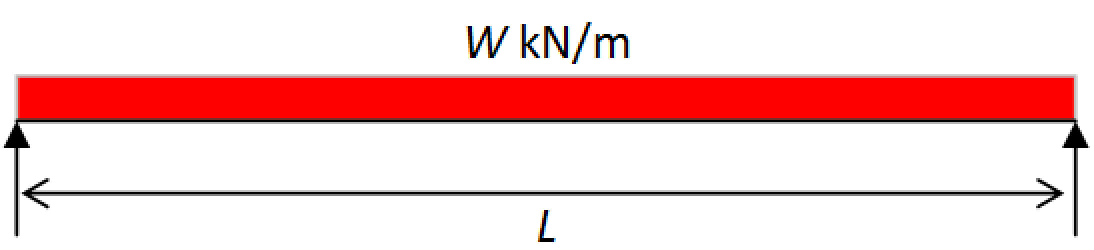
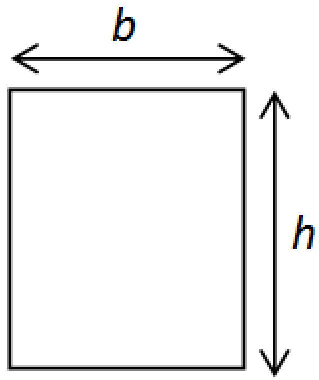
SIMPLY SUPPORT RECTANGULAR BEAM DESIGN

Simply Support Beam

A rectangular reinforced concrete beam is simply supported on two masonry walls 250mm thick and 8.0m apart (clear distance). The beam has to carry a distributed permanent action of 15kN/m (excluding beam selfweight) and a variable action of 10kN/m. The materials to be used are grade C20 concrete and grade 500 reinforcement. The beam is inside buildings which subjected to 1 hour fire resistance and design for 50 years design life. Design the beam.





1.0 SPECIFICATION

Effective span, L	= 8.25m
Characteristic actions:	
Permanent, Gk	= 15kN/m (excluding selfweight)
Variable, Qk	= 10kN/m
Design life	= 50 Years
Fire resistance	= R60
Exposure classes	= XC1
Materials:	
Characteristic strength of concrete, f_{ck}	= 20N/mm^2
Characteristic strength of steel, f_{yk}	= 500N/mm^2
Characteristic strength of link, f_{yk}	= 500N/mm^2
Unit weight of reinforced concrete	= 25kN/m^3
Assumed:	
$Ø_{bar1}$	= 20mm
$Ø_{bar2}$	= 12mm
$Ø_{link}$	= 8mm

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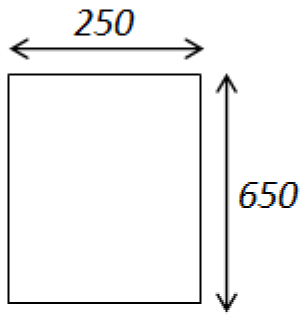
2.0 SIZE

Overall depth, h = L/13
= 8250/13
= 635mm

Width, b = 0.4h
= 0.4x635 = 254mm

Use b x h = 250 x 650mm

Max. b_{min} for fire resistance = 300mm



3.0 DURABILITY, FIRE AND BOND REQUIREMENTS

Min. concrete cover regard to bond, $C_{min,b}$ = 20mm

Min. concrete cover regard to durability, $C_{min,\ dur}$ = 15mm

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

$a_{sd} = a+10$ = 30+10

= 40mm

Min. concrete cover regard to fire

$C_{min} = a_{sd} - Ø_{link} - Ø_{bar}/2$ = 40-8-0.5(20)

= 22mm

Allowance in design for deviation, ΔCdev = 10mm

Nominal cover,

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

= 32mm

$\therefore C_{nom} = 35mm$

4.0 LOADING AND ANALYSIS

Beam self-weight	= (0.25x0.65)25
Permanent load (excluding self-weight)	= 4.06kN/m
Characteristic permanent action, G_k	= 15.00kN/m
Characteristic variable action, Q_k	= 19.06kN/m
	= 10.00kN/m
Design action, W_d	= $1.35G_k+1.5Q_k$
	= 1.35(19.06) + 1.5(10.00)
	= 40.73kN/m

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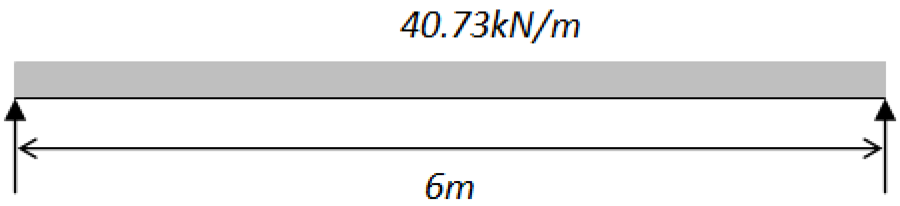

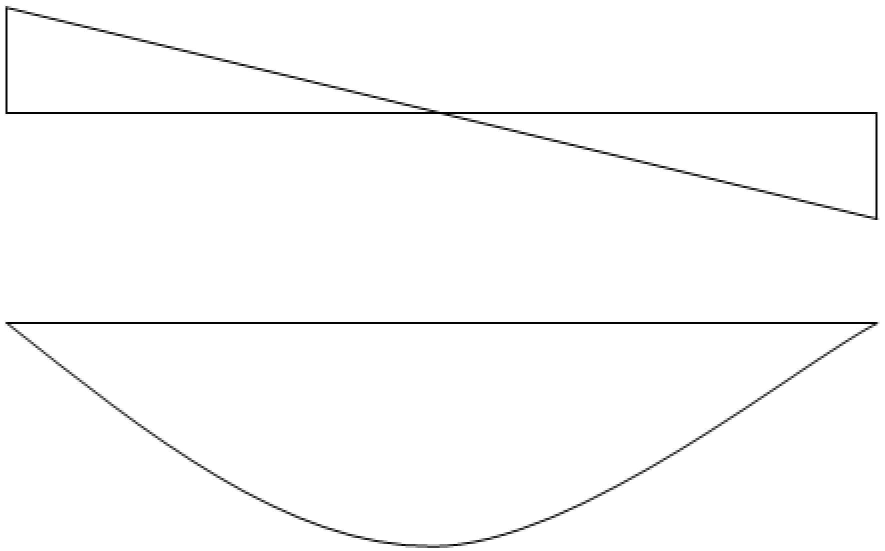

Shear Force,

$V = W_d L/2$

$= 168.0kN$

Bending Moment,

$M = W_d L^2/8$

$= 346.6kNm$

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Effective depth:

$d = h - C_{nom} - Ø_{link} - Ø_{bar}$ = 587mm

$d' = C_{nom} + Ø_{link} + Ø_{bar}/2$ = 49mm

Design bending moment, M_{ed} = 346.6kNm

$K = M/bd^2f_{ck}$ = 346.6x106/(250x587²x20)

= 0.201

Redistribution = 0%

Redistribution ratio, δ = 1.0

$K_{bal} = 0.454(\delta - k_1)/k_2 - 0.182[(\delta - k_1)k_2]^2$

$k_1 = 0.44$, $k_2 = 1.25$

$= 0.363(\delta - k_1) - 0.116(\delta - k_1)^2$

$= 0.363(\delta - 0.44) - 0.116(\delta - 0.44)^2$

$K > K_{bal}$

∴ Compression reinforcement is required

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$z = d[0.5+\sqrt{0.25 - K_{bal}/1.134}$

$z = 0.82d$ $= 0.82 \times 587$

$= 481.8mm$

$x = (d-z)/0.4$ $= 263.1mm$

d'/x $= 49/263.1$

$= 0.19 < 0.38$

$\Rightarrow$ The compression steel will have yielded

$f_{sc} = 0.87f_{yk}$

Area of compression steel

$$A_s' = \frac{(K-K_{bal})f_{ck}bd^2}{0.87f_{yk}(d-d')} = \frac{(0.201-0.167)\times(20\times250\times587^2)}{0.87\times500\times(587-49)}$$

$= 252mm^2$

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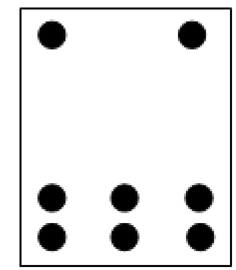
Area of tension steel

$A_s = \frac{K_{bal} f_{ck} b d^2}{0.87 f_{yk} z} + A_s'$ $= \frac{0.167\times(20\times250\times587^2}{0.87\times500\times481.8} + 252$

$= 1624mm^2$

Use: 3H12 ($339mm^2$)



Use: 6H20 ($1885mm^2$)

Min. and max. reinforcement area

$A_{s,min} = 0.26(f_{ctm}/f_{yk})bd$

$= 0.26(2.21/500)bd$

$= 0.0011bd$

Use=0.0013bd

$= 0.0013x250x587$

$= 191mm^2$

$A_{s,max} = 0.04Ac$

$= 0.04bh$

$= 0.04x250x650$

$= 6500mm^2$

6.0 SHEAR REINFORCEMENT

Design shear force, V_{Ed} = 168.0kN

Concrete strut capacity

$$V_{Rd,\,max} = \frac{0.3 b_w d f_{ck}(1-f_{ck}/250)}{(cot\theta + tan\theta)} = \frac{(0.36 \times 250 \times 587 \times 20(1-20/250))}{(cot\theta + tan\theta)}$$

= 338kN (θ = 22 deg, cotθ = 2.5)
= 486kN (θ = 45 deg, cotθ = 1.0)

$V_{Ed} < V_{Rd,\,max}$ cotθ = 2.5
$V_{Ed} < V_{Rd,\,max}$ cotθ = 1.0

$\therefore$ angle $\theta < 22$

$$\theta = 0.5\sin^{-1}\left[\frac{V_{Ed}}{0.18 b_w d f_{ck}(1 - f_{ck}/250)}\right]$$

$$\theta = 0.5\sin^{-1}\left[\frac{168\times10^3}{0.18\times250\times587\times20(1-20/250)}\right]$$

$= 0.5\sin^{-1}(0.35)$

$= 10.1^\circ$

Use: $\boldsymbol{\theta}=22.0^\circ$

$\tan\theta=0.40$, $\cot\theta=2.5$

Shear links

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

$= 168\text{x}10^3/(0.78\text{x}500\text{x}587\text{x}2.5)$

$= 0.297$

Try link: H8

$A_{sw}=101\text{mm}^2$

Spacing, s = 101/0.30

= 339mm

Maximum spacing, S_{max} = 0.75d

= 0.75x587

= 440mm

Use: H8-325

Minimum links

$A_{sw}/s = 0.08f_{ck}^{1/2}b_w/f_{yk}$ = $0.08(20)^{1/2}$x250/500

= 0.179

Try link: H8

Asw=101mm²

Spacing, s = 101/0.18

= 562mm > 0.75d (=440mm)

Use: H8-425

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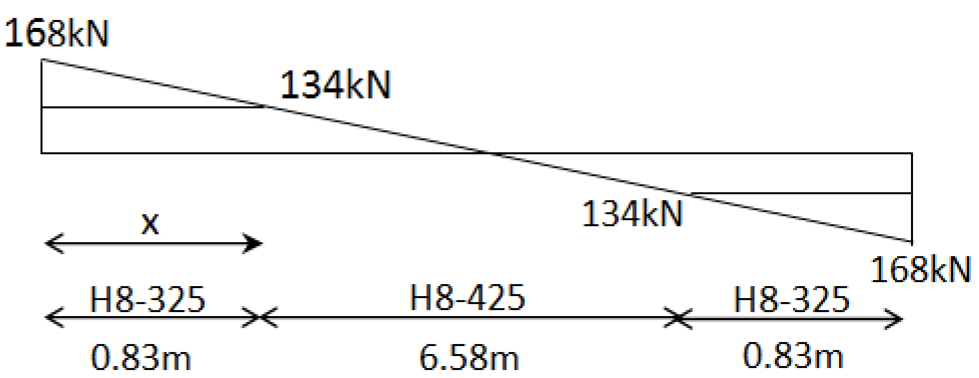
Shear resistance of minimum links

$V_{min} = (A_{sw}/s)(0.78 d f_{yk} \cot\theta)$

$= (101/425)(0.78 \times 587 \times 500 \times 2.5)$

$= 134kN$

Link arrangement



4.12m --------> 168kN

4.12- x --------> 134kN

x = 0.83m

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Additional longitudinal reinforcement

Additional tensile force, $= 0.5 \times 168 \times 2.48$

$\Delta F_{td} = 0.5 V_{Ed} \cot\theta$ $= 208kN$

$M_{Ed,max}/z$ $= 346.6 \times 10^6 / 481.8$

$= 719kN > \Delta F_{td}$

Additional longitudinal reinforcement

$$As = \frac{\Delta F_{td}}{0.87 f_{yk}} = \frac{207 \times 10^3}{0.87 \times 500}$$

$= 478mm^2$

Use: 2H 20 ($628mm^2$)

7.0 DEFLECTION

Percentage of required tension reinforcement,

$\rho = A_{s,req}/bd$ $= 1624/(250X587)$

$= 0.011$

Reference reinforcement ratio,

$\rho_0 = (f_{yk})^{1/2} x10^{-3}$ $= (20)^{1/2} x10^{-3}$

$= 0.0045$

Percentage of required compression reinforcement

$\rho' = A_{s',req}/bd$ $= 252/(250x587)$

$= 0.002$

Factor for structural system,

K = 1.0

$\rho > \rho_0$ ∴use equation (2)

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Factor for structural system, K = 1.0 $\rho > \rho_0$ ∴use equation (2)

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_0}}\right]$$

= 1.0(11+3.21+0.23)
= 14.4

Modification factor for span greater than 7m = 7/L
= 7/8
= 0.85

Modification factor for steel area provided = $A_{s,prov}/A_{s,req}$
= 1885/1624
= 1.16 < 1.5

Therefore allowable span-effective depth ratio = $(l/d)_{allowable}$
= 14.4x0.85x1.16
= 14.2

Actual span-effective depth = $(l/d)_{actual}$
= 8250/587
= 14.1 < $(l/d)_{allowable}$
OK

8.0 CRACKING

Limiting crack width, w_{max} = 0.3mm

Steel stress,

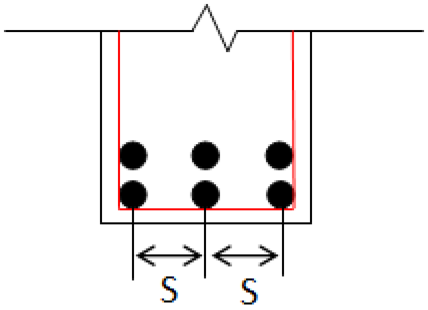
$$f_s = \frac{f_{yk}}{1.15} \times \left[\frac{G_k + 0.3Q_k}{1.35G_k + 1.5Q_k}\right]\frac{1}{\delta} = \left(\frac{500}{1.15}\right) \times \left[\frac{19.1 + (0.3 \times 10)}{40.7}\right] \times 1.0$$

= 235N/mm^2

Max. allowable bar spacing = 150mm

Bar spacing, S = [250-2(35)-2(8)-20]/2

= 72mm < 150mm



9.0 DETAILING