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REINFORCED CONCRETE DESIGN 1

Design of Beam (Examples and Tutorials)

by

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Example 1: Simply supported beam design - Rectangular

A rectangular reinforced concrete beam simply supported on two mansory walls 200 mm thick and 6 m apart. The beam has to carry a distributed permanent action of 10 kN/m (excluding beam self-weight) and variable action of 8 kN/m. The beam is inside building subject to a 1 hour fire resistance and design for 50 years design life. Design the beam with deflection and crack check. Illustrate the beam detailing. Use concrete characteristic strength, f_{ck} = 30 N/mm^2 and steel characteristic strength, f_{yk} = 500 N/mm^2

Example 1: Simply supported beam design - Rectangular

Specification

Effective span, *L* = 6 m

Characteristic action:

Permanent, g_k = 15 kN/m

Variable, q_k = 10 kN/m

Design Life = 50 years

Fire resistance = R60

Exposure classes = XC1

Materials

Concrete Char. strength, f_{ck} = 30 N/mm^2

Steel char. strength, f_{yk} = 500 N/mm^2

Links char. strength, f_{yk} = 500 N/mm^2

Reinforced concrete unit weight = 25 kN/m^3

Use , $\phi_{bar\ 1}$ = 20 mm

$\phi_{bar\ 2}$ = 12 mm

ϕ_{links} = 8 mm

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Beam Size

Overall depth, h = *L/14* = 6000/13 = 462 mm

Width, b = 0.4 (h) = 0.4 x 462 = 185 mm

Try: b x h = 200 x 500 mm

Durability, Fire & Bond Requirements

Min. cover with regards to bond, $C_{min,b}$ = 20 mm

Min. cover with regards to durability, $C_{min,dur}$ = 15 mm

Min. required axis distance for R60 fire resistance, a_{sd}

a_{sd} = 30+10 = 40 mm

Min. cover regards to fire, C_{min} = $a_{sd} - \phi_{links} - \phi_{bar}/2$

= 40 – 8 – 20/2 = 22 mm

Allowance in design for deviation, ΔC_{dev} = 10 mm

Nominal cover, C_{nom}

$C_{nom} = C_{min} + \Delta C_{dev}$ = 22 + 10 = 32 mm

Use: C_{nom} = 35 mm

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<u>LOADING & ANALYSIS</u>

Beam self-weight = 0.2 x 0.5 x 25 = 2.5 kN/m

Permanent load (Excluding self-weight) = 10 kN/m

Total Charc. Permenant action = 12.5 kN/m

Charc. Variable action = 8 kN/m

Design Action, w_d = 1.35 gk + 1.5qk = **28.88** kN/m

Shear force, V

$V = w_d L/2 = 28.88 * 6 /2 = 86.64$ kN

Bending Moment, M

$M = W_d L^2/8 = 28.88 \times 6^2/8 = 130$ kNm

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MAIN REINFORMENT

Effective depth,

d $= h - C_{nom} - \phi_{link} - \phi_{bar}/2 = 500 - 35 - 8 - 20/2 = 447$ mm

d' $= C_{nom} + \phi_{link} + \phi_{bar}/2 = 35 + 8 + 20/2 = 53$ mm

Design bending moment, $M_{Ed} =$ 193 kNm

K $= M / bd^2 f_{ck}$, $K_{bal} = 0.167$

$= 130 \times 10^6 / (200 \times 447^2 \times 30)$

$= 0.108 < K_{bal}$: No compression reinforcement required

z $= d[\,0.5 + (0.25 - K/1.134)^{1/2}]$

$= 0.89\,d = 0.89 \times 447$

$= 398$ mm

x $= (d - z) / 0.4 = 191$ mm

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Area of tension steel

$As = M/0.87f_{yk}z$

$= 130 \times 10^6/(0.87 \times 500 \times 398)$

$= 751 \ mm^2$

Use :

3H20 ($As = 943 \ mm^2$)

Minimun and maximum reinforcement area,

$As_{min} = 0.26 \ (f_{ctm} / f_{yk}) \ bd$

$= 0.26 \ (2.9/500) \ bd > 0.0013bd$

$= 0.0015 \ bd > 0.0013bd$ use 0.0015bd

$= 135 \ mm^2$

$As_{max} = 0.04Ac = 0.04 \times b \times h = 0.04 \times 200 \times 500$

$= 4000 \ mm^2$

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SHEAR REINFORCEMENT

Design shear force, $V_{Ed} = 86.64$ kN

Concrete strut capacity

$$V_{Rd,\,max} = \frac{0.36 b_w f_{ck} (1 - f_{ck}/250)}{(\cot\theta + \tan\theta)}$$

$= 655$ kN --------- $\theta = 22$ deg $\cot\theta = 2.5$

$= 950$ kN ---------$\theta = 45$ deg $\cot\theta = 1.0$

$V_{Ed} < V_{Rd,\,max}$ $\cot\theta = 2.5$

$V_{Ed} < V_{Rd,\,max}$ $\cot\theta = 1.0$

--- Therefore angle $\theta = 22^0$

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Shear links

$A_{sw} / s = V_{Ed} / 0.78 f_{yk}d \cot \theta = 0.513V_{Ed}/f_{yk}d$

$= 0.513 \times 86.64 \times 10^3 / (500 \times 447)$

$= 0.199$

Use links: H8. $A_{sw} = 101 \text{ mm}^2$

Spacing, $s = A_{sw}/0.199 = 101/0.199$

$= 508$ mm

Maximum spacing, Svmax = 0.75d = 335 mm < 508 mm : use 300 mm

Use: H8 - 300

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Additional longitudinal reinforcement

Additional tensile force,

F_{td} = $0.5\ V_{Ed} \cot\theta$ = $0.5 \times 86.64 \times 10^3 \times 2.5$

= 108.3 kN

Additional tension reinforcement,

A_s = $Ft_d / 0.87\ f_{yk}$ = $108.3 \times 10^3 / (0.87 \times 500)$

= 249 mm^2

Use :1H20 (As = 314 mm^2)

To be added to the As near support (after curtailment)

Example 1: Simply supported beam design - Rectangular

DEFLECTION

Percentage of required tension reinforcement

$\rho = As_{req} / bd = 751 / (200 \times 447) = 0.0084$

Reference reinforcement ratio.

$\rho_o = (f_{ck})^{1/2} \times 10^{-3} = (30)^{1/2} \times \times 10^{-3} = 0.0055$

Factor for structural system , K = 1.0

$\rho_o = 0.0055 < \rho = 0.0084$

Use $\frac{l}{d} = K \left[11 + 1.5\sqrt{fck}\frac{\rho o}{\rho - \rho'} + \frac{1}{12}\sqrt{fck}\sqrt{\frac{\rho'}{\rho}} \right]$

$l/d = 1.0 [11 + (1.5 (30)^{1/2} \times 0.655) + 3.2 \times (30)^{1/2} \times (0)^{1/2}]$

$= 1.0 [11 + 5.38 + 0] = 16.38$

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Example 1: Simply supported beam design - Rectangular

Therefore basic span-effective depth ratio , l/d = 16.38

Modification factor for steel area provided,

- Tension = As_{prov} / As_{req} = 943 / 751 = 1.26 < 1.5

Therefore allowable span effective depth, $(l/d)_{allowable}$

$(l/d)_{allowable}$ = 16.38 x 1.26 = 20.64

Actual span effective depth, $(l/d)_{actual}$

$(l/d)_{actual}$ = 6000/447 = 13.42

$(l/d)_{allowable} > (l/d)_{actual}$ ➔ OK

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CRACKING

Limiting crack width, w_{max} = 0.3 mm

Steel stress, f_s

$$f_s = \frac{fyk}{1.15} \times \frac{Gk+0.3Qk}{(1.35Gk+1.5Qk)} \frac{1}{\delta} = \frac{500}{1.15} \times \frac{12.5+0.3 \times 8}{(1.35(12.5)+1.5(8))}$$

= 224 N/mm^2

Max. allowable bar spacing = 200 mm

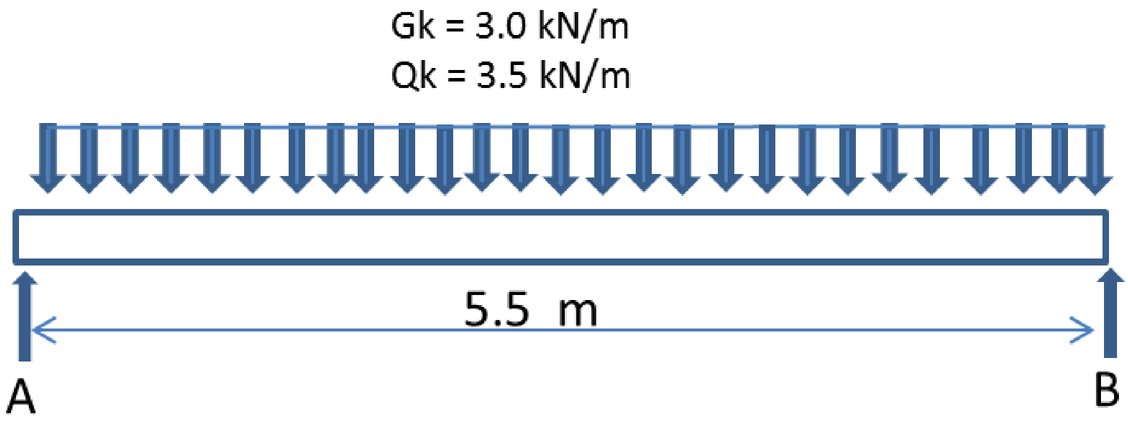
Actual bar spacing, s = [h – 2(C_{nom}) – 2(ϕ_{links}) - 20]/2

= [200 – 2(35) – 2(8) – 20]/2 = 47 mm

Actual = 47 mm < Allow, 200 mm ➔ OK

Tutorial 1: Simply supported beam

Figure below shows a 5.5 m simply supported beam with size of 150 x 350 mm. The characteristic permanents and variable action acting on the beam are 3.0 kN/m (excluding self-weight and brick wall) and 3.5 kN/m. This beam has to support the brick wall with 3.3 m height.



Tutorial 1: Simply supported beam

The properties of the beam are as follows:

Unit weight of concrete	= 25 kN/m^3
Unit weight of brick wall	= 2.6 kN/m^2
Concrete characteristic strength, f_{ck}	= 25 N/mm^2
Steel characteristic strength, f_{yk}	= 500 N/mm^2
Nominal cover, c_{nom}	= 25 mm
Use main reinforcement, ϕ_{main}	= 20 mm
Use shear reinforcement, ϕ_{link}	= 6 mm

Tutorial 1: Simply supported beam

By using the data above,

a) Calculate design load, bending moment and shear forced for the beam

b) Provide the main reinforcement for the beam

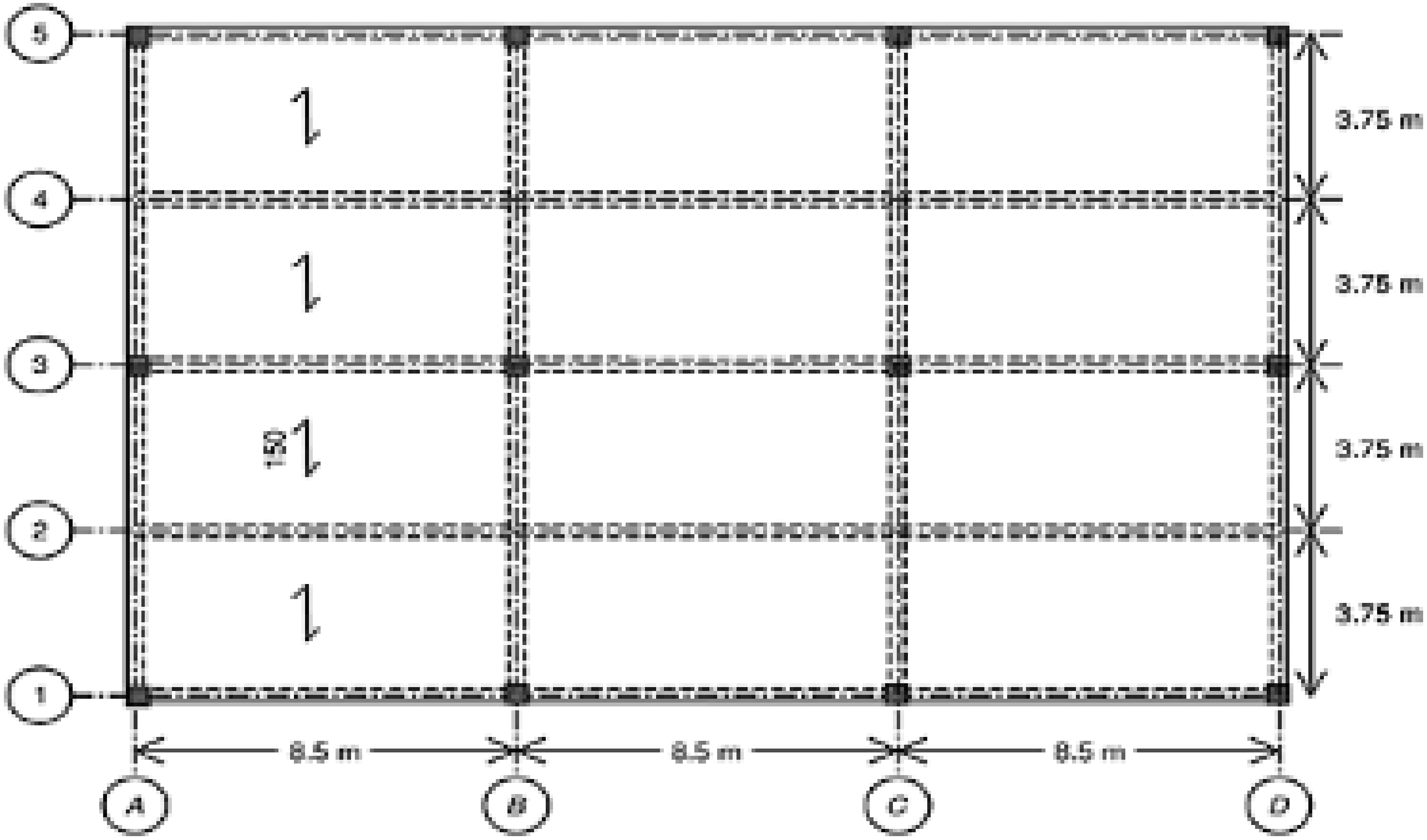
c) Provide the shear reinforcement for the beam

d) Check the beam due to the deflection

e) Skecth the detailing for this beam

Tutorial 2: Continuous beam

Design the continuous beam (3/A-D) in figure below with beam detailing.



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Tutorial 2: Continuous beam

The beam and slab will be casted monolithically. Use the following data to design the beam.

f_{ck}= 30N/mm^2
f_{yk}= 500N/mm^2
Cover, c = 25 mm
$\phi_{\text{main reinforcement}}$ = 8 mm
$q_{k,slab}$= 1.5kN/m^2
Slab fnishing = 1.0 kN/m^2
Slab thickness, h_{slab} = 150 mm
beam size, b x h = 150 x 400 mm

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