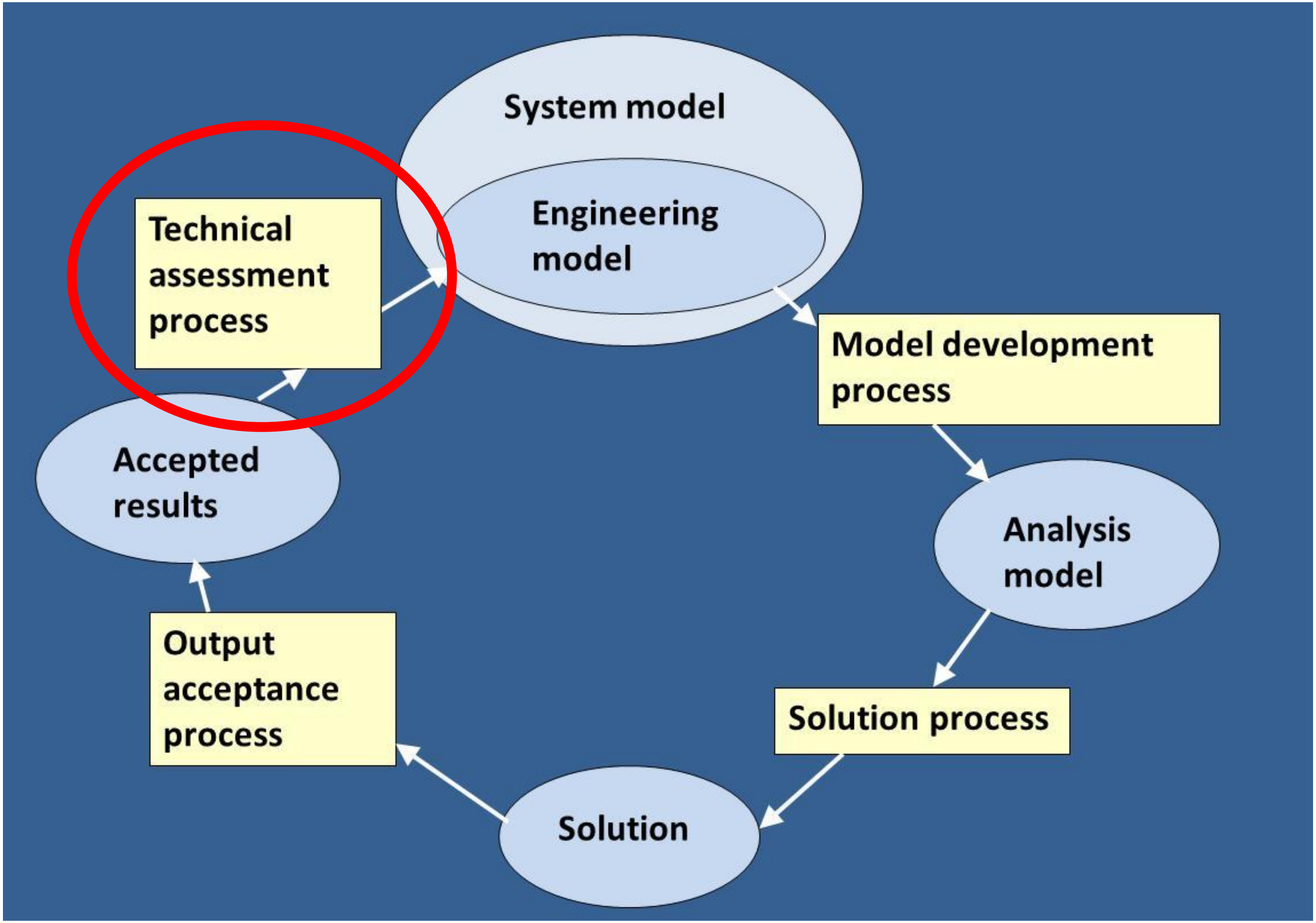
- ✓ Created analysis model
- ✓ Validated analysis model
- ✓ Verified analysis model
- ✓ Sensitivity analysis

What about the chosen section sizes????

= ‘technical assessment’

The modelling process



Technical assessment

- Sizes and details of members are established
- Ensure the design is fit for purpose

How?

- Assess the structure against code of practice rules.

Technical assessment

- **Strength** – the structure must be strong enough to resist the worst loading conditions without collapse

  = "Ultimate Limit State (ULS)"

- **Stiffness** – the structure must be stiff enough to resist normal working conditions without excessive deflection of deformation.

  = "Serviceability Limit State (SLS)"

Limit state design

- The 2 main limit states:

  - Strength ULS
    - Yielding, buckling, stability against overturning and sway, fatigue, fracture
    - ‘Resistance’ in Eurocodes
    - Based on ‘Ultimate’ loads (including partial factors of safety)

  - Serviceability SLS
    - Deflection, vibration, durability, cracking, corrosion.
    - Based on behaviour at working ‘Service’ load (unfactored)

Factors of Safety

For Limit State Design Partial Factors of Safety are applied.

Partial Safety Factors (psf) - applied, separately & independently, to all un-related loads & materials.

- Basic applied loads - multiplied by psf to get design loads.

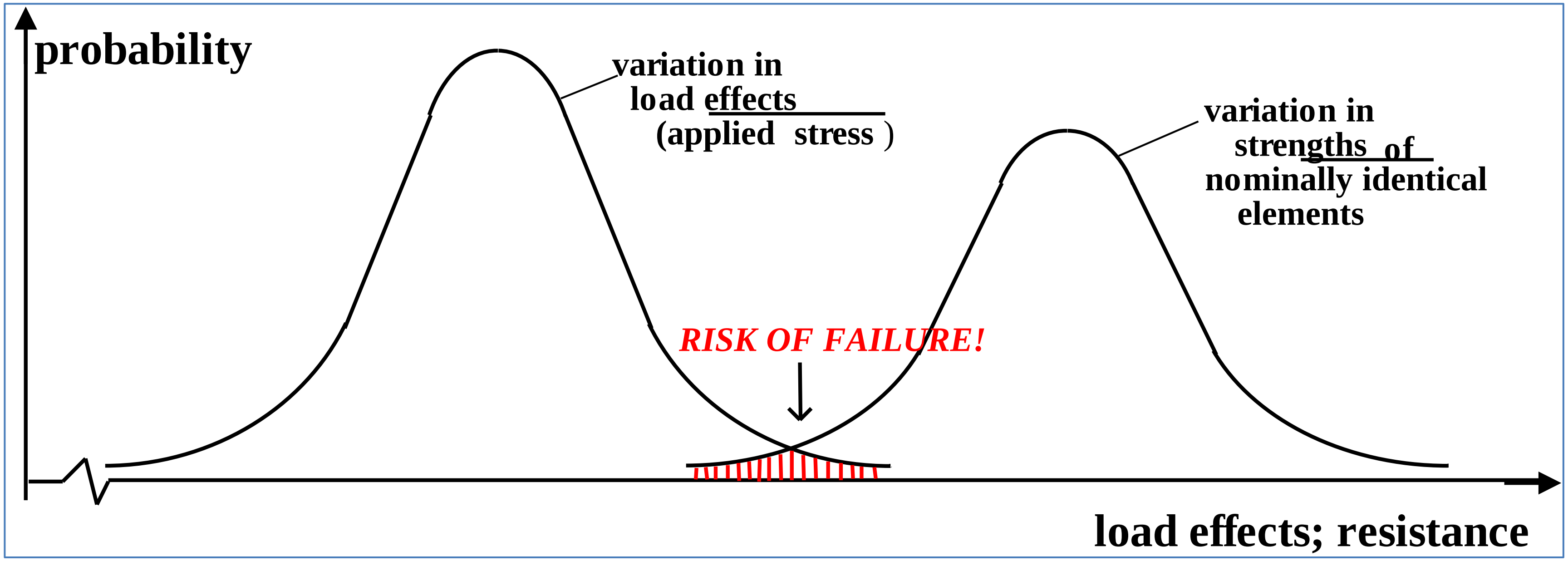
- Basic material strengths - divided by other psf to get design strengths.

<u>Strength Check</u>:

- effects of factored-up loads (bending; compression; shear) < ability of factored-down materials to cope with them!

Requirement for a safe design

‘Normal distribution’



Code requirements control the size of the area defined by the intersection of the curves.

Eurocodes

- Eurocode 0, BS EN 1990 - Basis of Structural Design
- Eurocode 1, BS EN 1991 – Actions on Structures
- Eurocode 2, BS EN 1992 – Design of Concrete Structures
- Eurocode 3, BS EN 1993 – Design of Steel Structures
- Eurocode 4, BS EN 1994 – Design of Composite Steel and Concrete Structures
- Eurocode 5, BS EN 1995 – Design of Timber Structures

Use of Eurocodes

- The following guidelines have been **simplified**.
- They should not be used as a substitution for design with the Eurocode in future.

Steel Structures

Material

- Mild steel 'S275' (for thickness $t<40mm$)

– yield strength $f_y = 275N/mm^2$

– ultimate tensile strength $f_u = 430N/mm^2$

- γ_{M0} = Partial safety factor for resistance of cross-section = 1.0

Steel Structures

Tension

Design plastic resistance of a steel member in tension

Axial force at the limit state of strength

$N_{Ed} \leq N_{t,Rd}$

Nett area - allow for holes

yield stress use f_y = 275 /mm^2

Use Fx value from analysis . Assume that partial factors for load have been applied.

Use $N_{t,Rd} = Af_y/\gamma_{MO}$

Partial factor for material use γ_{MO} = 1.0

Steel Structures

Compression

Design plastic resistance of a steel member in compression

Axial force at the limit state of strength

$$N_{Ed} \leq N_{c,Rd}$$

Use Fx value from analysis . Assume that partial factors for load have been applied.

Area

yield stress
use f_y = 275 /mm^2

Use $N_{t,Rd} = Af_y/\gamma_{MO}$

Partial factor for material use γ_{MO} = 1.0

Neglect buckling effect

Steel Structures

Bending

Design plastic resistance of a steel member in bending

Bending moment at the limit state of strength.

$M_{Ed} \leq M_{pl,Rd}$

Plastic modulus see steel section tables

yield stress use $f_y = 275 /mm^2$

Use Mx value from analysis . Assume that partial factors for load have been applied.

Use $M_{pl,Rd} = W_{pl} f_y / \gamma_{MO}$

Partial factor for material use $\gamma_{MO} = 1.0$

Neglect lateral torsional buckling

Steel Structures

Combined Bending and Axial

Use a simplified utilisation ratio:

$$\left[\frac{N_{Ed}}{N_{c,Rd}}\right] + \left[\frac{M_{y,Ed}}{M_{c,Rd,y}}\right] + \left[\frac{M_{z,Ed}}{M_{c,Rd,z}}\right] \leq 1.0$$

Assumes NO buckling present.

Timber Structures

Material

Timber design typically assesses stresses (not forces).

Stresses due to applied factored design load < Factored and *Modified* material design strengths.

Modify tabulated characteristic material strengths

Modify predominantly due to:

- effect of the duration of the loads
- in-service condition related to moisture content

BS EN 338 – Structural timber; strength classes

Table 1 — Strength classes - Characteristic values

		Softwood species												Hardwood species							
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D18	D24	D30	D35	D40	D50	D60	D70
Strength properties (in N/mm^2)																					
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	18	24	30	35	40	50	60	70
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	11	14	18	21	24	30	36	42
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29	18	21	23	25	26	29	32	34
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	7,5	7,8	8,0	8,1	8,3	9,3	10,5	13,5
Shear	$f_{v,k}$	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0	4,0	3,4	4,0	4,0	4,0	4,0	4,0	4,5	5,0
Stiffness properties (in kN/mm^2)																					
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	9,5	10	11	12	13	14	17	20
5 % modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8	8,5	9,2	10,1	10,9	11,8	14,3	16,8
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,63	0,67	0,73	0,80	0,86	0,93	1,13	1,33
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,59	0,62	0,69	0,75	0,81	0,88	1,06	1,25
Density (in kg/m^3)																					
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	475	485	530	540	550	620	700	900
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550	570	580	640	650	660	750	840	1080

NOTE 1 Values given above for tension strength, compression strength, shear strength, 5 % modulus of elasticity, mean modulus of elasticity perpendicular to grain and mean shear modulus, have been calculated using the equations given in Annex A.
NOTE 2 The tabulated properties are compatible with timber at a moisture content consistent with a temperature of 20 °C and a relative humidity of 65 %.
NOTE 3 Timber conforming to classes C45 and C50 may not be readily available.
NOTE 4 Characteristic values for shear strength are given for timber without fissures, according to EN 408. The effect of fissures should be covered in design codes.

Timber Structures

Design strength = characteristic strength x (k_{mod} / γ_M)

- K_{mod} - EC5 Table 3.1, modification factor to take account of duration of the service class and the load duration class.

Service class 1: Temperature of 20° C and relative humidity only exceeding 65% for a few weeks per year.

Service class 2 - as class 1 but with the relative humidity only exceeding 85% for a few weeks per year

Service class 3 - for all moisture contents greater than service class 2

Permanent action (eg self-weight)	k_{mod} = 0.6
Long-term action (eg storage)	k_{mod} = 0.7
Medium-term action (eg floor LL & roof snow?)	k_{mod} = 0.8
Short-term action (eg roof snow?)	k_{mod} = 0.9
Instantaneous action (eg wind)	k_{mod} = 1.1

- Material safety factor for solid timber, *Table 2.3,* $\gamma_M = 1.3$

Timber Structures

Tension

Use $\sigma = F_x/A$
Assume partial factors for load have been applied

$$\sigma_{t,0,d} \leq f_{t,0,d}$$

$$f_{t,0,d} = k_{mod}\, f_{t,0,k}/\gamma_m$$

from Table 3.1 of EN 1995
Use $k_{mod} = 0.6$

Characteristic strength value from Table 1 of EN 338
Use $f_{t,0,k} = 12$ N/mm^2

from Table 2.3 of EN 1995
Use $\gamma_m = 1.3$

Timber Structures

Compression

Use σ = Fx/A
Assume partial factors for load have been applied

$$f_{c,0,d} = k_{mod} f_{c,0,k} / \gamma_m$$

from Table 3.1 of EN 1995
Use k_{mod} = 0.6

Characteristic strength value from Table 1 of EN 338
Use $f_{c,0,k}$ = 19 N/mm^2

from Table 2.3 of EN 1995
Use γ_m = 1.3

$$\sigma_{c,0,d} \leq f_{c,0,d}$$

Neglect buckling

Timber Structures

Bending

$\sigma_{m,y,d}$ is the bending stress in the beam at the limit state of strength

$f_{m,y,d}$ is the design property for the beam at the limit state of strength

$f_{m,y,d} = k_{mod} f_{m,k} / \gamma_m$

Use $f_{m,y,d} = 10$ N/mm^2

Use the maximum moment M_z from the analysis model. i.e. assume that load partial factors have been applied.

$\sigma = M_z/Z$ where Z is the elastic modulus of the beam = $bd^2/6$ for a rectangular section

$$\boldsymbol{\sigma_{m,y,d} \leq f_{m,y,d}}$$

Concrete Structures

Material

Concrete:

$f_{cd} = \alpha_{cc} f_{ck} / \gamma_c$

Use ‘standard’ C25/30 concrete, f_{ck} = 25N/mm2

(f_{ck} - the characteristic cylinder strength of the concrete)

$\gamma_c = 1.5$ and $\alpha_{cc} = 0.85$

Reinforcement:

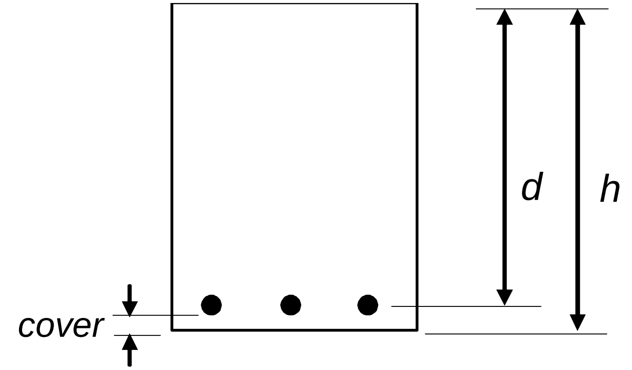
Failure stress $f_{yd} = f_{yk} / \gamma_s$.

Use ‘standard’ UK reinforcement, f_{yk} = 500N/mm2

(f_{yk} - the characteristic yield strength of the reinforcement)

$\gamma_s = 1.15$

Concrete Structures



Definitions

d - the effective depth of the section = distance from the top of the section to the centre of area of the reinforcement

h - total depth of the section

b – breadth of section

A_s - area of tensile reinforcement

x - the distance from the top of the beam to the neutral axis

z - the lever arm for the moment

s - the depth of the stress block = 0.85x

Concrete Structures

Bending

M_{Ed} is the applied moment at the limit state of strength

$M_{Rd,c}$ is the design moment of resistance of the concrete beam

f_{yk} is the characteristic yield strength of the reinforcement.

Use the maximum moment from the analysis model. i.e. assume that load partial factors have been applied.

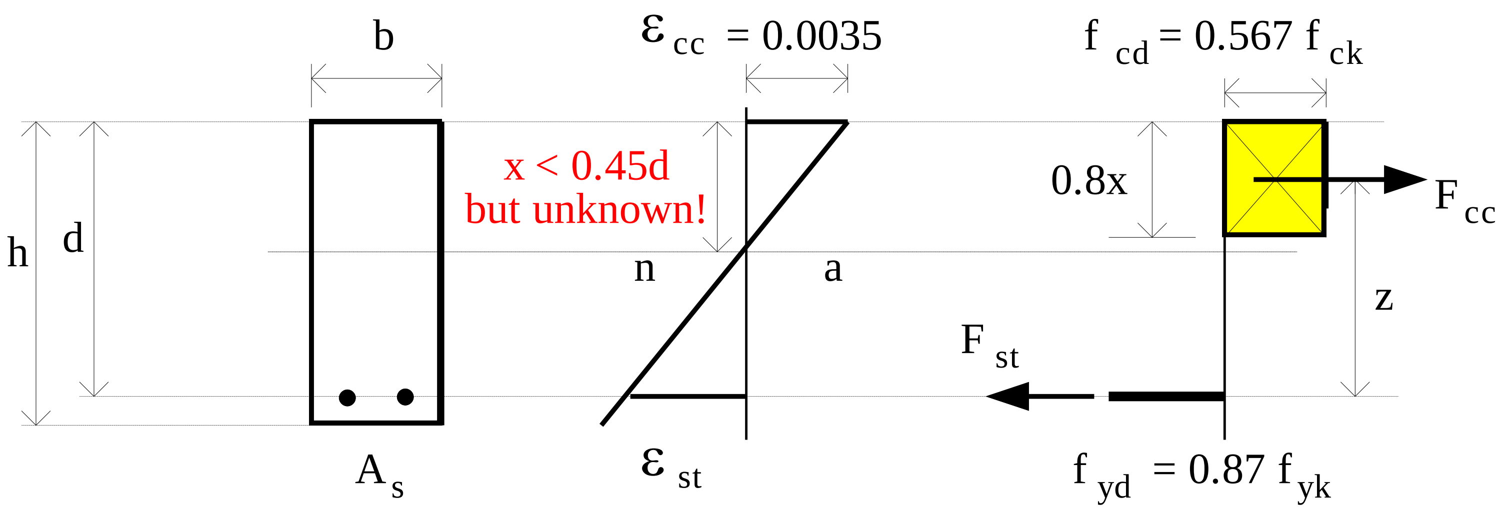
$$M_{Ed} < M_{Rd.c}$$

Use: $M_{Rd.c} = 0.87 f_{yk} A_{st} z$

A_{st} is the area of the reinforcement for example: 4 x 16 mm dia bars

z is the lever arm for the moment. Use z = 0.8d where d is the effective depth (or calculate)

Concrete Structures



F_{cc} = strength x area = $(0.567\, f_{ck})\,(0.8\, x)\,(b)$

$z = d - ½(0.8\, x)$

$M_R = F_{cc}\,.\,z = 1.134\, f_{ck}\, bd^2\,(z/d - (z/d)^2)$ - a quadratic.

Let coefficient $K = 1.134\,(z/d - (z/d)^2)$,and **let** $\boldsymbol{M_R = M_{Ed}}$, so, $M_{Ed} = K\, bd^2 f_{ck}$

$\boldsymbol{K = M_{Ed} / (bd^2 f_{ck})}$

Solving K quadratic gives

$\boldsymbol{z = [0.5 + \sqrt{(0.25 - K/1.134)}]\, d}$

F_{st} = strength x area = $(0.87\, f_{yk})\, A_s$

$M_R = F_{st}\,.\,z = (0.87\, f_{yk})\, A_s\,.\,z$

Again, **let** $\boldsymbol{M_R = M_{Ed}}$:

$\boldsymbol{A_s = M_{Ed} / (0.87\, f_{yk}\, z)}$

Concrete Structures

Shear

V_{Ed} is the shear force at the limit state of strength

$V_{Rd,c}$ is the design shear resistance of the concrete beam

f_{ck} is the characteristic strength of the concrete.

Use the maximum shear from the analysis model. i.e. assume that load partial factors have been applied.

$$V_{Ed} < V_{Rd.c}$$

Use: $V_{Rd.c} = [0.12k(100\rho_1 f_{ck})^{1/3}]bd$

$k = [1 + (100/d)^{1/2}] \leq 2.0$
with d in mm

$\rho_1 = A_{sl} /(bd) \leq 0.02$
A_{sl} is the area of the tensile reinforcement where the shear is defined. Use $A_{sl} = A_{st}$

Serviceability

For steel and timber, beam deflection checks can be carried out in serviceability assessment.

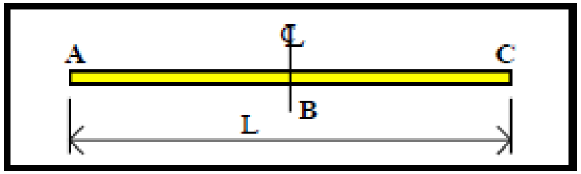
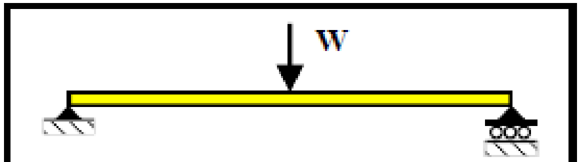
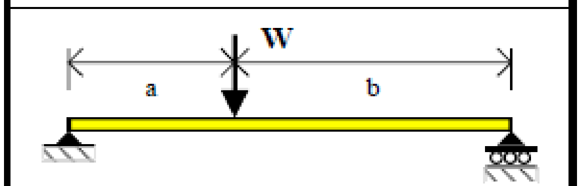
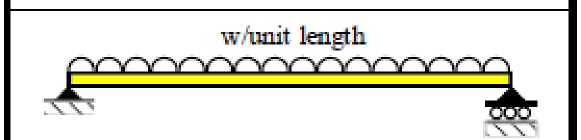
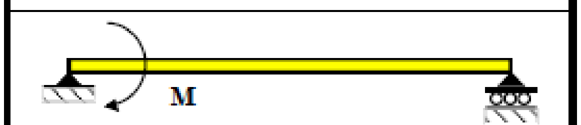
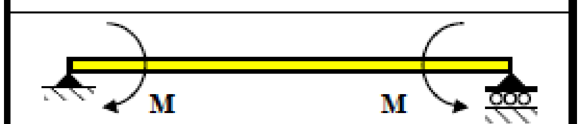
Calculated deflection values can be compared with results from the analysis model – do they correlate?

NB. Deflection rarely controls with normal loading situations on beams but it can be an issue on long-span, lightly-loaded beams (eg roofs).

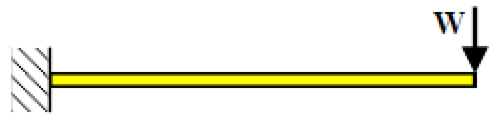
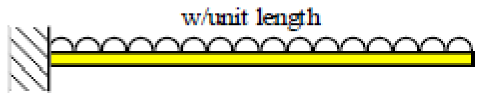
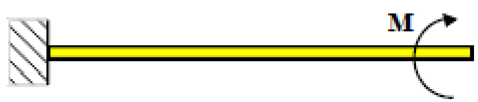
Deflection criteria for concrete are typically controlled by limiting span-to-depth ratios.

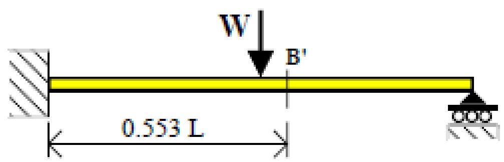
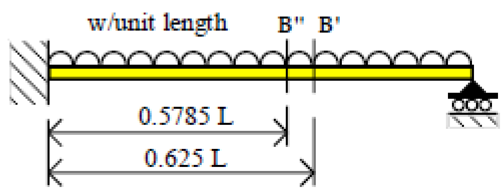
Beam deflection formula

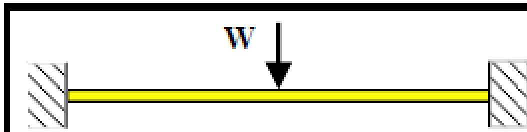
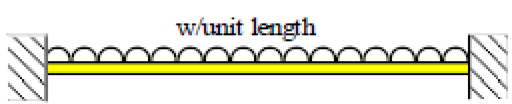
Moment & deflection formulae for standard beams

	Maximum moment	Maximum deflection
	$\frac{WL}{4}$ @B	$\frac{WL^3}{48EI}$ @B
	$\frac{Wab}{L}$ @W	$\frac{WL^3}{48EI}\left\{\frac{3a}{L}-4\left(\frac{a}{L}\right)^3\right\}$@B (within 2½% of max.)
	$\frac{wL^2}{8}$ @B	$\frac{5wL^4}{384EI}$ @B
	M @ A	$\frac{ML^2}{16EI}$ @B (within 4% of max.)
	M	$\frac{ML^2}{8EI}$ @B

Beam deflection formula

	WL @ A	$\frac{WL^3}{3EI}$ @ C
	$\frac{wL^2}{2}$ @ A	$\frac{wL^4}{8EI}$ @ C
	M	$\frac{ML^2}{2EI}$ @ C

	$\frac{3WL}{16}$ @ A $\frac{5WL}{32}$ @ B	$\frac{3WL^3}{322EI}$ @ B'
	$\frac{wL^2}{8}$ @ A $\frac{9wL^2}{128}$ @ B'	$\frac{wL^4}{185EI}$ @ B"

	$\frac{WL}{8}$ @ A, B, C	$\frac{WL^3}{192EI}$ @ B
	$\frac{wL^2}{12}$ @ A, C $\frac{wL^2}{24}$ @ B	$\frac{wL^4}{384EI}$ @ B