\, 0{,}01\, f_{yd} + 0{,}8\, f_{cd}) = 1/15 = 0{,}067$

$b = h =$ 0,26 ~ 0,30 m > 0,20 m

Assignment 3 – concrete column

Assess required reinforcement area A_s of a short reinforced concrete column 0,3×0,3 m exposed to the centric force N_{Ed}= 1500 kN, consider the characteristic strength of reinforcement f_{yk} = 500 MPa, the partial factor γ_s = 1,15, the characteristic strength of concrete f_{ck} = 20 MPa the partial factor γ_c = 1,5. The column resistance is $N_{Rd} = 0{,}8\, A_c f_{cd} + A_s f_{yd}$.



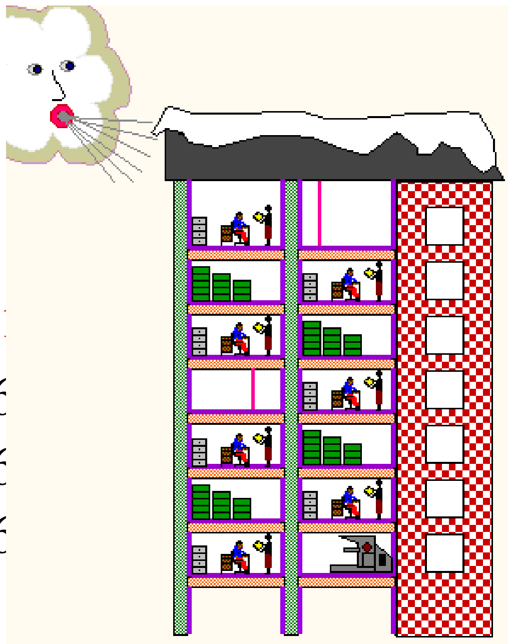
Solution of the assignment 3

- $f_{yd} = f_{yk}/\gamma_s$ = 500 / 1,15 = 435 MPa,
- $f_{cd} = f_{ck}/\gamma_s$ = 20 /1,5 = 13,3 MPa
- $N_{Ed} = N_{Rd} = 0{,}8\, A_c f_{cd} + A_s f_{yd} \rightarrow$
- A_s= (1,5 – 0,8×13.3×0,3×0,3)/435= 0,001247 m^2
- 0,003×0,3×0,3 = 0,00027< 0,001247 <

  < 0,08×0,3×0,3 = 0,0072 m^2

Load Combinations

EN 1990, 24.04.2002



Ultimate limit states:

- Persistent and transient design s

  EQU - equilibrium (6

  STR - structure (6

  GEO - soil or rock (6

  FAT - fatigue (general rules)

- Accidental and seismic des. s. (6.11), (6.12)

Serviceability:

Characteristic - irreversible	(6.14)
Frequent - reversible	(6.15)
Quasi-permanent - long-term effects	(6.16)

Ultimate Limit States

- Persistent and transient situation - fundamental combination

Leading and accompanying variable actions

$$\sum_{j\geq 1}\gamma_{Gj}G_{kj}+\gamma_P P_k+\gamma_{Q1}Q_{k1}+\sum_{i>1}\gamma_{Qi}\psi_{0i}Q_i \quad (6.10) \qquad A$$

- or

$$\sum_{j\geq 1}\gamma_{Gj}G_{kj}+\left\langle\gamma_P P_k+\sum_{i\geq 1}\gamma_{Qi}\psi_{0i}Q_i\right\rangle \quad (6.10a)$$

$$\sum_{j\geq 1}\xi_j\gamma_{Gj}G_{kj}+\gamma_P P_k+\gamma_{Q1}Q_{k1}+\sum_{i>1}\gamma_{Qi}\psi_{0i}Q_i \quad (6.10b)$$

B

- Accidental design situation

$$\sum_{j\geq 1}G_{kj}+P_k+A_d+(\psi_{11}\text{ or }\psi_{21})\,Q_{k1}+\sum_{i>1}\psi_{2i}Q_{ki} \quad (6.11b)$$

- Seismic design situation

$$\sum_{j\geq 1}\gamma_{Gj}G_{kj}+P_k+\gamma_I A_{Ed}+\sum_{i\geq 1}\psi_{2i}Q_{ki} \quad (6.12b)$$

Serviceability Limit States

- The characteristic - irreversible effects

$$\sum_{j\geq 1}G_{kj}+P_k+Q_{k1}+\sum_{i>1}\psi_{0i}Q_i \quad (6.14)$$

- Frequent combination - reversible and local effects

$$\sum_{j\geq 1}G_{kj}+P_k+\psi_{11}Q_{k1}+\sum_{i>1}\psi_{2i}Q_{ki} \quad (6.15)$$

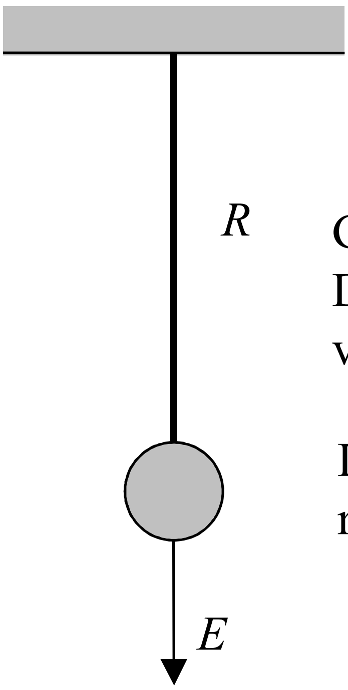
- Quasi-permanent combination - long-term effects

$$\sum_{j\geq 1}G_{kj}+P_k+\sum_{i\geq 1}\psi_{2i}Q_{ki} \quad (6.17)$$

Factors ψ_i

EN 1990, 24.04.2002

Actions	ψ_0	ψ_1	ψ_2
Imposed A, B	0,7	0,5	0,3
Imposed C, D	0,7	0,7	0,6
Imposed E	1,0	0,9	0,8
Snow	0,5-0,7	0,2-0,5	0,0-0,2
Wind	0,6	0,2	0,0
Temperature	0,6	0,5	0,0



A steel rod

	Load effect	Resistance
General	$E = G + Q$	$R = A\,f_y$
Design values	$E_d = \gamma_G G_k + \gamma_Q Q_k$	$R_d = A\,f_{yk}/\gamma_M = A\,f_{yd}$

Design of rod area A

$\mathbf{E_d < R_d}$ → $\mathbf{A > E_d / f_{yd}}$, or

$\gamma_G G_k + \gamma_Q Q_k < A\,f_{yk}/\gamma_M$ →

$A > (\gamma_G G_k + \gamma_Q Q_k) / (f_{yk}/\gamma_M)$

An example: $G_k = 0{,}6$ MN, $Q_k = 0{,}4$ MN, $\gamma_G = 1{,}35$, $\gamma_Q = 1{,}5$

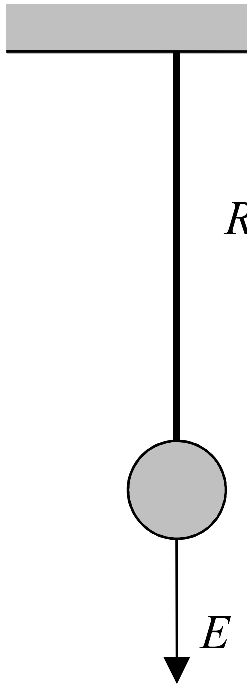
$E_d = 1{,}35.0{,}6 + 1{,}5.0{,}4 = 1{,}41$ MN

$f_{yk} = 235$ MPa, $\gamma_M = 1{,}10$, $f_{yd} = f_{yk}/\gamma_M = 214$ MPa

$\mathbf{A > E_d / f_{yd} = 1{,}41/214 = 0{,}00659\ m^2 = 65{,}9\ cm^2}$

Assignment 5 – A steel rod

Specify section area A of a steel rod



	Load effect	Resistance
General	$E = G + Q$	$R = A\,f_y$
Design values	A: $E_d = \gamma_G G_k + \gamma_Q Q_k$	$R_d = A\,f_{yk} / \gamma_M = A\,f_{yd}$
	B: $E_d > \xi\,\gamma_G G_k + \gamma_Q Q_k$	
	$> \gamma_G G_k + \psi_0 \gamma_Q Q_k$	

Design of the area A $\quad \mathbf{E_d < R_d} \;\longrightarrow\; \mathbf{A > E_d / f_{yd}}$,

Concider : $\gamma_G = 1{,}35$, $\gamma_Q = 1{,}5$, $\xi = 0{,}85$, $\psi_0 = 0{,}7$, $\gamma_M = 1{,}10$

$f_{yk} = 235$ MPa, thus $f_{yd} = f_{yk} / \gamma_M = 214$ MPa

Choose your own values: $G_k \sim 0{,}6$ MN, $Q_k \sim 0{,}4$ MN,

A: $E_d = 1{,}35 \times 0{,}6 + 1{,}5 \times 0{,}4 = 1{,}41$ MN

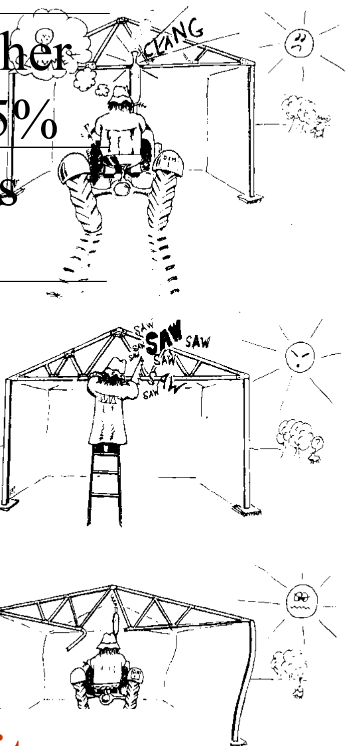
B: $E_d = 1{,}35.0{,}6 + 0{,}7 \times 1{,}5 \times 0{,}4 = 1{,}23$ MN

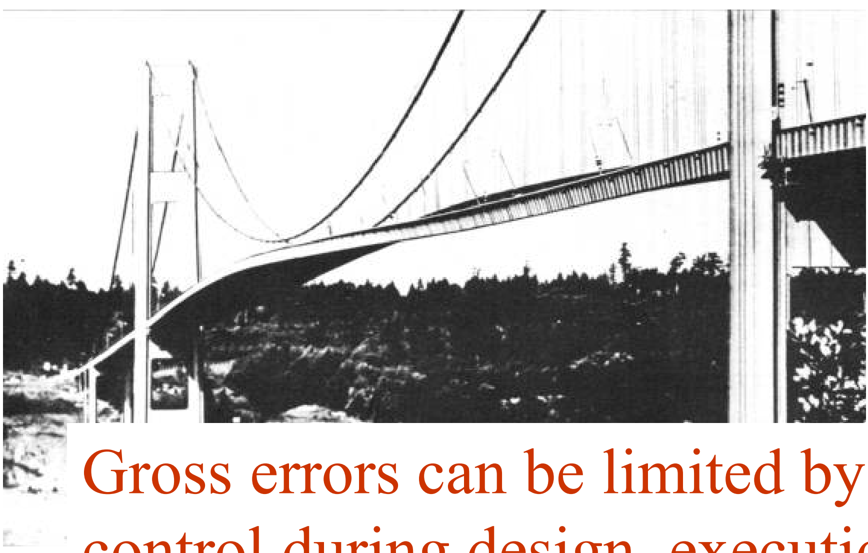
A: $A > 1{,}41/214 = 0{,}00659\ \text{m}^2$

B: $A > 1{,}23/214 = 0{,}00574\ \text{cm}^2\ (= 0{,}87 \times 0{,}00659)$

Origin and causes of structural failure

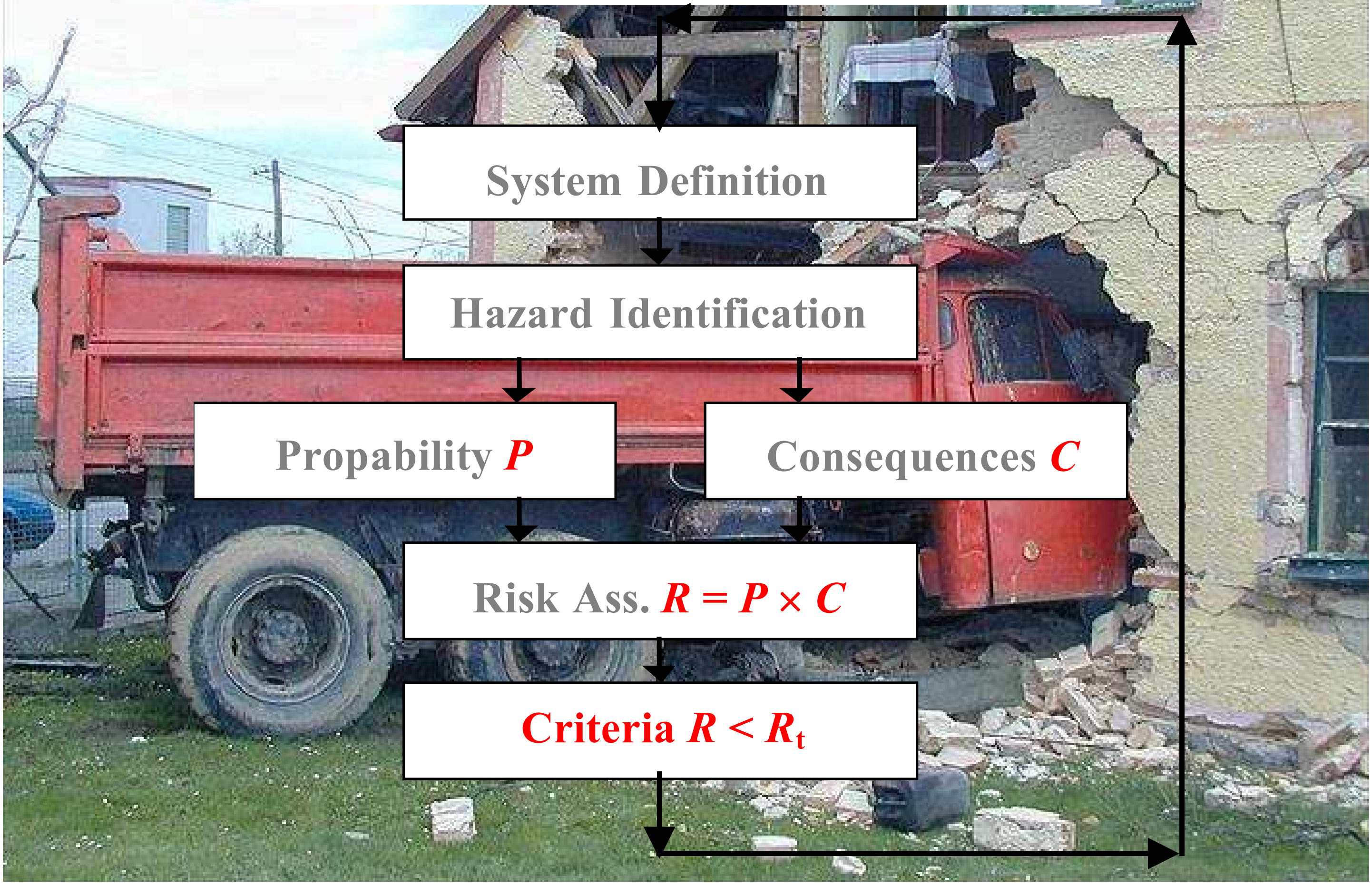
Origin	Design 20%	Execution 50%	Use 15%	Other 15%
Causes	Gross errors 80%		Actions 20%	





Gross errors can be limited by quality control during design, execution and use.

Risk Assessment



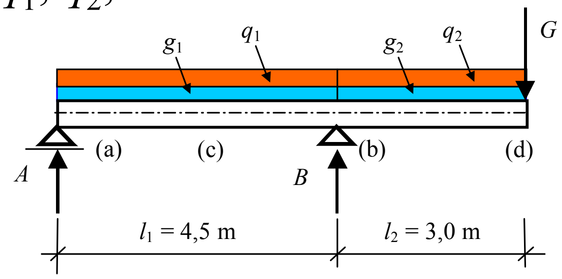
Summary - the most important points

- Historical methods of reliability verification
- Classification of basic variables
- Uncertainties and possibility of their description
- Definition of reliability – reliability measures
- Reliability differentiation in international documents
- Concepts of design situations and limit states
- Structural integrity - robustness
- Principles of partial factor method
- Combination of actions and reliability elements
- General procedure of risk assessment
- Origin and causes of structural failure

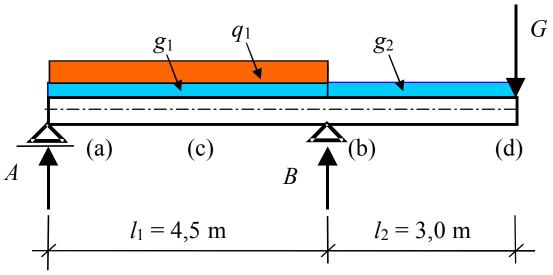
Cantilever beam

Actions g_1, g_2, q_1, q_2, G

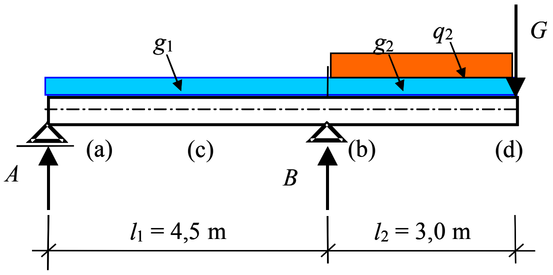
The maximum bending moment at (b) and reaction B



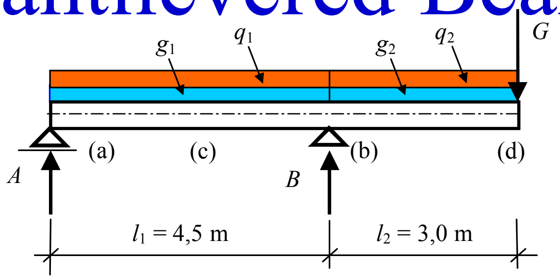
The maximum moment v (c)



Static equilibrium (the minimmu reaction A)



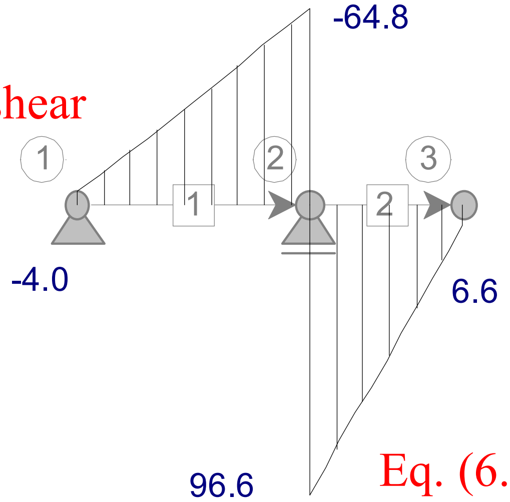
Cantilevered Beam



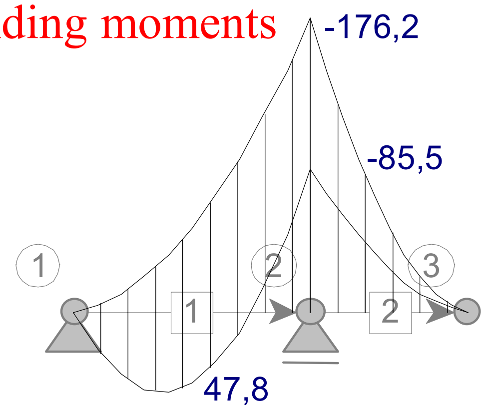
Load case	Limit state	Action				
		g_1	g_2	q_1	q_2	G
1	Equilibrium, eq. (6.7)	0,90	1,10	-	1,50	1,10
2	Ultimate, eq. (6.10) (c)	1,35	1,00	1,50	-	1,00
3	Ultimate, eq. (6.10) (b)	1,00	1,35	-	1,50	1,35
4	Ultimate, eq. (6.10)	1,35	1,35	1,50	1,50	1,35
5	Ultimate, eq. (6.10a) (c)	1,35	1,00	1,50×0,7	-	1,00
6	Ultimate, eq. (6.10b) (c)	0,85×1,35	1,00	1,50	-	1,00
7	Ultimate, eq. (6.10a) (b)	1,00	1,35	-	1,50×0,7	1,35
8	Ultimate, eq. (6.10b) (b)	1,00	0,85×1,35	-	1,50	0,85×1,35
9	Serviceability, eq. (6.14)	1,00	1,00	1,00	-	1,00
10	Serviceability, eq. (6.14)	1,00	1,00	-	1,00	1,00
11	Serviceability, eq. (6.15)	1,00	1,00	1,00×0,5	-	1,00
12	Serviceability, eq. (6.15)	1,00	1,00	-	1,00×0,5	1,00
13	Serviceability, eq. (6.16)	1,00	1,00	1,00×0,3	-	1,00
14	Serviceability, eq. (6.16)	1,00	1,00	-	1,00×0,3	1,00

Load Effects

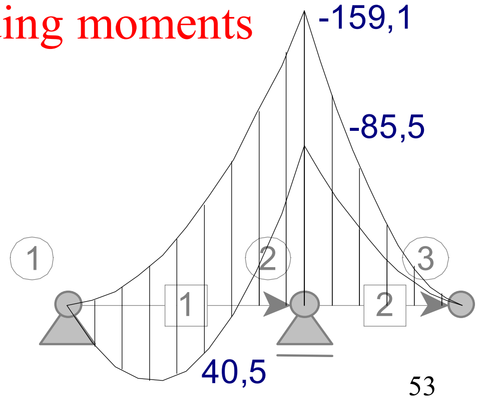
Eq(6.7) - shear



Eq. (6.10)
bending moments



Eq. (6.10a) and (6.10b)
bending moments

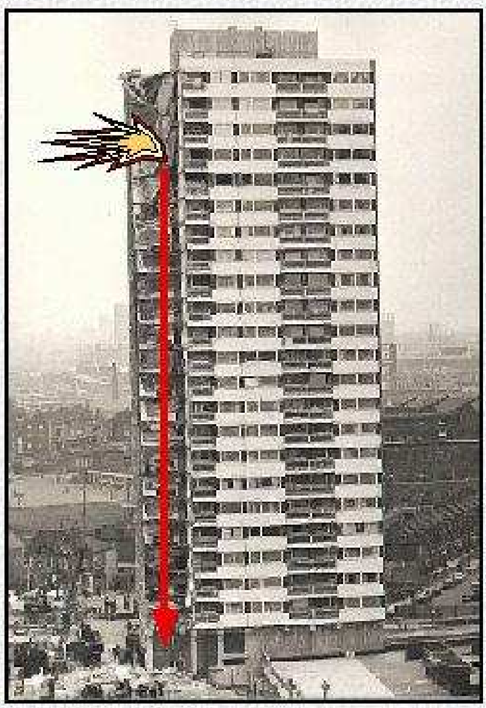


Robustness

Early one morning in 1967 a large part of this block of flats in North London collapsed, after an explosion on the 20th floor.

The resulting enquiry led to major developments in the way we think about design.

It made designers aware of ROBUSTNESS.



RONAN POINT

Disintegration due to explosion

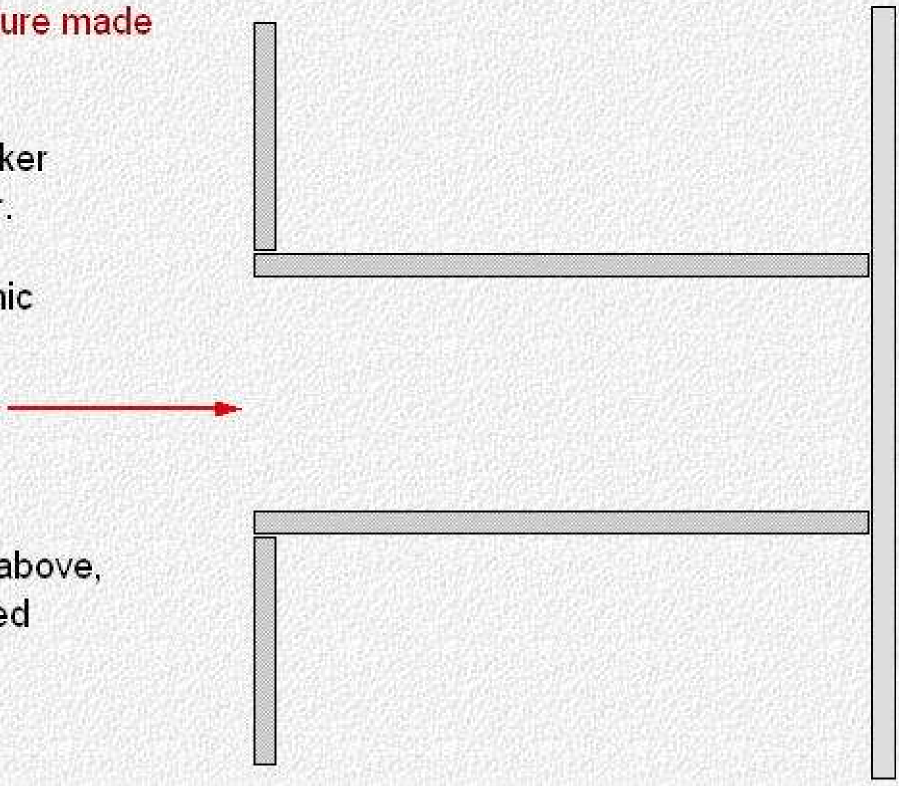
Ronan Point is a large panel structure made from precast wall and floor units.

Very early one morning a gas cooker exploded in a flat on the 19th floor.

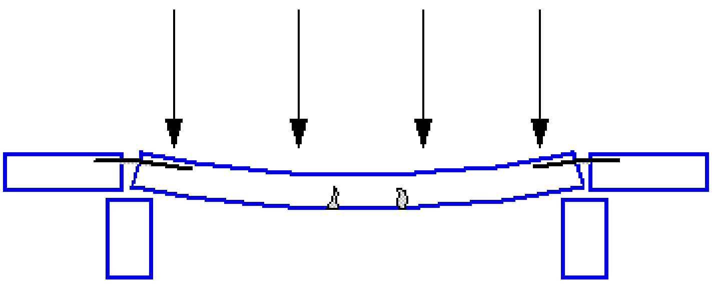
The result proved to be catastrophic

The explosion caused the kitchen wall to disintegrate.

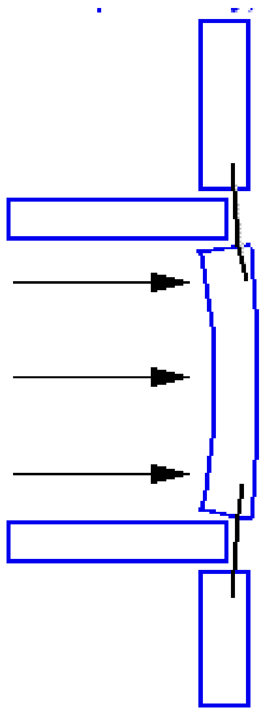
This led to the collapse of the flat above, since its support had been removed



Ties to secure robustness

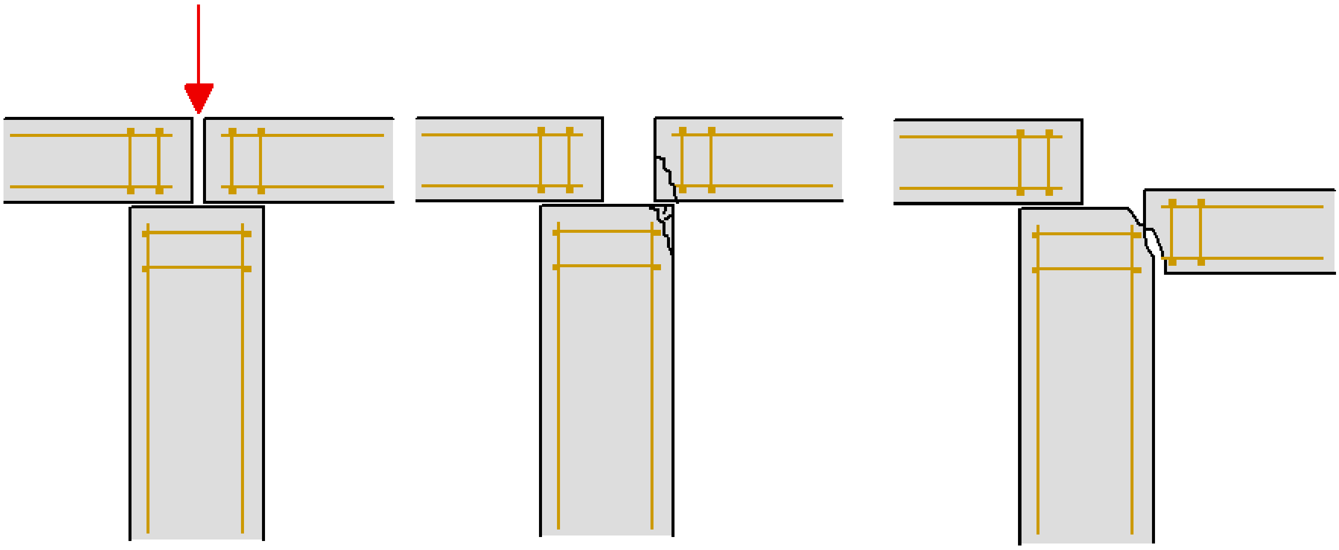


Horizontal tie



V

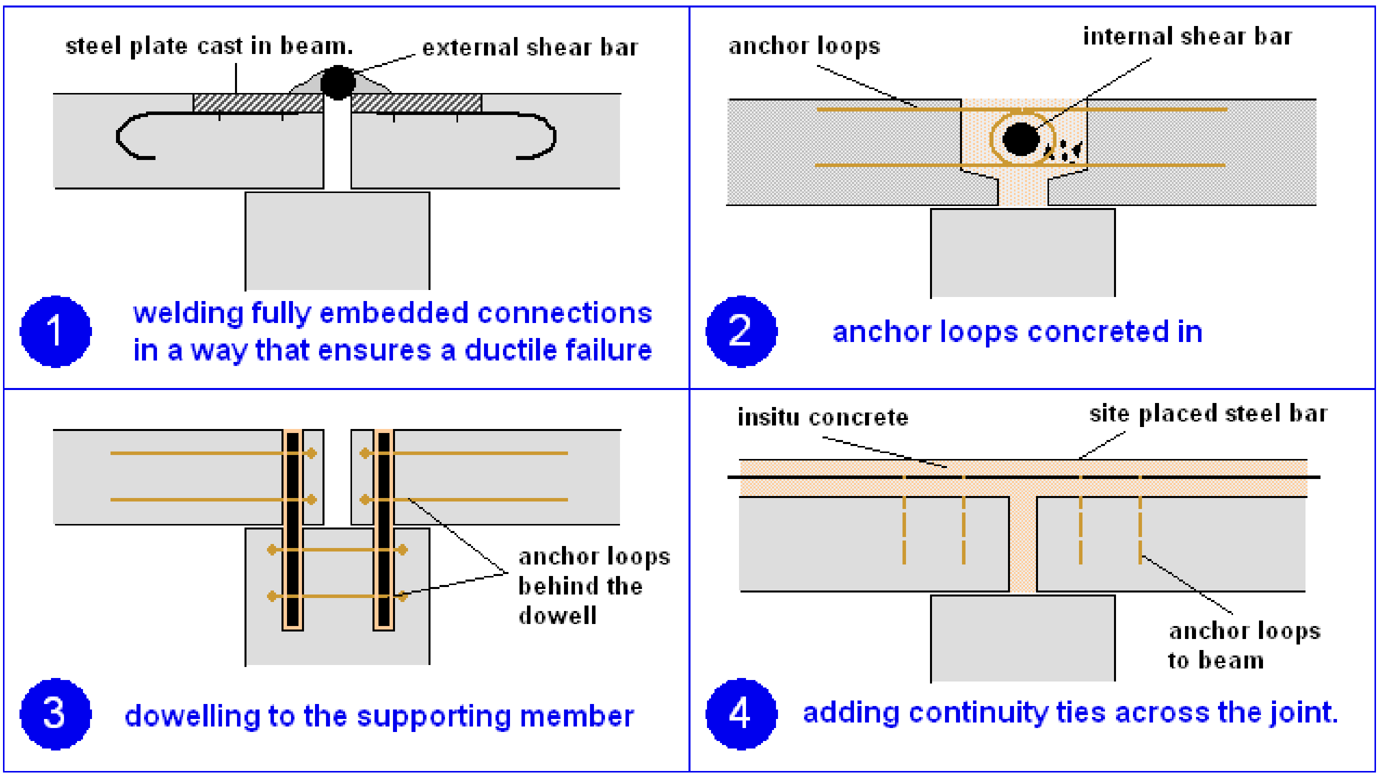
Partial collapse of untied components



Untied components, spalling of cover zone, partial collapse

Structural continuity

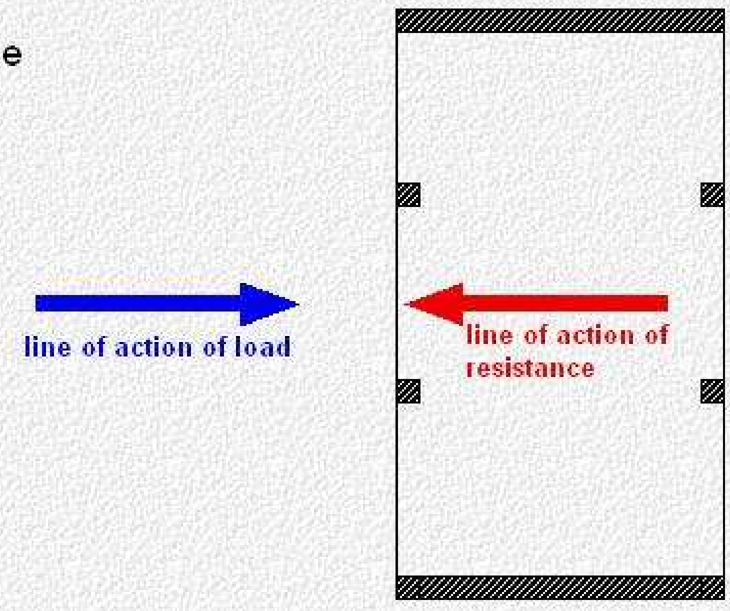
What is missing in this situation is some form of structural continuity. There are a number of ways of providing this by ....



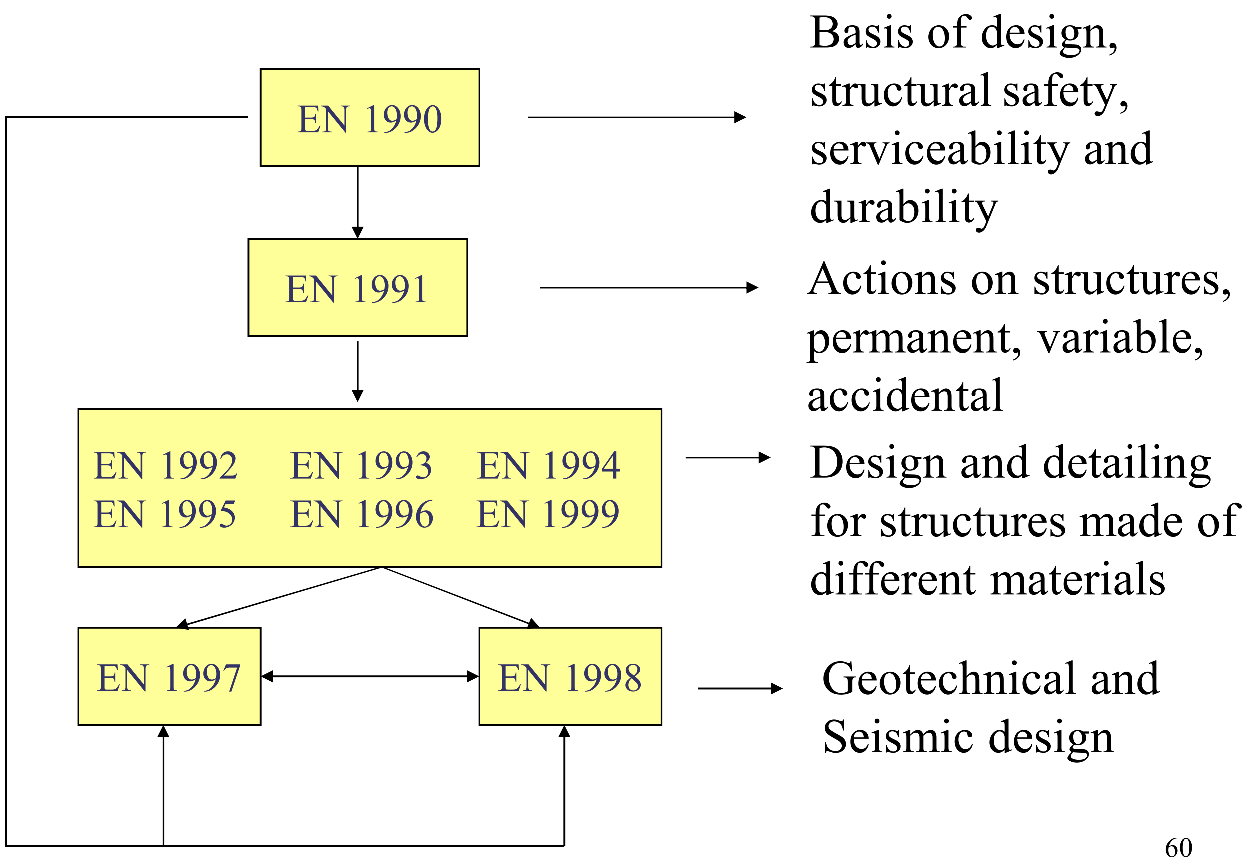
Two dimensional robustness

The members resisting lateral loads should generally be arranged so that the line of action of resistance is roughly in the same position as the line of action of the load

In this case the addition of another wall opposite the original would cause the line of resistance to shift and become more effective against the action of load.



Links between the Eurocodes

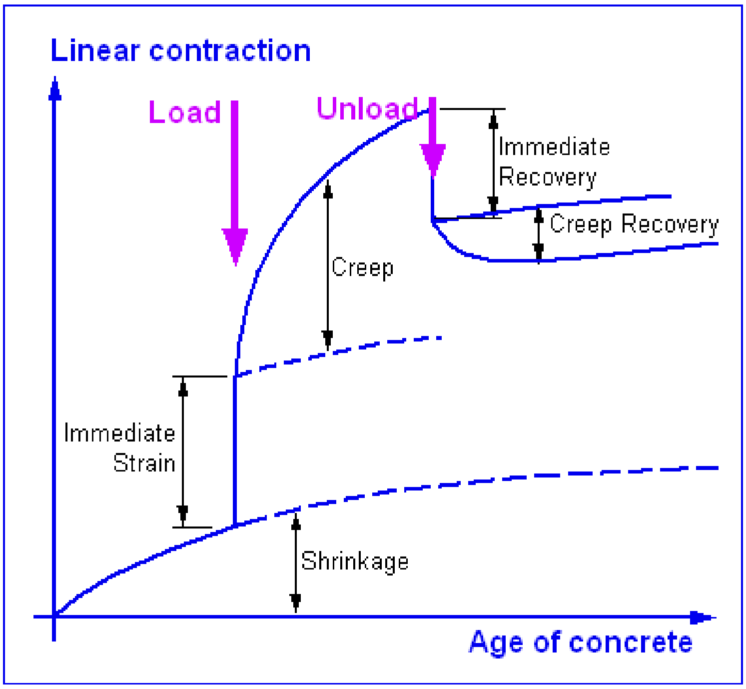


Concrete creep

Creep is defined as the long term deformation under a sustained load. Water within the hardened cement paste is forced to move as a result of the applied load.

This movement of moisture is the primary cause of creep deformation. Some movement also occurs due to the propagation of microcracks.

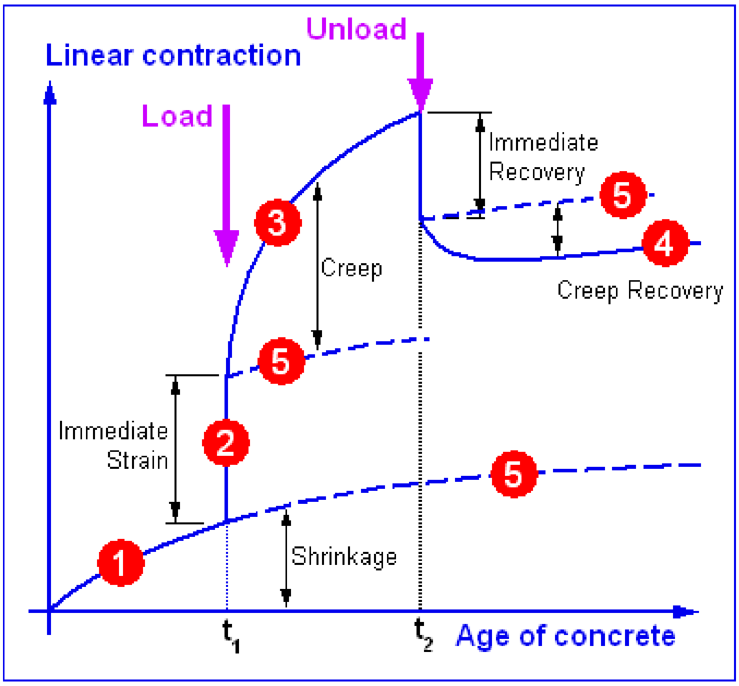
If we look again at the figure shown earlier we can see that the movement due to creep can be greater than the elastic strains on loading.



Creep can continue over a long period of time (more than 30 years in some cases) after the application of the load.

Deformation of concrete

A general view of the nature of deformation is now given.



1. The first part of the curve represents the initial shrinkage due to drying.
2. If a load is now applied there is an instantaneous deformation.
3. If the load is held constant for a period of time there will be further deformation resulting from creep.
4. If the load is removed at a time t_2 there will be an immediate recovery followed by further recovery due to creep. The magnitude of the recovery is always less than the deformation.
5. The dotted lines on the curve represent the shrinkage due to drying if no load was applied.

Concrete cover and quality

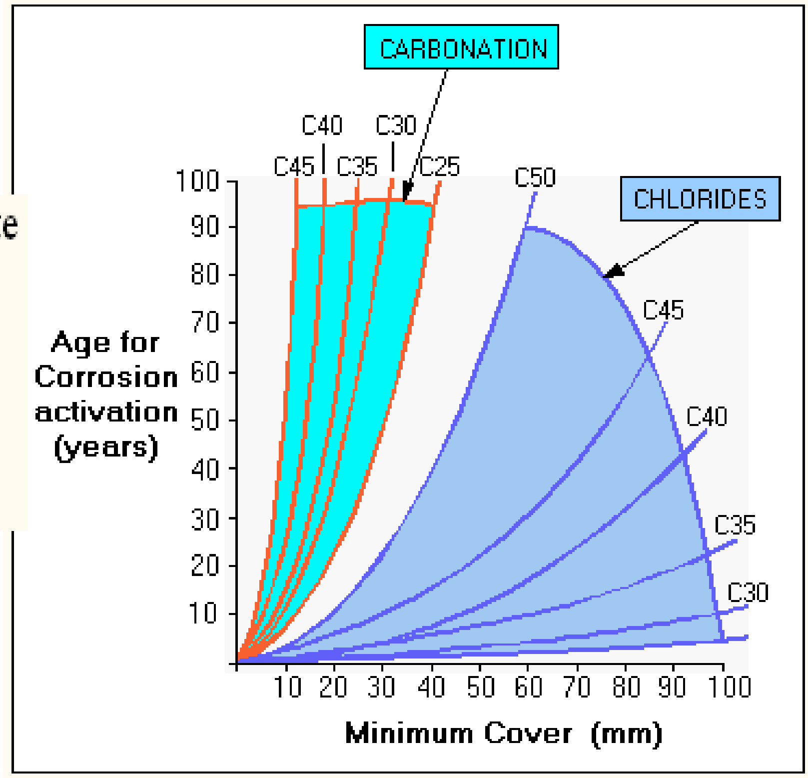
Cover to reinforcement and concrete quality for durability					
Exposure class	Nominal cover (mm)				
1	20	20	20	20	20
2a	—	35	35	30	30
2b	—	—	35	30	30
3	—	—	40	35	35
4a	—	—	40	35	35
4b	—	—	40	35	35
5a	—	—	35	30	30
5b	—	—	—	30	30
5c	—	—	—	—	45
Maximum free water/ cement ratio	0.65	0.60	0.55	0.50	0.45
Minimum cement content (kg/m^3)	260	280	300	300	300
Lowest concrete strength class	C25/30	C30/37	C35/45	C40/50	C45/55
Protective barrier to prevent direct contact with aggressive media should be provided : 280 kg/m for exposure classes 2b and 5a.					

The durability chart

This durability chart[1] attempts to relate

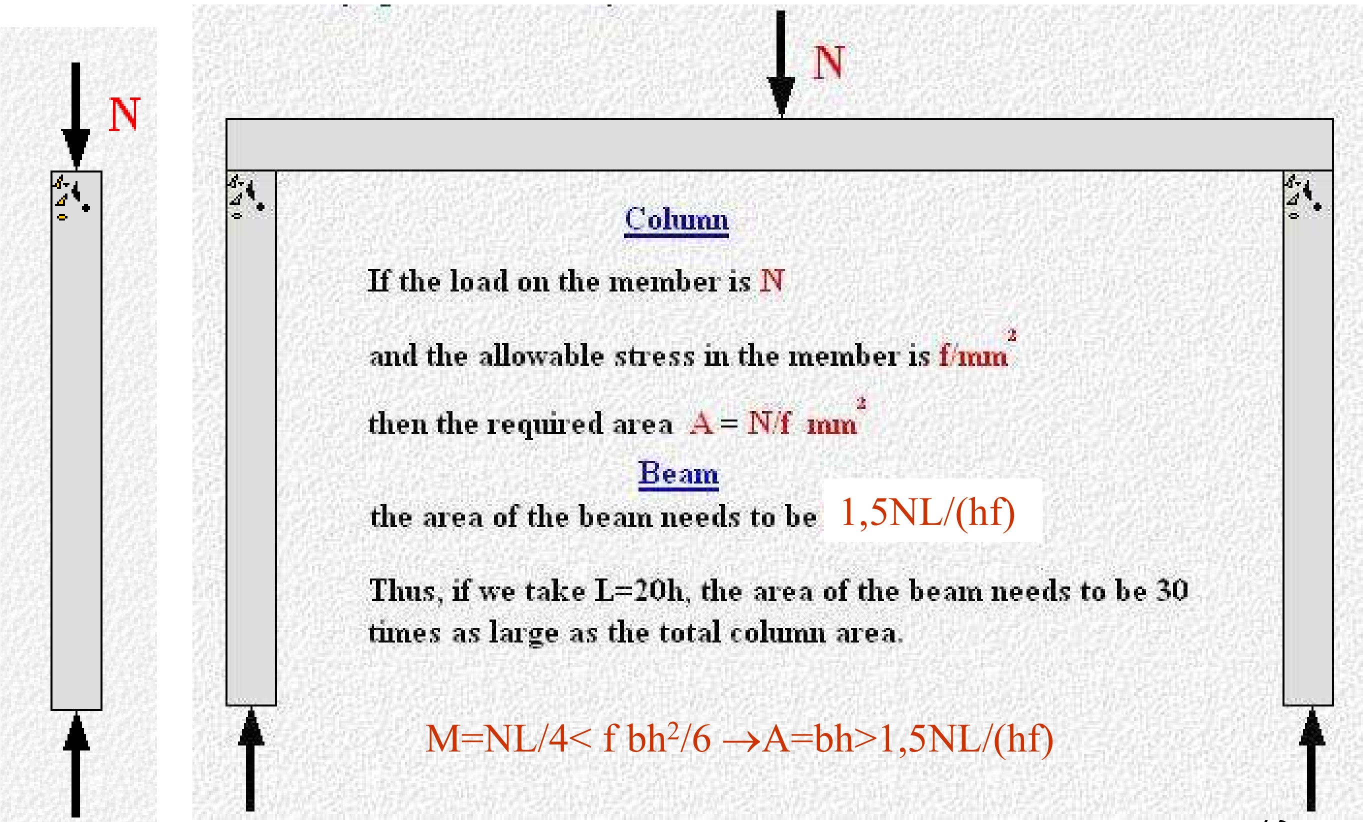
age for corrosion activity to start,
minimum concrete cover, and
concrete grade,

to carbonation and chloride attack.

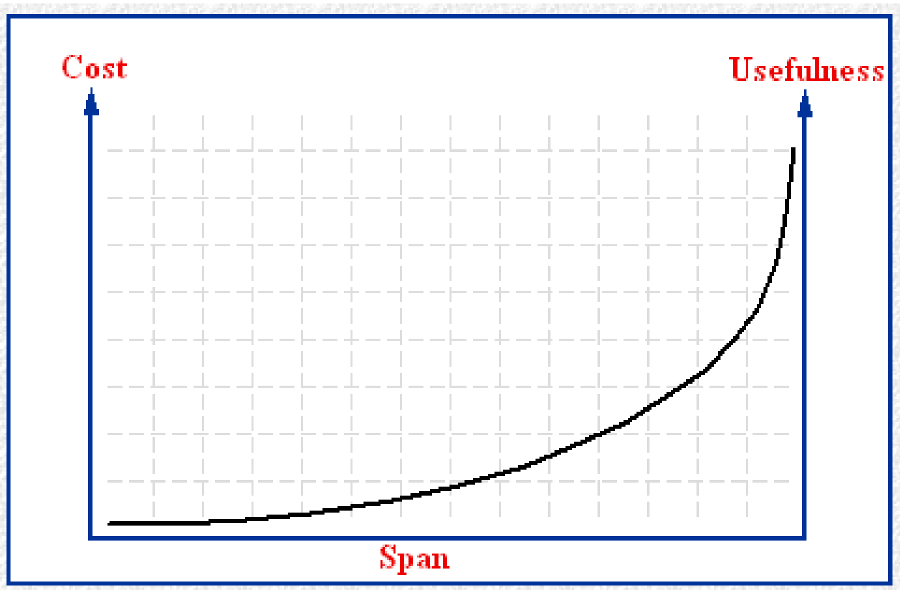


1. Dr R D Browne - Taywood Engineering Ltd

Enclosing a space



Span, cost utility

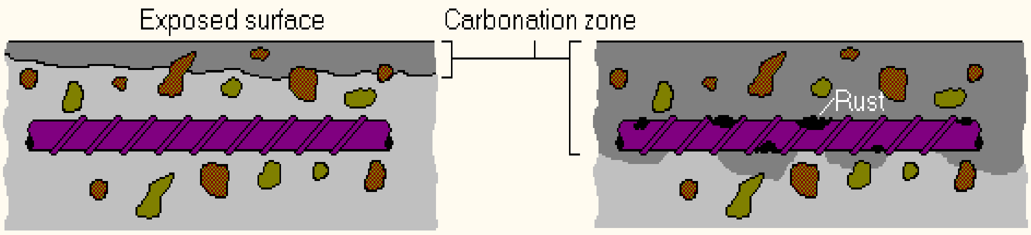


Clearly, compromises are necessary to balance utility and economy.

Durability - Reinforcement corrosion

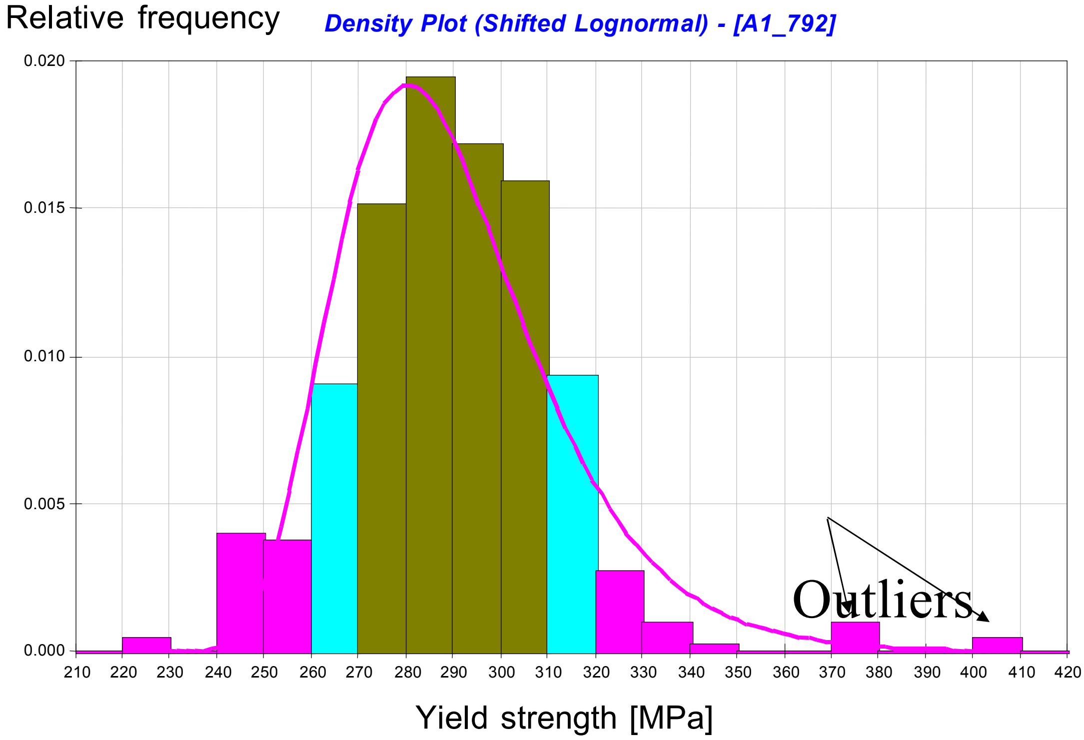
Steel embedded in concrete is surrounded by a highly alkaline pore solution with a pH value in excess of 12.5. Such an alkaline environment causes the steel to be passivated, that is, the formation of a highly impermeable oxide layer on the surface of the steel which protects it from corrosion. Corrosion of the steel reinforcement is likely to occur when loss of passivity takes place, which is usually due to carbonation and/or chloride attack.

Carbonation - Acidic gases like carbon dioxide react with any free alkali that may be present and cause a reduction in the pH value. This process, which starts at the surface of the concrete, slowly penetrates deeper and deeper. The penetration is nearly proportional to $\text{Time}^{0.5}$.



Early stages   Carbonation progression

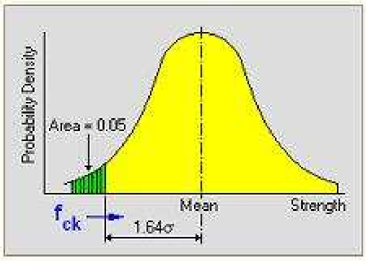
Yield strength

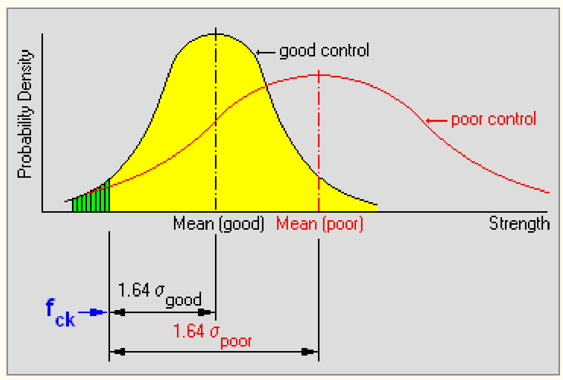


Partial factors of structural steel: γ_s= 1,0; 1,10; 1,15; 1,20

Reinforcement: γ_s = 1,15

The characteristic strength





It can be seen from the normal distribution curve that the mean strength of a material is unsuitable for design purposes since 50% of all test results might be expected to fall below the mean.

The compressive strength of concrete is therefore expressed in terms of its characteristic strength, f_{ck}, which is defined as "that value of concrete strength which is exceeded by 95% of the concrete".

From the diagram it is seen that :

$$\text{mean strength} = f_{ck} + 1.64\sigma$$

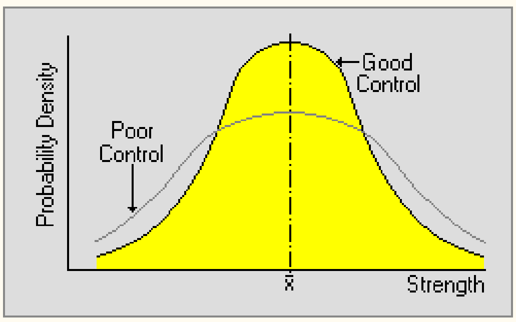
Thus to obtain a concrete with a characteristic strength of 35 N/mm^2 from a concrete batching plant for which a standard deviation of 5 N/mm^2 is expected, the required mean strength will be :-

$$35 + (1.64 \times 5) = 43.2 \ N/mm^2$$

Resistance - design statistics

When designing a structure, the designer will specify that the concrete should have a given strength (characteristic strength). When producing concrete, the mix is designed to have a specific mean strength. Tests on samples show that the actual strength (tested strength) deviates from the mean. The deviation or the spread of the test results depends on how closely the production process is controlled, and upon the properties of the individual materials in the mix.

The spread of test results approximates to the normal distribution curve, where $\bar{x}$ is the mean strength and the spread of the results is measured by the standard deviation, σ.



For a set of n test results these are given by :-

$$\bar{x} = \frac{\Sigma x}{n}$$

$$\sigma = \left(\frac{\Sigma (x - \bar{x})^2}{n} \right)^{0.5}$$

However, when testing concrete it is usual to have only a small number of test results, so σ must be increased thus :-

$$\sigma = \left(\frac{\Sigma (x - \bar{x})^2}{n - 1} \right)^{0.5}$$