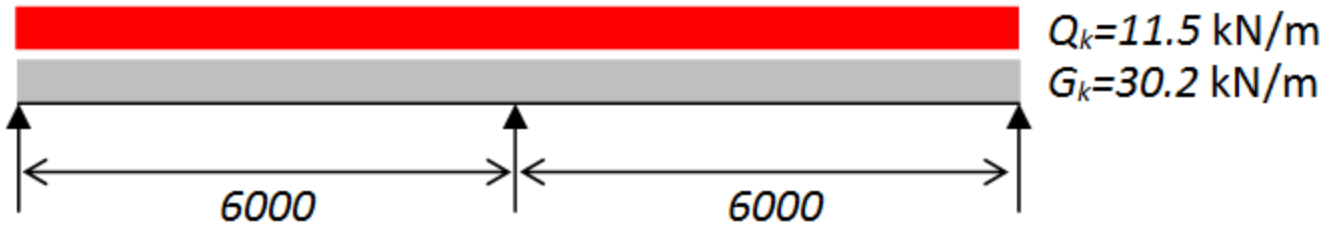
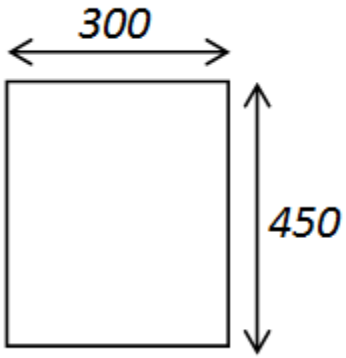
CONTINUOUS BEAM DESIGN

Continuous Beam

A 450mm deep with 300mm wide rectangular beam is required to support office loads of G_k=30.2kN/m and Q_k=11.5kN/m over 2 of 6m spans. Assume 300mm wide supports, a 50-year design life and a requirement for a 2-hour resistance to fire in an external but sheltered environment. The reinforced concrete beam is designed for moderate humidity or cyclic wet and dry, and secondarily for moderate water saturation with f_{ck}=30MPa, f_{yk}=500MPa.





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1.0 SPECIFICATION

Effective span, L	= 6m
Characteristic actions:	
Permanent, G_k	= 30.2kN/m
Variable, Q_k	= 11.5kN/m
Design life	= 50 Years
Fire resistance	= R60
Exposure classes	= XC3 + XF1
Materials:	
Characteristic strength of concrete, f_{ck}	= 30N/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:	
$Ø_{bar1}$ (tension)	= 25mm
$Ø_{bar2}$ (compression)	= 12mm
$Ø_{link}$	= 10mm

2.0 DURABILITY, FIRE AND BOND REQUIREMENTS

Min. concrete cover regard to bond, $C_{min,b}$	= 25mm
Min. concrete cover regard to durability, $C_{min,\ dur}$	= 25mm
Min. required axis distance for R60 fire resistance, a_{sd}	
$a_{sd} = a+10$	= 25+10
	= 35mm
Min. concrete cover regard to fire	
$C_{min} = a_{sd} - \emptyset_{link} - \emptyset_{bar}/2$	= 35-12-0.5(25)
	= 10.5mm
Allowance in design for deviation, $\Delta Cdev$	= 10 mm
Nominal cover,	
$C_{nom} = C_{min} + \Delta C_{dev}$	=25+10
	=35 mm

$\therefore C_{nom}$=35mm

3.0 LOADING AND ANALYSIS

Characteristic permanent action, G_k = 30.2kN/m

Characteristic variable action, Q_k = 11.5kN/m

Design action, W_d = $1.35G_k+1.5Q_k$

= 1.35(30.2) + 1.5(11.5)

= 58.02kN/m

$Q_k \leq G_k$ (but the number of spans is less than 3)

Table 3.5 – Design ultimate bending moments and shear forces

	At outer support	Near middle of end span	At first interior support	At middle of interior spans	At interior supports
Moment	**0**	**0.09*Fl***	**-0.11*Fl***	**0.07*Fl***	**-0.08*Fl***
Shear	**0.45*F***	**-**	**0.6*F***	**-**	**0.55*F***

NOTE: l is the effective span;
F is the total design ultimate load $(1.35G_k + 1.5Q_k)$
No redistribution of the moment calculated from this table should be made.

Continuous Beam

Design moments

Span:-

$M_{Ed} = (0.090G+0.100Q)L^2$ or $0.09FL^2$

$= [(0.09\times1.35\times30.2)+$
$(0.1\times1.5\times11.5)]\times6^2$
$= 187.98kNm$

Support:-

$M_{Ed} = (0.106G+0.10600Q)L^2$ or $0.11FL^2$

$= 0.106\times58.02\times6^2$
$= 201.17kNm$

Shear force

Outer support:-

$V_{Ed} = 0.45(G+Q)L$

$= 0.45\times58.02\times6$
$= 137.16kN$

Inner support:-

$V_{Ed} = 0.63\ (G+Q)L$

$= 0.63\times58.02\times6$
$= 192.02kN$

Continuous Beam

4.0 MAIN REINFORCEMENT (FLEXURAL DESIGN)

Effective depth:

$d = h - C_{nom} - \emptyset_{link} - \emptyset_{bar}/2$ $= 450-35-10-(25/2)$

$= 392mm$

$d' = C_{nom} + \emptyset_{link} + \emptyset_{bar}/2$ $= 35+10+(25/2)$

$= 57.5mm$

Flexure in span

Design bending moment, M_{Ed} $= 187.98kNm$

$K = M/bd^2f_{ck}$ $= 187.98x10^6/(300x392^2x30)$

$= 0.136$

Redistribution = 0%

Redistribution ratio, $\delta = 1.0$

$K_{bal} = 0.363(\delta-0.44)-0.116(\delta-0.44)^2$ $= 0.363(1-0.44)-0.116(1-0.44)^2$

$= 0.167$

$K < K_{bal}$

∴ Compression reinforcement is not required

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

$z = 0.86d$

$= 0.86 \times 392$

$= 337.12$ mm

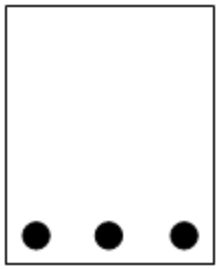
Area of tension steel

$$A_s = \frac{M_{ed}}{0.87 f_{yk} z}$$

$$= \frac{187.98 \times 10^6}{0.87 \times 500 \times 337.12}$$

$= 1281.85 mm^2$

∴ Try 3H25 ($1473 mm^2$)



Continuous Beam

Check cracking:-

Check spacing,

Spacing of outer bars = 300-(2×35)-(2×10)-25

= 185mm

∴ S = 93mm

Steel stress,

$$\sigma_s = \frac{f_{yk}}{1.15} \times \left[\frac{G_k + 0.3Q_k}{1.35G_k + 1.5Q_k}\right]\frac{1}{\delta}$$

= 237MPa

Maximum crack width, w_{max} = 0.3mm

∴ Maximum bar size = 16mm or

Maximum spacing = 200mm

S < Maximum spacing

Use 3H25 (1473mm^2)

Continuous Beam

Check deflection:-

Percentage of required tension reinforcement,

$\rho = A_{s,req}/bd$

$= 1473/(300 \times 392)$

$= 0.0125$

Reference reinforcement ratio,

$\rho_0 = (f_{ck})^{1/2} \times 10^{-3}$

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

$= 0.0055$

Percentage of required compression reinforcement

$\rho' = A_{s',req}/bd$

$= 0/(300 \times 392)$

$= 0$

Factor for structural system,

K = 1.3

$\rho > \rho_0$ ∴use equation (2)

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_0}}\right] \quad = 19$$

$A_{s,prov}/A_{s,req}$ = 1473/1281.85

=1.15 < 1.5

Max. span = (19 x1.15)x 392 = 8565 mm > 6000 mm

(OK)

Continuous Beam

Flexural support

M_{Ed} = 201.17kNm

$K = M/bd^2f_{ck}$ = 0.145

K_{bal} = 0.167

$K < K_{bal}$

∴ Compression reinforcement is not required

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

$z = 0.85d$ = 0.85 x 392

= 333mm

Area of tension steel

$$A_s = \frac{M_{Ed}}{0.87 f_{yk} z}$$ = 1338mm2

∴ Try 3H25 (1473mm^2)

Check deflection:-

ρ = 0.0133, l/d =19.5, $A_{s,prov}/A_{s,req}$ = 1.06

Max. span = (19.5 x1.06)x 392

= 8107 mm > 6000 mm

(OK)

Continuous Beam

5.0 SHEAR REINFORCEMENT

Support B (critical)

Shear at central support = 192kN
At d from face of support
V_{Ed} = 192-(0.300/2+0.392)x50.8 = 164.5kN

Max. shear resistance
f_{ck} = 30MPa, cotθ = 2.5
$V_{Rd,\,max}$ = 388.20kN

→ $V_{Rd,\,max} > V_{Ed}$ (OK)
Use cotθ = 2.5 or θ=22

Shear reinforcement:-
$A_{sw}/s = V_{Ed}/(0.78 f_{yk} d \cot\theta)$

$= 164.5 \times 10^3/(0.78 \times 500 \times 392 \times 2.5)$
$= 0.429$

Try link H8, $A_{sw} = 101 mm^2$
Spacing, s = 101/0.429 = 236mm → Use H8-200 or H8-225

Continuous Beam

Max. spacing, S = 0.75d = 294mm

Minimum links:-

$A_{sw}/s = (0.08f_{ck}^{1/2}b_w)/f_{yk}$ = $(0.08x30^{1/2}x300)/500$

= 0.263 (Not critical)

Use H8-200

Support A (and C)

Shear at end support = 137.2kN

At face of support,

V_{ed} = 137.2-(0.150+0.392)x50.8 = 109.7kN

By inspection, shear reinforcement required and

cotθ = 2.5

$A_{sw}/s = V_{Ed}/(0.78f_{yk}dcot\theta)$ = 0.285

Use H8-200 (A_{sw}/s = 0.5) throughout

Continuous Beam

6.0 DETAILING CHECKS

Min. area

$A_{s,min} = 0.26(f_{ctm}/f_{yk})b_t d \geq 0.0013 b_t d$

$= 0.26 \times 0.30 \times 30^{0.666} \times 300 \times 392/500$

$= 177 mm^2$

where;

b_t = width of tension zone

$f_{ctm} = 0.30 \times f_{ck}^{0.666}$

Curtailment of main bars

Bottom: curtail

75% main bars 0.08L from end support $= 480mm$ (say 450mm from A)

70% main bars $0.30L - a_l$ $= 0.3 \times 6000 - 1.125xd$

$= 1800 - 1.125 \times 392$

$= 1359$ mm (say 1350 from A)

Continuous Beam

Top: curtail

40% main bars $0.15L+a_l$ = 900+441

= 1341mm (say 1350 from B)

65% main bars $0.30L+a_l$ = 1800+441

=2241mm (say 2250 from B)

At supports:

25% of A_s to be anchored at the supports

25% of 1225mm^2 = 314mm^2

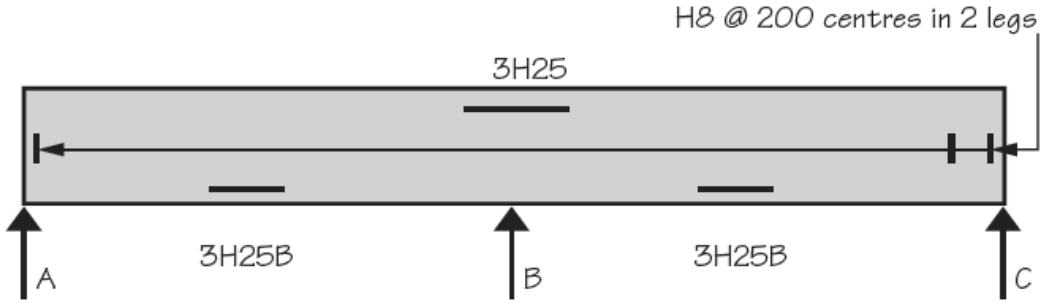
Use min. 2H16 (402mm^2) at support A, B and C

Detail lap U-bars tension lap with main steel = 780mm (say 800mm)

Continuous Beam

7.0 REINFORCEMENT DETAILS

Summary of design,



Complete reinforcement details,