

RC MEMBER ANALYSIS & DESIGN (EN1992-1-1:2004)

In accordance with EN1992-1-1:2004 incorporating Corrigenda January 2008 and the UK national annex

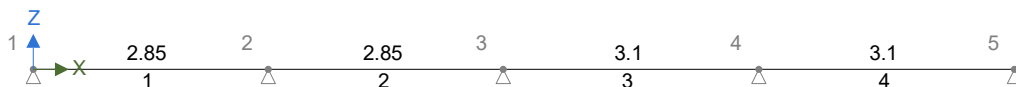
Tedds calculation version 3.0.10

ANALYSIS

Tedds calculation version 1.0.23

Geometry

Geometry (m) - Concrete (C28 2500 Quartzite) - R 450x450



Span	Length (m)	Section	Start Support	End Support
1	2.85	R 450x450	Pinned	Pinned
2	2.85	R 450x450	Pinned	Pinned
3	3.1	R 450x450	Pinned	Pinned
4	3.1	R 450x450	Pinned	Pinned

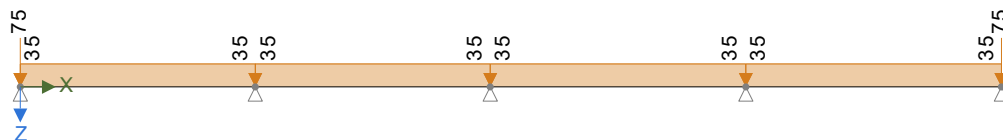
R 450x450: A = 2025 cm², I_y = 341719 cm⁴, I_z = 341719 cm⁴, A_y = 1688 cm², A_z = 1688 cm²

Concrete (C28 2500 Quartzite): Density 2500 kg/m³, Youngs 32.3082497 kN/mm², Shear 13.4617707 kN/mm², Thermal 0.00001 °C⁻¹

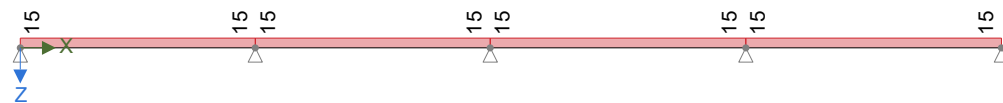
Loading

Self weight included

Permanent - Loading (kN/m,kN)



Imposed - Loading (kN/m)



Load combination factors

Load combination	Self Weight	Permanent	Imposed
LoadCombination1 (Strength)	1.35	1.35	1.50

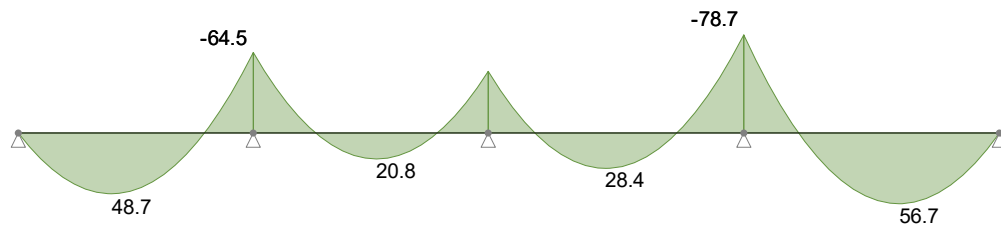
Member Loads

Member	Load case	Load Type	Orientation	Description
Beam	Permanent	UDL	GlobalZ	35 kN/m
Beam	Permanent	Point load	GlobalZ	75 kN at 0 m
Beam	Permanent	Point load	GlobalZ	75 kN at 11.9 m
Beam	Imposed	UDL	GlobalZ	15 kN/m

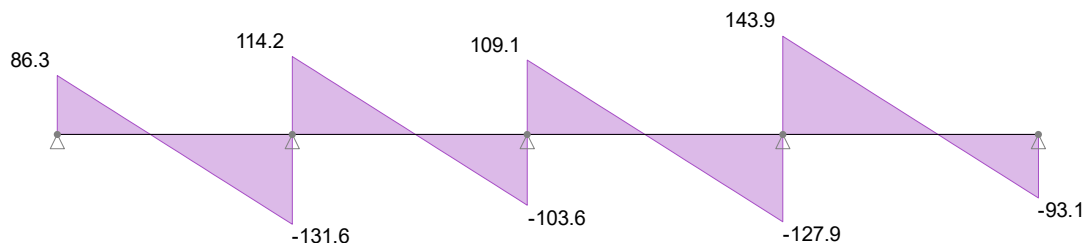
Results

Forces

Strength combinations - Moment envelope (kNm)



Strength combinations - Shear envelope (kN)



Concrete details - Table 3.1. Strength and deformation characteristics for concrete

Concrete strength class	C28/35
Aggregate type	Quartzite
Aggregate adjustment factor - cl.3.1.3(2)	AAF = 1.0
Characteristic compressive cylinder strength	$f_{ck} = 28 \text{ N/mm}^2$
Characteristic compressive cube strength	$f_{ck,cube} = 35 \text{ N/mm}^2$
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = 36 \text{ N/mm}^2$
Mean value of axial tensile strength	$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = 2.8 \text{ N/mm}^2$
Secant modulus of elasticity of concrete	$E_{cm} = 22 \text{ kN/mm}^2 \times [f_{cm} / 10 \text{ N/mm}^2]^{0.3} \times \text{AAF} = 32308 \text{ N/mm}^2$
Ultimate strain - Table 3.1	$\epsilon_{cu2} = 0.0035$
Shortening strain - Table 3.1	$\epsilon_{cu3} = 0.0035$
Effective compression zone height factor	$\lambda = 0.80$
Effective strength factor	$\eta = 1.00$

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Coefficient k_1	$k_1 = 0.40$
Coefficient k_2	$k_2 = 1.0 \times (0.6 + 0.0014 / \epsilon_{cu2}) = 1.00$
Coefficient k_3	$k_3 = 0.40$
Coefficient k_4	$k_4 = 1.0 \times (0.6 + 0.0014 / \epsilon_{cu2}) = 1.00$
Partial factor for concrete - Table 2.1N	$\gamma_C = 1.50$
Compressive strength coefficient - cl.3.1.6(1)	$\alpha_{cc} = 0.85$
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = 15.9 \text{ N/mm}^2$
Compressive strength coefficient - cl.3.1.6(1)	$\alpha_{ccw} = 1.00$
Design compressive concrete strength - exp.3.15	$f_{cwd} = \alpha_{ccw} \times f_{ck} / \gamma_C = 18.7 \text{ N/mm}^2$
Maximum aggregate size	$h_{agg} = 20 \text{ mm}$
Monolithic simple support moment factor	$\beta_1 = 0.25$

Reinforcement details

Characteristic yield strength of reinforcement	$f_{yk} = 500 \text{ N/mm}^2$
Partial factor for reinforcing steel - Table 2.1N	$\gamma_S = 1.15$
Design yield strength of reinforcement	$f_{yd} = f_{yk} / \gamma_S = 435 \text{ N/mm}^2$

Nominal cover to reinforcement

Nominal cover to top reinforcement	$c_{nom_t} = 70 \text{ mm}$
Nominal cover to bottom reinforcement	$c_{nom_b} = 70 \text{ mm}$
Nominal cover to side reinforcement	$c_{nom_s} = 50 \text{ mm}$

Fire resistance

Standard fire resistance period	$R = 60 \text{ min}$
Number of sides exposed to fire	3
Minimum width of beam - EN1992-1-2 Table 5.6	$b_{min} = 120 \text{ mm}$

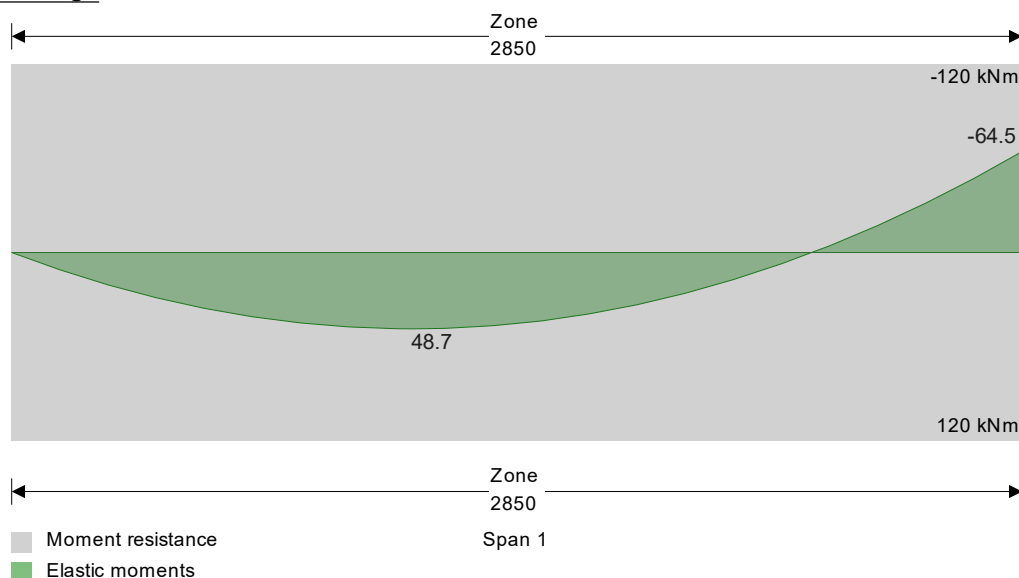
Beam - Span 1

Rectangular section details

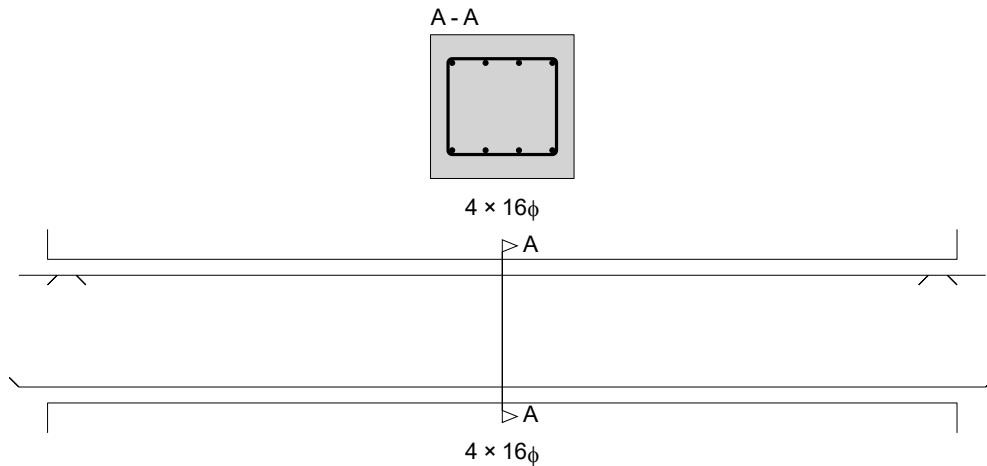
Section width	$b = 450 \text{ mm}$
Section depth	$h = 450 \text{ mm}$

PASS - Minimum dimensions for fire resistance met

Moment design



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Positive moment - section 6.1

Design bending moment

Effective depth of tension reinforcement

Redistribution ratio

$$M = \text{abs}(M_{m1_s1_z2_max_red}) = 48.7 \text{ kNm}$$

$$d = 362 \text{ mm}$$

$$\delta = \min(M_{pos_red_z2} / M_{pos_z2}, 1) = 1.000$$

$$K = M / (b \times d^2 \times f_{ck}) = 0.029$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

Depth of neutral axis

Area of tension reinforcement required

Tension reinforcement provided

Area of tension reinforcement provided

Minimum area of reinforcement - exp.9.1N

Maximum area of reinforcement - cl.9.2.1.1(3)

$$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$$

$$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$$

$$A_{s,req} = M / (f_{yd} \times z) = 326 \text{ mm}^2$$

$$4 \times 16\phi$$

$$A_{s,prov} = 804 \text{ mm}^2$$

$$A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$$

$$A_{s,max} = 0.04 \times b \times h = 8100 \text{ mm}^2$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width

Design value modulus of elasticity reinf - 3.2.7(4)

Mean value of concrete tensile strength

Stress distribution coefficient

Non-uniform self-equilibrating stress coefficient

$$w_k = 0.3 \text{ mm}$$

$$E_s = 200000 \text{ N/mm}^2$$

$$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$$

$$k_c = 0.4$$

$$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$$

Actual tension bar spacing

$$s_{bar} = (b - (2 \times (c_{nom_s} + \phi_{m1_s1_z2_v}) + \phi_{m1_s1_z2_b_L1} \times N_{m1_s1_z2_b_L1})) / (N_{m1_s1_z2_b_L1} - 1) + \phi_{m1_s1_z2_b_L1} = 104.7 \text{ mm}$$

Maximum stress permitted (Table 7.3N)

$$\sigma_s = 316 \text{ N/mm}^2$$

Steel to concrete modulus of elast. ratio

$$\alpha_{cr} = E_s / E_{cm} = 6.19$$

Distance of the Elastic NA from bottom of beam

$$y = (b \times h^2 / 2 + A_{s,prov} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,prov} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$$

Area of concrete in the tensile zone

$$A_{ct} = b \times y = 100005 \text{ mm}^2$$

Minimum area of reinforcement required - exp.7.1

$$A_{s,min} = k_c \times k \times f_{ct,eff} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$$

PASS - Area of tension reinforcement provided exceeds minimum required for crack control

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Permanent load ratio
Service stress in reinforcement
Maximum bar spacing - Tables 7.3N

$$R_{PL} = 0.65$$

$$\sigma_{sr} = f_{yd} \times A_{s,req} / A_{s,prov} \times R_{PL} = 114 \text{ N/mm}^2$$

$$s_{bar,max} = 300 \text{ mm}$$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio
Required tension reinforcement ratio
Required compression reinforcement ratio
Structural system factor - Table 7.4N
Basic allowable span to depth ratio

$$\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$$

$$\rho_m = A_{s,req} / (b \times d) = 0.00200$$

$$\rho'_m = A_{s2,req} / (b \times d) = 0.00000$$

$$K_b = 1.3$$

$$\text{span_to_depth}_{basic} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 88.105$$

Reinforcement factor - exp.7.17
Flange width factor
Long span supporting brittle partition factor
Allowable span to depth ratio

$$K_s = \min(A_{s,prov} / A_{s,req} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$$

$$F1 = 1 = 1.000$$

$$F2 = 1 = 1.000$$

$$\text{span_to_depth}_{allow} = \min(\text{span_to_depth}_{basic} \times K_s \times F1 \times F2, 40 \times K_b) = 52.000$$

Actual span to depth ratio

$$\text{span_to_depth}_{actual} = L_{m1_s1} / d = 7.873$$

PASS - Actual span to depth ratio is within the allowable limit

Negative moment - section 6.1

Design bending moment
Effective depth of tension reinforcement
Redistribution ratio

$$M = \max(\beta_1 \times \text{abs}(M_{m1_s1_max_red}), \text{abs}(M_{m1_s1_z2_min_red})) = 64.5 \text{ kNm}$$

$$d = 362 \text{ mm}$$

$$\delta = \min(M_{neg_red_z2} / M_{neg_z2}, 1) = 1.000$$

$$K = M / (b \times d^2 \times f_{ck}) = 0.039$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$$

K' > K - No compression reinforcement is required

Lever arm
Depth of neutral axis
Area of tension reinforcement required
Tension reinforcement provided
Area of tension reinforcement provided
Minimum area of reinforcement - exp.9.1N
Maximum area of reinforcement - cl.9.2.1.1(3)

$$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$$

$$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$$

$$A_{s,req} = M / (f_{yd} \times z) = 432 \text{ mm}^2$$

$$4 \times 16\phi$$

$$A_{s,prov} = 804 \text{ mm}^2$$

$$A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$$

$$A_{s,max} = 0.04 \times b \times h = 8100 \text{ mm}^2$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width
Design value modulus of elasticity reinf - 3.2.7(4)
Mean value of concrete tensile strength
Stress distribution coefficient
Non-uniform self-equilibrating stress coefficient

$$w_k = 0.3 \text{ mm}$$

$$E_s = 200000 \text{ N/mm}^2$$

$$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$$

$$K_c = 0.4$$

$$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$$

Actual tension bar spacing

$$s_{bar} = (b - (2 \times (c_{nom_s} + \phi_{m1_s1_z2_v}) + \phi_{m1_s1_z2_t_L1} \times N_{m1_s1_z2_t_L1})) / (N_{m1_s1_z2_t_L1} - 1) + \phi_{m1_s1_z2_t_L1} = 104.7 \text{ mm}$$

Maximum stress permitted (Table 7.3N)
Steel to concrete modulus of elast. ratio

$$\sigma_s = 316 \text{ N/mm}^2$$

$$\alpha_{cr} = E_s / E_{cm} = 6.19$$

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Distance of the Elastic NA from bottom of beam $y = (b \times h^2 / 2 + A_{s,prov} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,prov} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$

Area of concrete in the tensile zone $A_{ct} = b \times y = 100005 \text{ mm}^2$

Minimum area of reinforcement required - exp.7.1 $A_{sc,min} = k_c \times k \times f_{ct,eff} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$

PASS - Area of tension reinforcement provided exceeds minimum required for crack control

Permanent load ratio $R_{PL} = 0.65$

Service stress in reinforcement $\sigma_{sr} = f_{yd} \times A_{s,req} / A_{s,prov} \times R_{PL} = 152 \text{ N/mm}^2$

Maximum bar spacing - Tables 7.3N $s_{bar,max} = 300 \text{ mm}$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio $\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$

Required tension reinforcement ratio $\rho_m = A_{s,req} / (b \times d) = 0.00265$

Required compression reinforcement ratio $\rho'_m = A_{s2,req} / (b \times d) = 0.00123$

Structural system factor - Table 7.4N $K_b = 1.3$

Basic allowable span to depth ratio $\text{span_to_depth}_{basic} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 56.808$

Reinforcement factor - exp.7.17 $K_s = \min(A_{s,prov} / A_{s,req} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$

Flange width factor $F1 = 1 = 1.000$

Long span supporting brittle partition factor $F2 = 1 = 1.000$

Allowable span to depth ratio $\text{span_to_depth}_{allow} = \min(\text{span_to_depth}_{basic} \times K_s \times F1 \times F2, 40 \times K_b) = 52.000$

Actual span to depth ratio $\text{span_to_depth}_{actual} = L_{m1_s1} / d = 7.873$

PASS - Actual span to depth ratio is within the allowable limit

Minimum bar spacing (Section 8.2)

Top bar spacing $S_{top} = (b - (2 \times (C_{nom_s} + \phi_{m1_s1_z2_v}) + \phi_{m1_s1_z2_t_L1} \times N_{m1_s1_z2_t_L1})) / (N_{m1_s1_z2_t_L1} - 1) = 88.7 \text{ mm}$

Minimum allowable top bar spacing $S_{top,min} = \max(\phi_{m1_s1_z2_t_L1} \times K_{s1}, h_{agg} + K_{s2}, 20\text{mm}) = 25.0 \text{ mm}$

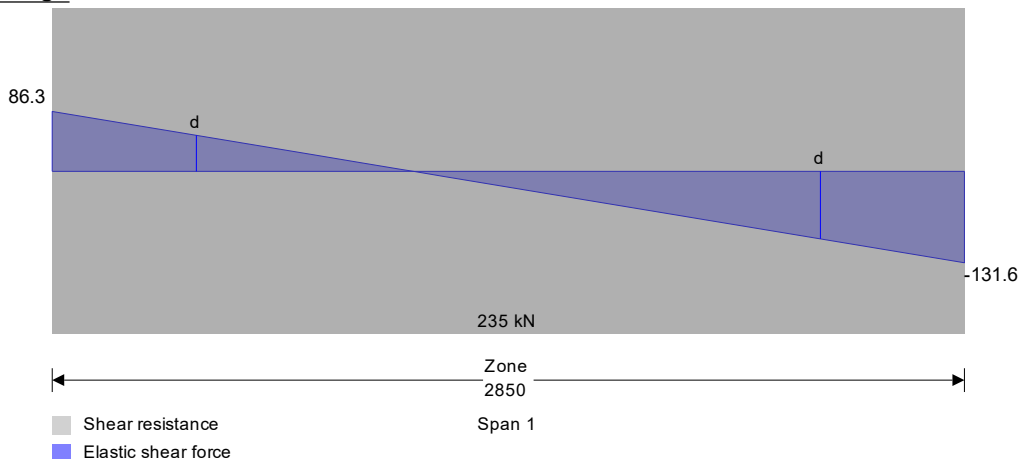
PASS - Actual bar spacing exceeds minimum allowable

Bottom bar spacing $S_{bot} = (b - (2 \times (C_{nom_s} + \phi_{m1_s1_z2_v}) + \phi_{m1_s1_z2_b_L1} \times N_{m1_s1_z2_b_L1})) / (N_{m1_s1_z2_b_L1} - 1) = 88.7 \text{ mm}$

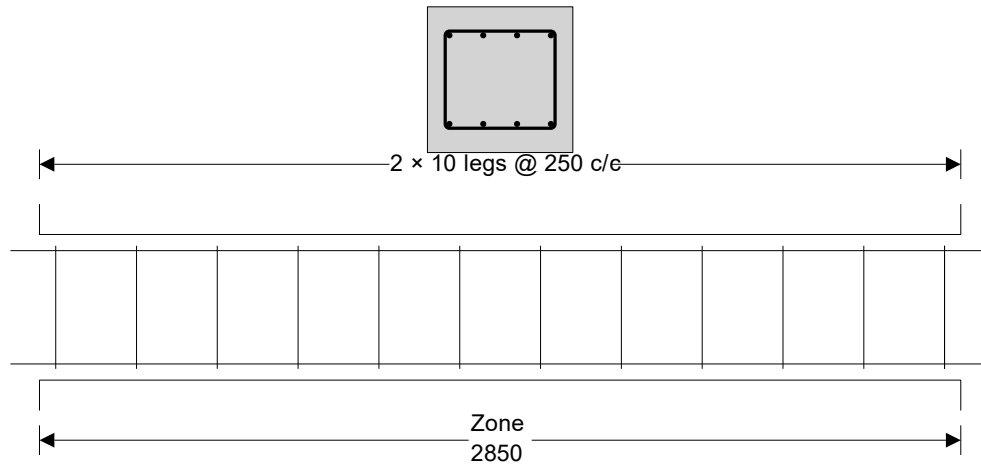
Minimum allowable bottom bar spacing $S_{bot,min} = \max(\phi_{m1_s1_z2_b_L1} \times K_{s1}, h_{agg} + K_{s2}, 20\text{mm}) = 25.0 \text{ mm}$

PASS - Actual bar spacing exceeds minimum allowable

Shear design



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Angle of comp. shear strut for maximum shear	$\theta_{\max} = 45 \text{ deg}$
Strength reduction factor - cl.6.2.3(3)	$v_1 = 0.6 \times (1 - f_{ck} / 250 \text{ N/mm}^2) = \mathbf{0.533}$
Compression chord coefficient - cl.6.2.3(3)	$\alpha_{cw} = \mathbf{1.00}$
Minimum area of shear reinforcement - exp.9.5N	$A_{sv,min} = 0.08 \text{ N/mm}^2 \times b \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / f_{yk} = \mathbf{381 \text{ mm}^2/\text{m}}$

Section in shear - section 6.2

Design shear force at support	$V_{Ed,max} = \max(\text{abs}(V_{z2_max}), \text{abs}(V_{z2_red_max})) = \mathbf{97 \text{ kN}}$
Min lever arm in shear zone	$z = \mathbf{344 \text{ mm}}$
Maximum design shear resistance - exp.6.9	$V_{Rd,max} = \alpha_{cw} \times b \times z \times v_1 \times f_{cwd} / (\cot(\theta_{\max}) + \tan(\theta_{\max})) = \mathbf{770 \text{ kN}}$

PASS - Design shear force at support is less than maximum design shear resistance

Design shear force within zone	$V_{Ed} = \mathbf{97 \text{ kN}}$
Design shear stress	$v_{Ed} = V_{Ed} / (b \times z) = \mathbf{0.628 \text{ N/mm}^2}$
Angle of concrete compression strut - cl.6.2.3	$\theta = \min(\max(0.5 \times A_{sin}(\min(2 \times v_{Ed} / (\alpha_{cw} \times f_{cwd} \times v_1), 1)), 21.8 \text{ deg}), 45 \text{ deg}) = \mathbf{21.8 \text{ deg}}$
Area of shear reinforcement required - exp.6.8	$A_{sv,des} = V_{Ed} \times b / (f_{yd} \times \cot(\theta)) = \mathbf{260 \text{ mm}^2/\text{m}}$
Area of shear reinforcement required	$A_{sv,req} = \max(A_{sv,min}, A_{sv,des}) = \mathbf{381 \text{ mm}^2/\text{m}}$
Shear reinforcement provided	$2 \times 10 \text{ legs @ } 250 \text{ c/c}$
Area of shear reinforcement provided	$A_{sv,prov} = \mathbf{628 \text{ mm}^2/\text{m}}$

PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing - exp.9.6N	$s_{vl,max} = 0.75 \times d = \mathbf{271 \text{ mm}}$
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PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

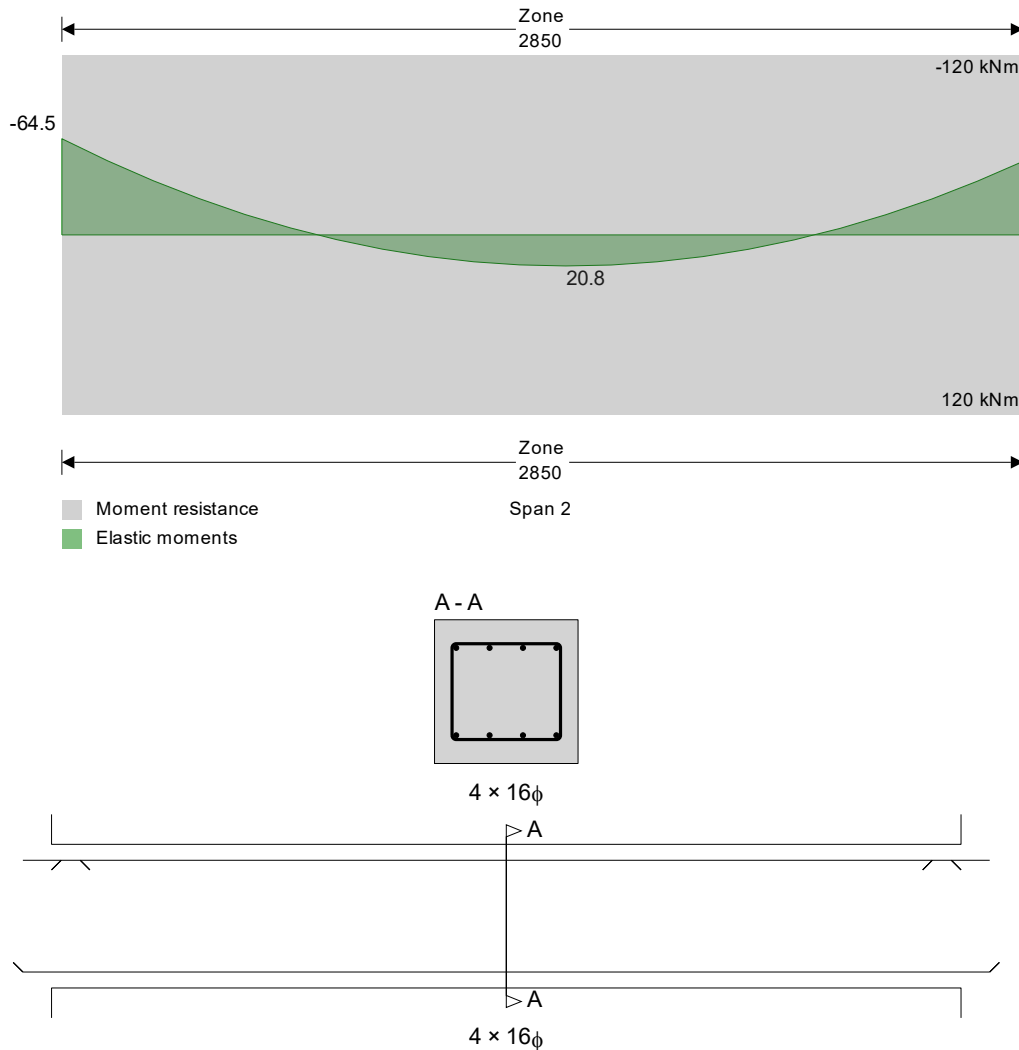
Beam - Span 2

Rectangular section details

Section width	$b = \mathbf{450 \text{ mm}}$
Section depth	$h = \mathbf{450 \text{ mm}}$

PASS - Minimum dimensions for fire resistance met

Moment design



Positive moment - section 6.1

Design bending moment

Effective depth of tension reinforcement

Redistribution ratio

$$M = \text{abs}(M_{m1_s2_z2_max_red}) = 20.8 \text{ kNm}$$

$$d = 362 \text{ mm}$$

$$\delta = \min(M_{pos_red_z2} / M_{pos_z2}, 1) = 1.000$$

$$K = M / (b \times d^2 \times f_{ck}) = 0.013$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$$

Depth of neutral axis

$$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$$

Area of tension reinforcement required

$$A_{s,req} = M / (f_{yd} \times z) = 139 \text{ mm}^2$$

Tension reinforcement provided

$$4 \times 16\phi$$

Area of tension reinforcement provided

$$A_{s,prov} = 804 \text{ mm}^2$$

Minimum area of reinforcement - exp.9.1N

$$A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{s,max} = 0.04 \times b \times h = 8100 \text{ mm}^2$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

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Crack control - Section 7.3

Maximum crack width	$w_k = 0.3 \text{ mm}$
Design value modulus of elasticity reinf - 3.2.7(4)	$E_s = 200000 \text{ N/mm}^2$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$
Stress distribution coefficient	$k_c = 0.4$
Non-uniform self-equilibrating stress coefficient	$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$
Actual tension bar spacing	$s_{bar} = (b - (2 \times (c_{nom_s} + \phi_{m1_s2_z2_v}) + \phi_{m1_s2_z2_b_L1} \times N_{m1_s2_z2_b_L1})) / (N_{m1_s2_z2_b_L1} - 1) + \phi_{m1_s2_z2_b_L1} = 104.7 \text{ mm}$
Maximum stress permitted (Table 7.3N)	$\sigma_s = 316 \text{ N/mm}^2$
Steel to concrete modulus of elast. ratio	$\alpha_{cr} = E_s / E_{cm} = 6.19$
Distance of the Elastic NA from bottom of beam	$y = (b \times h^2 / 2 + A_{s,prov} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,prov} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$
Area of concrete in the tensile zone	$A_{ct} = b \times y = 100005 \text{ mm}^2$
Minimum area of reinforcement required - exp.7.1	$A_{sc,min} = k_c \times k \times f_{ct,eff} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$
PASS - Area of tension reinforcement provided exceeds minimum required for crack control	
Permanent load ratio	$R_{PL} = 0.65$
Service stress in reinforcement	$\sigma_{sr} = f_{yd} \times A_{s,req} / A_{s,prov} \times R_{PL} = 49 \text{ N/mm}^2$
Maximum bar spacing - Tables 7.3N	$s_{bar,max} = 300 \text{ mm}$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio	$\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$
Required tension reinforcement ratio	$\rho_m = A_{s,req} / (b \times d) = 0.00085$
Required compression reinforcement ratio	$\rho'_{m} = A_{s2,req} / (b \times d) = 0.00000$
Structural system factor - Table 7.4N	$K_b = 1.5$
Basic allowable span to depth ratio	$\text{span_to_depth}_{basic} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 390.768$
Reinforcement factor - exp.7.17	$K_s = \min(A_{s,prov} / A_{s,req} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$
Flange width factor	$F1 = 1 = 1.000$
Long span supporting brittle partition factor	$F2 = 1 = 1.000$
Allowable span to depth ratio	$\text{span_to_depth}_{allow} = \min(\text{span_to_depth}_{basic} \times K_s \times F1 \times F2, 40 \times K_b) = 60.000$
Actual span to depth ratio	$\text{span_to_depth}_{actual} = L_{m1_s2} / d = 7.873$

PASS - Actual span to depth ratio is within the allowable limit

Negative moment - section 6.1

Design bending moment	$M = \text{abs}(M_{m1_s2_z2_min_red}) = 64.5 \text{ kNm}$
Effective depth of tension reinforcement	$d = 362 \text{ mm}$
Redistribution ratio	$\delta = \min(M_{neg_red_z2} / M_{neg_z2}, 1) = 1.000$
	$K = M / (b \times d^2 \times f_{ck}) = 0.039$
	$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$
	$K' > K$ - No compression reinforcement is required
Lever arm	$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$
Depth of neutral axis	$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$
Area of tension reinforcement required	$A_{s,req} = M / (f_{yd} \times z) = 432 \text{ mm}^2$

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Tension reinforcement provided $4 \times 16\phi$
Area of tension reinforcement provided $A_{s,prov} = 804 \text{ mm}^2$
Minimum area of reinforcement - exp.9.1N $A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$
Maximum area of reinforcement - cl.9.2.1.1(3) $A_{s,max} = 0.04 \times b \times h = 8100 \text{ mm}^2$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width $w_k = 0.3 \text{ mm}$
Design value modulus of elasticity reinf - 3.2.7(4) $E_s = 200000 \text{ N/mm}^2$
Mean value of concrete tensile strength $f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$
Stress distribution coefficient $k_c = 0.4$
Non-uniform self-equilibrating stress coefficient $k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$
Actual tension bar spacing $s_{bar} = (b - (2 \times (c_{nom_s} + \phi_{m1_s2_z2_v}) + \phi_{m1_s2_z2_t_L1} \times N_{m1_s2_z2_t_L1})) / (N_{m1_s2_z2_t_L1} - 1) + \phi_{m1_s2_z2_t_L1} = 104.7 \text{ mm}$
Maximum stress permitted (Table 7.3N) $\sigma_s = 316 \text{ N/mm}^2$
Steel to concrete modulus of elast. ratio $\alpha_{cr} = E_s / E_{cm} = 6.19$
Distance of the Elastic NA from bottom of beam $y = (b \times h^2 / 2 + A_{s,prov} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,prov} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$
Area of concrete in the tensile zone $A_{ct} = b \times y = 100005 \text{ mm}^2$
Minimum area of reinforcement required - exp.7.1 $A_{s,min} = k_c \times k \times f_{ct,eff} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$

PASS - Area of tension reinforcement provided exceeds minimum required for crack control

Permanent load ratio $R_{PL} = 0.65$
Service stress in reinforcement $\sigma_{sr} = f_{yd} \times A_{s,req} / A_{s,prov} \times R_{PL} = 152 \text{ N/mm}^2$
Maximum bar spacing - Tables 7.3N $s_{bar,max} = 300 \text{ mm}$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio $\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$
Required tension reinforcement ratio $\rho_m = A_{s,req} / (b \times d) = 0.00265$
Required compression reinforcement ratio $\rho'_m = A_{s2,req} / (b \times d) = 0.00000$
Structural system factor - Table 7.4N $K_b = 1.5$
Basic allowable span to depth ratio $\text{span_to_depth}_{basic} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 65.548$
Reinforcement factor - exp.7.17 $K_s = \min(A_{s,prov} / A_{s,req} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$
Flange width factor $F1 = 1 = 1.000$
Long span supporting brittle partition factor $F2 = 1 = 1.000$
Allowable span to depth ratio $\text{span_to_depth}_{allow} = \min(\text{span_to_depth}_{basic} \times K_s \times F1 \times F2, 40 \times K_b) = 60.000$
Actual span to depth ratio $\text{span_to_depth}_{actual} = L_{m1_s2} / d = 7.873$

PASS - Actual span to depth ratio is within the allowable limit

Minimum bar spacing (Section 8.2)

Top bar spacing $s_{top} = (b - (2 \times (c_{nom_s} + \phi_{m1_s2_z2_v}) + \phi_{m1_s2_z2_t_L1} \times N_{m1_s2_z2_t_L1})) / (N_{m1_s2_z2_t_L1} - 1) = 88.7 \text{ mm}$
Minimum allowable top bar spacing $s_{top,min} = \max(\phi_{m1_s2_z2_t_L1} \times k_{s1}, h_{agg} + k_{s2}, 20\text{mm}) = 25.0 \text{ mm}$
PASS - Actual bar spacing exceeds minimum allowable
Bottom bar spacing $s_{bot} = (b - (2 \times (c_{nom_s} + \phi_{m1_s2_z2_v}) + \phi_{m1_s2_z2_b_L1} \times N_{m1_s2_z2_b_L1})) / (N_{m1_s2_z2_b_L1} - 1) = 88.7 \text{ mm}$

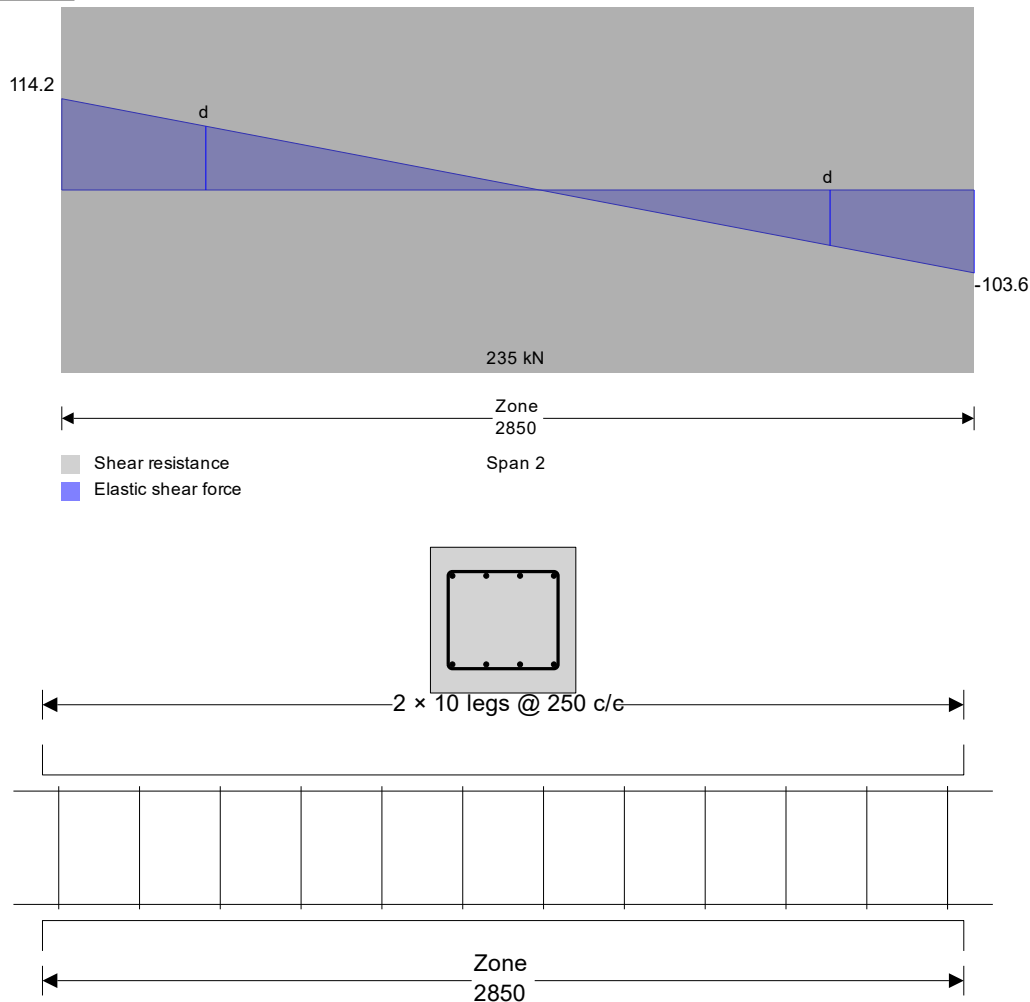
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Minimum allowable bottom bar spacing

$$s_{bot,min} = \max(\phi_{m1_s2_z2_b_L1} \times k_{s1}, h_{agg} + k_{s2}, 20\text{mm}) = 25.0 \text{ mm}$$

PASS - Actual bar spacing exceeds minimum allowable

Shear design



Angle of comp. shear strut for maximum shear

$$\theta_{max} = 45 \text{ deg}$$

Strength reduction factor - cl.6.2.3(3)

$$v_1 = 0.6 \times (1 - f_{ck} / 250 \text{ N/mm}^2) = 0.533$$

Compression chord coefficient - cl.6.2.3(3)

$$\alpha_{cw} = 1.00$$

Minimum area of shear reinforcement - exp.9.5N

$$A_{sv,min} = 0.08 \text{ N/mm}^2 \times b \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / f_{yk} = 381 \text{ mm}^2/\text{m}$$

Section in shear - section 6.2

Design shear force at support

$$V_{Ed,max} = \max(\text{abs}(V_{z2_max}), \text{abs}(V_{z2_red_max})) = 80 \text{ kN}$$

Min lever arm in shear zone

$$z = 344 \text{ mm}$$

Maximum design shear resistance - exp.6.9

$$V_{Rd,max} = \alpha_{cw} \times b \times z \times v_1 \times f_{cwd} / (\cot(\theta_{max}) + \tan(\theta_{max})) = 770 \text{ kN}$$

PASS - Design shear force at support is less than maximum design shear resistance

Design shear force within zone

$$V_{Ed} = 80 \text{ kN}$$

Design shear stress

$$v_{Ed} = V_{Ed} / (b \times z) = 0.516 \text{ N/mm}^2$$

Angle of concrete compression strut - cl.6.2.3

$$\theta = \min(\max(0.5 \times \text{Asin}(\min(2 \times v_{Ed} / (\alpha_{cw} \times f_{cwd} \times v_1)), 1)), 21.8 \text{ deg}), 45 \text{ deg}) = 21.8 \text{ deg}$$

Area of shear reinforcement required - exp.6.8

$$A_{sv,des} = V_{Ed} \times b / (f_{yd} \times \cot(\theta)) = 214 \text{ mm}^2/\text{m}$$

Area of shear reinforcement required

$$A_{sv,req} = \max(A_{sv,min}, A_{sv,des}) = 381 \text{ mm}^2/\text{m}$$

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Shear reinforcement provided

2×10 legs @ 250 c/c

Area of shear reinforcement provided

$A_{sv,prov} = 628 \text{ mm}^2/\text{m}$

PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing - exp.9.6N

$s_{vl,max} = 0.75 \times d = 271 \text{ mm}$

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

Beam - Span 3

Rectangular section details

Section width

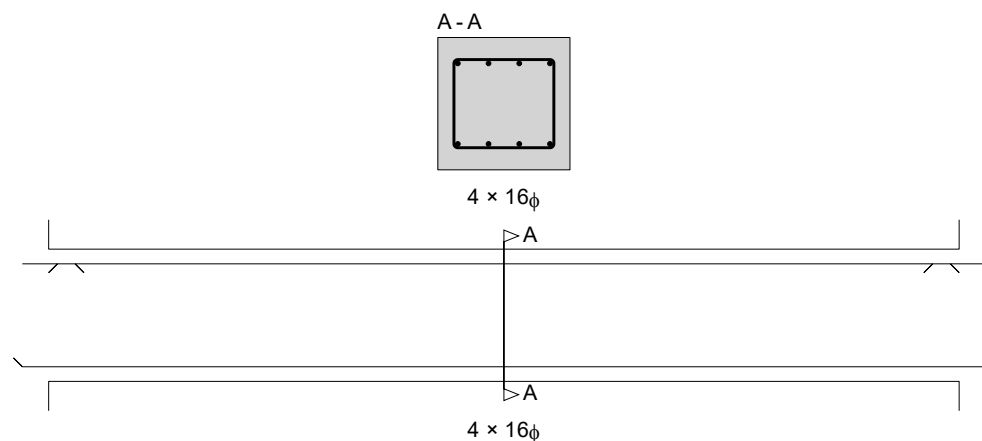
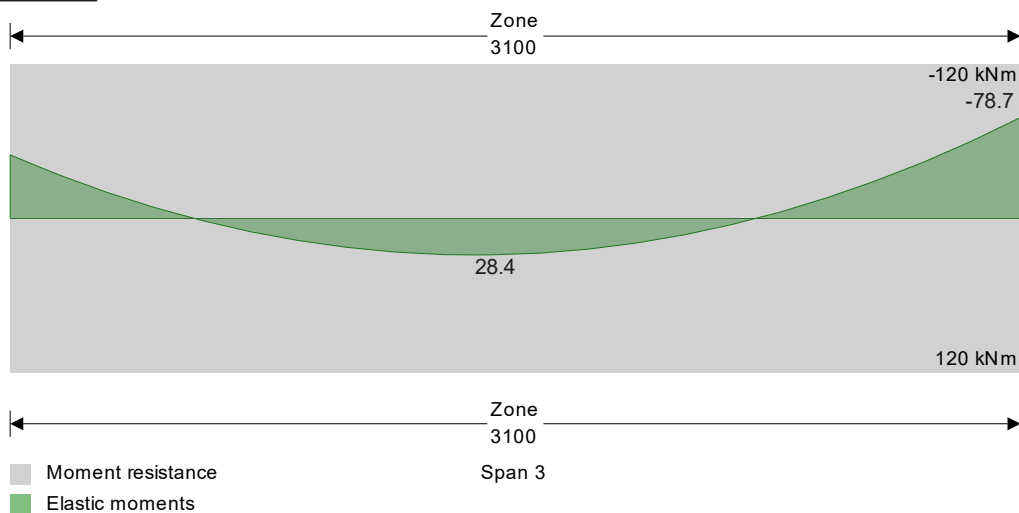
$b = 450 \text{ mm}$

Section depth

$h = 450 \text{ mm}$

PASS - Minimum dimensions for fire resistance met

Moment design



Positive moment - section 6.1

Design bending moment

$M = \text{abs}(M_{m1_s3_z2_max_red}) = 28.4 \text{ kNm}$

Effective depth of tension reinforcement

$d = 362 \text{ mm}$

Redistribution ratio

$\delta = \min(M_{pos_red_z2} / M_{pos_z2}, 1) = 1.000$

$K = M / (b \times d^2 \times f_{ck}) = 0.017$

$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$

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K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$
Depth of neutral axis	$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$
Area of tension reinforcement required	$A_{s,req} = M / (f_{yd} \times z) = 190 \text{ mm}^2$
Tension reinforcement provided	$4 \times 16\phi$
Area of tension reinforcement provided	$A_{s,prov} = 804 \text{ mm}^2$
Minimum area of reinforcement - exp.9.1N	$A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{s,max} = 0.04 \times b \times h = 8100 \text{ mm}^2$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width	$w_k = 0.3 \text{ mm}$
Design value modulus of elasticity reinf - 3.2.7(4)	$E_s = 200000 \text{ N/mm}^2$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$
Stress distribution coefficient	$k_c = 0.4$
Non-uniform self-equilibrating stress coefficient	$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$
Actual tension bar spacing	$S_{bar} = (b - (2 \times (c_{nom,s} + \phi_{m1_s3_z2_v}) + \phi_{m1_s3_z2_b_L1} \times N_{m1_s3_z2_b_L1})) / (N_{m1_s3_z2_b_L1} - 1) + \phi_{m1_s3_z2_b_L1} = 104.7 \text{ mm}$
Maximum stress permitted (Table 7.3N)	$\sigma_s = 316 \text{ N/mm}^2$
Steel to concrete modulus of elast. ratio	$\alpha_{cr} = E_s / E_{cm} = 6.19$
Distance of the Elastic NA from bottom of beam	$y = (b \times h^2 / 2 + A_{s,prov} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,prov} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$
Area of concrete in the tensile zone	$A_{ct} = b \times y = 100005 \text{ mm}^2$
Minimum area of reinforcement required - exp.7.1	$A_{s,min} = k_c \times k \times f_{ct,eff} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$

PASS - Area of tension reinforcement provided exceeds minimum required for crack control

Permanent load ratio	$R_{PL} = 0.65$
Service stress in reinforcement	$\sigma_{sr} = f_{yd} \times A_{s,req} / A_{s,prov} \times R_{PL} = 67 \text{ N/mm}^2$
Maximum bar spacing - Tables 7.3N	$S_{bar,max} = 300 \text{ mm}$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio	$\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$
Required tension reinforcement ratio	$\rho_m = A_{s,req} / (b \times d) = 0.00116$
Required compression reinforcement ratio	$\rho'_{m} = A_{s2,req} / (b \times d) = 0.00000$
Structural system factor - Table 7.4N	$K_b = 1.5$
Basic allowable span to depth ratio	$\text{span_to_depth}_{basic} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 239.984$
Reinforcement factor - exp.7.17	$K_s = \min(A_{s,prov} / A_{s,req} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$
Flange width factor	$F1 = 1 = 1.000$
Long span supporting brittle partition factor	$F2 = 1 = 1.000$
Allowable span to depth ratio	$\text{span_to_depth}_{allow} = \min(\text{span_to_depth}_{basic} \times K_s \times F1 \times F2, 40 \times K_b) = 60.000$
Actual span to depth ratio	$\text{span_to_depth}_{actual} = L_{m1_s3} / d = 8.564$

PASS - Actual span to depth ratio is within the allowable limit

Negative moment - section 6.1

Design bending moment	$M = \text{abs}(M_{m1_s3_z2_min_red}) = 78.7 \text{ kNm}$
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Effective depth of tension reinforcement

$$d = 362 \text{ mm}$$

Redistribution ratio

$$\delta = \min(M_{\text{neg_red_z2}} / M_{\text{neg_z2}}, 1) = 1.000$$

$$K = M / (b \times d^2 \times f_{ck}) = 0.048$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$$

Depth of neutral axis

$$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$$

Area of tension reinforcement required

$$A_{s,\text{req}} = M / (f_{yd} \times z) = 526 \text{ mm}^2$$

Tension reinforcement provided

$$4 \times 16\phi$$

Area of tension reinforcement provided

$$A_{s,\text{prov}} = 804 \text{ mm}^2$$

Minimum area of reinforcement - exp.9.1N

$$A_{s,\text{min}} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{s,\text{max}} = 0.04 \times b \times h = 8100 \text{ mm}^2$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width

$$w_k = 0.3 \text{ mm}$$

Design value modulus of elasticity reinf - 3.2.7(4)

$$E_s = 200000 \text{ N/mm}^2$$

Mean value of concrete tensile strength

$$f_{ct,\text{eff}} = f_{ctm} = 2.8 \text{ N/mm}^2$$

Stress distribution coefficient

$$k_c = 0.4$$

Non-uniform self-equilibrating stress coefficient

$$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$$

Actual tension bar spacing

$$s_{\text{bar}} = (b - (2 \times (c_{\text{nom}_s} + \phi_{m1_s3_z2_v}) + \phi_{m1_s3_z2_t_L1} \times N_{m1_s3_z2_t_L1})) / (N_{m1_s3_z2_t_L1} - 1) + \phi_{m1_s3_z2_t_L1} = 104.7 \text{ mm}$$

Maximum stress permitted (Table 7.3N)

$$\sigma_s = 316 \text{ N/mm}^2$$

Steel to concrete modulus of elast. ratio

$$\alpha_{cr} = E_s / E_{cm} = 6.19$$

Distance of the Elastic NA from bottom of beam

$$y = (b \times h^2 / 2 + A_{s,\text{prov}} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,\text{prov}} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$$

Area of concrete in the tensile zone

$$A_{ct} = b \times y = 100005 \text{ mm}^2$$

Minimum area of reinforcement required - exp.7.1

$$A_{s,\text{c,min}} = k_c \times k \times f_{ct,\text{eff}} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$$

PASS - Area of tension reinforcement provided exceeds minimum required for crack control

Permanent load ratio

$$R_{PL} = 0.65$$

Service stress in reinforcement

$$\sigma_{sr} = f_{yd} \times A_{s,\text{req}} / A_{s,\text{prov}} \times R_{PL} = 185 \text{ N/mm}^2$$

Maximum bar spacing - Tables 7.3N

$$s_{\text{bar,max}} = 268.9 \text{ mm}$$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio

$$\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$$

Required tension reinforcement ratio

$$\rho_m = A_{s,\text{req}} / (b \times d) = 0.00323$$

Required compression reinforcement ratio

$$\rho'_{m} = A_{s2,\text{req}} / (b \times d) = 0.00000$$

Structural system factor - Table 7.4N

$$K_b = 1.5$$

Basic allowable span to depth ratio

$$\text{span_to_depth}_{\text{basic}} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 48.967$$

Reinforcement factor - exp.7.17

$$K_s = \min(A_{s,\text{prov}} / A_{s,\text{req}} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$$

Flange width factor

$$F1 = 1 = 1.000$$

Long span supporting brittle partition factor

$$F2 = 1 = 1.000$$

Allowable span to depth ratio

$$\text{span_to_depth}_{\text{allow}} = \min(\text{span_to_depth}_{\text{basic}} \times K_s \times F1 \times F2, 40 \times K_b) = 60.000$$

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Actual span to depth ratio

$$\text{span_to_depth}_{\text{actual}} = L_{m1_s3} / d = 8.564$$

PASS - Actual span to depth ratio is within the allowable limit

Minimum bar spacing (Section 8.2)

Top bar spacing

$$s_{\text{top}} = (b - (2 \times (c_{\text{nom_s}} + \phi_{m1_s3_z2_v}) + \phi_{m1_s3_z2_t_L1} \times N_{m1_s3_z2_t_L1})) / (N_{m1_s3_z2_t_L1} - 1) = 88.7 \text{ mm}$$

Minimum allowable top bar spacing

$$s_{\text{top,min}} = \max(\phi_{m1_s3_z2_t_L1} \times k_{s1}, h_{\text{agg}} + k_{s2}, 20\text{mm}) = 25.0 \text{ mm}$$

PASS - Actual bar spacing exceeds minimum allowable

Bottom bar spacing

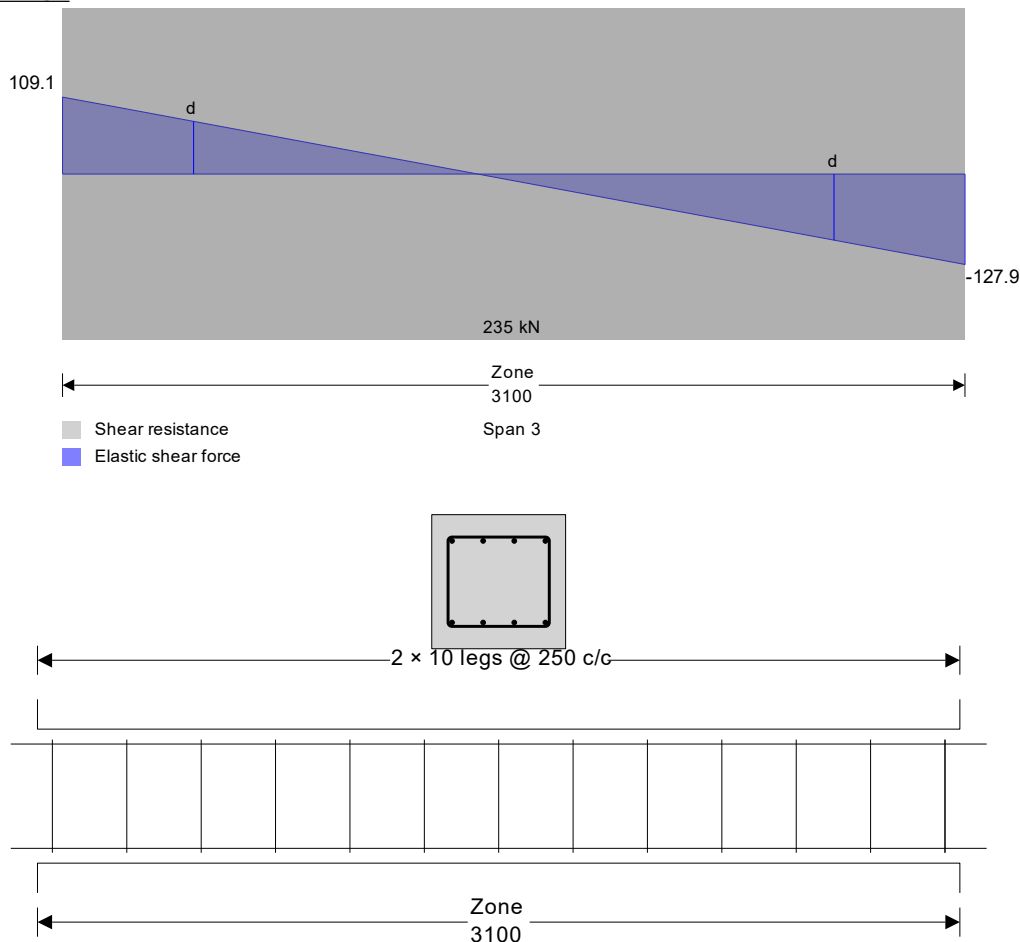
$$s_{\text{bot}} = (b - (2 \times (c_{\text{nom_s}} + \phi_{m1_s3_z2_v}) + \phi_{m1_s3_z2_b_L1} \times N_{m1_s3_z2_b_L1})) / (N_{m1_s3_z2_b_L1} - 1) = 88.7 \text{ mm}$$

Minimum allowable bottom bar spacing

$$s_{\text{bot,min}} = \max(\phi_{m1_s3_z2_b_L1} \times k_{s1}, h_{\text{agg}} + k_{s2}, 20\text{mm}) = 25.0 \text{ mm}$$

PASS - Actual bar spacing exceeds minimum allowable

Shear design



Angle of comp. shear strut for maximum shear

$$\theta_{\text{max}} = 45 \text{ deg}$$

Strength reduction factor - cl.6.2.3(3)

$$v_1 = 0.6 \times (1 - f_{ck} / 250 \text{ N/mm}^2) = 0.533$$

Compression chord coefficient - cl.6.2.3(3)

$$\alpha_{cw} = 1.00$$

Minimum area of shear reinforcement - exp.9.5N

$$A_{sv,\text{min}} = 0.08 \text{ N/mm}^2 \times b \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / f_{yk} = 381 \text{ mm}^2/\text{m}$$

Section in shear - section 6.2

Design shear force at support

$$V_{\text{Ed,max}} = \max(\text{abs}(V_{z2_\text{max}}), \text{abs}(V_{z2_red_max})) = 94 \text{ kN}$$

Min lever arm in shear zone

$$z = 344 \text{ mm}$$

Maximum design shear resistance - exp.6.9

$$V_{\text{Rd,max}} = \alpha_{cw} \times b \times z \times v_1 \times f_{c\text{wd}} / (\cot(\theta_{\text{max}}) + \tan(\theta_{\text{max}})) = 770 \text{ kN}$$

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PASS - Design shear force at support is less than maximum design shear resistance

Design shear force within zone	$V_{Ed} = 94 \text{ kN}$
Design shear stress	$V_{Ed} = V_{Ed} / (b \times z) = 0.604 \text{ N/mm}^2$
Angle of concrete compression strut - cl.6.2.3	$\theta = \min(\max(0.5 \times \text{Asin}(\min(2 \times V_{Ed} / (\alpha_{cw} \times f_{cwd} \times v_1), 1)), 21.8 \text{ deg}), 45 \text{ deg}) = 21.8 \text{ deg}$
Area of shear reinforcement required - exp.6.8	$A_{sv,des} = V_{Ed} \times b / (f_{yd} \times \cot(\theta)) = 250 \text{ mm}^2/\text{m}$
Area of shear reinforcement required	$A_{sv,req} = \max(A_{sv,min}, A_{sv,des}) = 381 \text{ mm}^2/\text{m}$
Shear reinforcement provided	2 x 10 legs @ 250 c/c
Area of shear reinforcement provided	$A_{sv,prov} = 628 \text{ mm}^2/\text{m}$
PASS - Area of shear reinforcement provided exceeds minimum required	
Maximum longitudinal spacing - exp.9.6N	$s_{vl,max} = 0.75 \times d = 271 \text{ mm}$

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

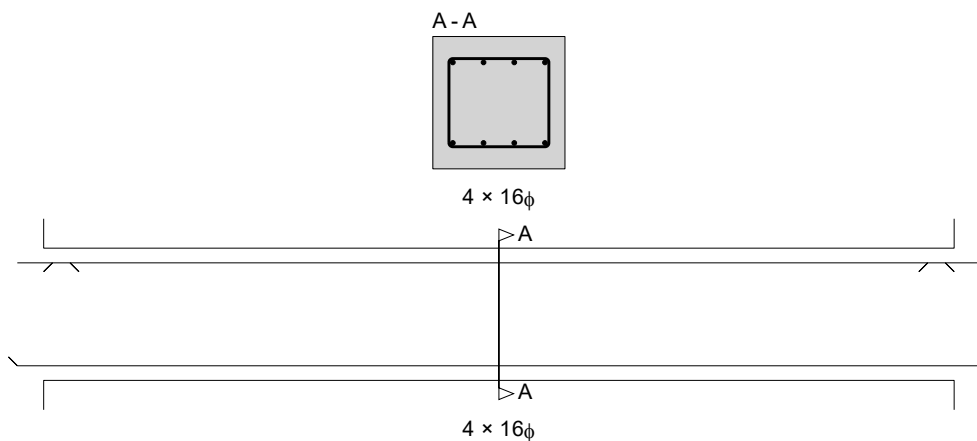
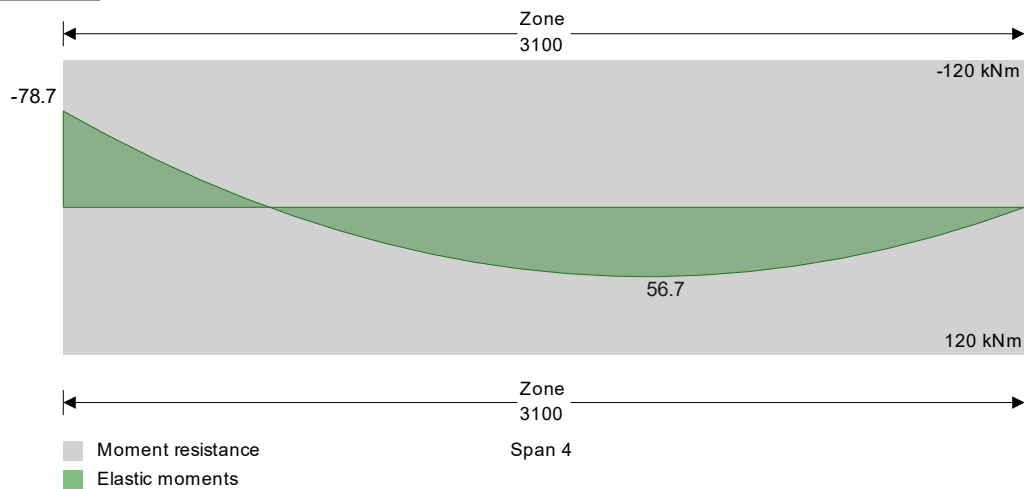
Beam - Span 4

Rectangular section details

Section width	$b = 450 \text{ mm}$
Section depth	$h = 450 \text{ mm}$

PASS - Minimum dimensions for fire resistance met

Moment design



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Positive moment - section 6.1

Design bending moment	$M = \text{abs}(M_{m1_s4_z2_max_red}) = 56.7 \text{ kNm}$
Effective depth of tension reinforcement	$d = 362 \text{ mm}$
Redistribution ratio	$\delta = \min(M_{pos_red_z2} / M_{pos_z2}, 1) = 1.000$
	$K = M / (b \times d^2 \times f_{ck}) = 0.034$
	$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$
	$K' > K$ - No compression reinforcement is required
Lever arm	$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$
Depth of neutral axis	$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$
Area of tension reinforcement required	$A_{s,req} = M / (f_{yd} \times z) = 379 \text{ mm}^2$
Tension reinforcement provided	$4 \times 16\phi$
Area of tension reinforcement provided	$A_{s,prov} = 804 \text{ mm}^2$
Minimum area of reinforcement - exp.9.1N	$A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{s,max} = 0.04 \times b \times h = 8100 \text{ mm}^2$
	PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width	$w_k = 0.3 \text{ mm}$
Design value modulus of elasticity reinf - 3.2.7(4)	$E_s = 200000 \text{ N/mm}^2$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = 2.8 \text{ N/mm}^2$
Stress distribution coefficient	$k_c = 0.4$
Non-uniform self-equilibrating stress coefficient	$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$
Actual tension bar spacing	$s_{bar} = (b - (2 \times (C_{nom_s} + \phi_{m1_s4_z2_v}) + \phi_{m1_s4_z2_b_L1} \times N_{m1_s4_z2_b_L1})) / (N_{m1_s4_z2_b_L1} - 1) + \phi_{m1_s4_z2_b_L1} = 104.7 \text{ mm}$
Maximum stress permitted (Table 7.3N)	$\sigma_s = 316 \text{ N/mm}^2$
Steel to concrete modulus of elast. ratio	$\alpha_{cr} = E_s / E_{cm} = 6.19$
Distance of the Elastic NA from bottom of beam	$y = (b \times h^2 / 2 + A_{s,prov} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s,prov} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$
Area of concrete in the tensile zone	$A_{ct} = b \times y = 100005 \text{ mm}^2$
Minimum area of reinforcement required - exp.7.1	$A_{s,min} = k_c \times k \times f_{ct,eff} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$
	PASS - Area of tension reinforcement provided exceeds minimum required for crack control
Permanent load ratio	$R_{PL} = 0.65$
Service stress in reinforcement	$\sigma_{sr} = f_{yd} \times A_{s,req} / A_{s,prov} \times R_{PL} = 133 \text{ N/mm}^2$
Maximum bar spacing - Tables 7.3N	$s_{bar,max} = 300 \text{ mm}$
	PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio	$\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$
Required tension reinforcement ratio	$\rho_m = A_{s,req} / (b \times d) = 0.00233$
Required compression reinforcement ratio	$\rho'_m = A_{s2,req} / (b \times d) = 0.00000$
Structural system factor - Table 7.4N	$K_b = 1.3$
Basic allowable span to depth ratio	$\text{span_to_depth}_{basic} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 69.339$
Reinforcement factor - exp.7.17	$K_s = \min(A_{s,prov} / A_{s,req} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$
Flange width factor	$F1 = 1 = 1.000$

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Long span supporting brittle partition factor

$$F2 = 1 = 1.000$$

Allowable span to depth ratio

$$\text{span_to_depth}_{\text{allow}} = \min(\text{span_to_depth}_{\text{basic}} \times K_s \times F1 \times F2, 40 \times K_b) = 52.000$$

Actual span to depth ratio

$$\text{span_to_depth}_{\text{actual}} = L_{m1_s4} / d = 8.564$$

PASS - Actual span to depth ratio is within the allowable limit

Negative moment - section 6.1

Design bending moment

$$M = \max(\beta_1 \times \text{abs}(M_{m1_s4_max_red}), \text{abs}(M_{m1_s4_z2_min_red})) = 78.7 \text{ kNm}$$

Effective depth of tension reinforcement

$$d = 362 \text{ mm}$$

Redistribution ratio

$$\delta = \min(M_{\text{neg_red_z2}} / M_{\text{neg_z2}}, 1) = 1.000$$

$$K = M / (b \times d^2 \times f_{ck}) = 0.048$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - k_1) / (2 \times k_2)) \times (\lambda \times (\delta - k_1) / (2 \times k_2)) = 0.207$$

K' > K - No compression reinforcement is required

Lever arm

$$z = \min(0.5 \times d \times [1 + (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}], 0.95 \times d) = 344 \text{ mm}$$

Depth of neutral axis

$$x = 2 \times (d - z) / \lambda = 45 \text{ mm}$$

Area of tension reinforcement required

$$A_{s, \text{req}} = M / (f_{yd} \times z) = 526 \text{ mm}^2$$

Tension reinforcement provided

$$4 \times 16\phi$$

Area of tension reinforcement provided

$$A_{s, \text{prov}} = 804 \text{ mm}^2$$

Minimum area of reinforcement - exp.9.1N

$$A_{s, \text{min}} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times b \times d = 234 \text{ mm}^2$$

Maximum area of reinforcement - cl.9.2.1.1(3)

$$A_{s, \text{max}} = 0.04 \times b \times h = 8100 \text{ mm}^2$$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Maximum crack width

$$w_k = 0.3 \text{ mm}$$

Design value modulus of elasticity reinf - 3.2.7(4)

$$E_s = 200000 \text{ N/mm}^2$$

Mean value of concrete tensile strength

$$f_{ct, \text{eff}} = f_{ctm} = 2.8 \text{ N/mm}^2$$

Stress distribution coefficient

$$k_c = 0.4$$

Non-uniform self-equilibrating stress coefficient

$$k = \min(\max(1 + (300 \text{ mm} - \min(h, b)) \times 0.35 / 500 \text{ mm}, 0.65), 1) = 0.90$$

Actual tension bar spacing

$$s_{\text{bar}} = (b - (2 \times (c_{\text{nom_s}} + \phi_{m1_s4_z2_v}) + \phi_{m1_s4_z2_t_L1} \times N_{m1_s4_z2_t_L1})) / (N_{m1_s4_z2_t_L1} - 1) + \phi_{m1_s4_z2_t_L1} = 104.7 \text{ mm}$$

Maximum stress permitted (Table 7.3N)

$$\sigma_s = 316 \text{ N/mm}^2$$

Steel to concrete modulus of elast. ratio

$$\alpha_{cr} = E_s / E_{cm} = 6.19$$

Distance of the Elastic NA from bottom of beam

$$y = (b \times h^2 / 2 + A_{s, \text{prov}} \times (\alpha_{cr} - 1) \times (h - d)) / (b \times h + A_{s, \text{prov}} \times (\alpha_{cr} - 1)) = 222 \text{ mm}$$

Area of concrete in the tensile zone

$$A_{ct} = b \times y = 100005 \text{ mm}^2$$

Minimum area of reinforcement required - exp.7.1

$$A_{s, \text{min}} = k_c \times k \times f_{ct, \text{eff}} \times A_{ct} / \sigma_s = 313 \text{ mm}^2$$

PASS - Area of tension reinforcement provided exceeds minimum required for crack control

Permanent load ratio

$$R_{PL} = 0.65$$

Service stress in reinforcement

$$\sigma_{sr} = f_{yd} \times A_{s, \text{req}} / A_{s, \text{prov}} \times R_{PL} = 185 \text{ N/mm}^2$$

Maximum bar spacing - Tables 7.3N

$$s_{\text{bar, max}} = 268.9 \text{ mm}$$

PASS - Maximum bar spacing exceeds actual bar spacing for crack control

Deflection control - Section 7.4

Reference reinforcement ratio

$$\rho_{m0} = (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / 1000 = 0.00529$$

Required tension reinforcement ratio

$$\rho_m = A_{s, \text{req}} / (b \times d) = 0.00323$$

Required compression reinforcement ratio

$$\rho'_m = A_{s2, \text{req}} / (b \times d) = 0.00123$$

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Structural system factor - Table 7.4N

Basic allowable span to depth ratio

Reinforcement factor - exp.7.17

Flange width factor

Long span supporting brittle partition factor

Allowable span to depth ratio

Actual span to depth ratio

$$K_b = 1.3$$

$$\text{span_to_depth}_{\text{basic}} = K_b \times [11 + 1.5 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times \rho_{m0} / \rho_m + 3.2 \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times (\rho_{m0} / \rho_m - 1)^{1.5}] = 42.438$$

$$K_s = \min(A_{s,\text{prov}} / A_{s,\text{req}} \times 500 \text{ N/mm}^2 / f_{yk}, 1.5) = 1.500$$

$$F1 = 1 = 1.000$$

$$F2 = 1 = 1.000$$

$$\text{span_to_depth}_{\text{allow}} = \min(\text{span_to_depth}_{\text{basic}} \times K_s \times F1 \times F2, 40 \times K_b) = 52.000$$

$$\text{span_to_depth}_{\text{actual}} = L_{m1_s4} / d = 8.564$$

PASS - Actual span to depth ratio is within the allowable limit

Minimum bar spacing (Section 8.2)

Top bar spacing

$$S_{\text{top}} = (b - (2 \times (c_{\text{nom}_s} + \phi_{m1_s4_z2_v}) + \phi_{m1_s4_z2_t_L1} \times N_{m1_s4_z2_t_L1})) / (N_{m1_s4_z2_t_L1} - 1) = 88.7 \text{ mm}$$

Minimum allowable top bar spacing

$$S_{\text{top,min}} = \max(\phi_{m1_s4_z2_t_L1} \times k_{s1}, h_{\text{agg}} + k_{s2}, 20\text{mm}) = 25.0 \text{ mm}$$

PASS - Actual bar spacing exceeds minimum allowable

Bottom bar spacing

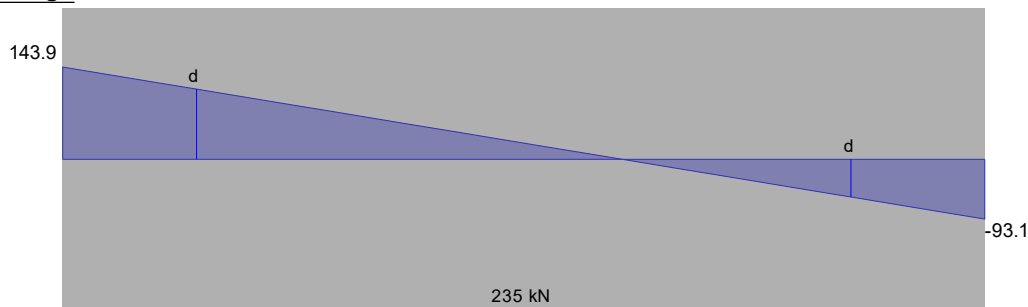
$$S_{\text{bot}} = (b - (2 \times (c_{\text{nom}_s} + \phi_{m1_s4_z2_v}) + \phi_{m1_s4_z2_b_L1} \times N_{m1_s4_z2_b_L1})) / (N_{m1_s4_z2_b_L1} - 1) = 88.7 \text{ mm}$$

Minimum allowable bottom bar spacing

$$S_{\text{bot,min}} = \max(\phi_{m1_s4_z2_b_L1} \times k_{s1}, h_{\text{agg}} + k_{s2}, 20\text{mm}) = 25.0 \text{ mm}$$

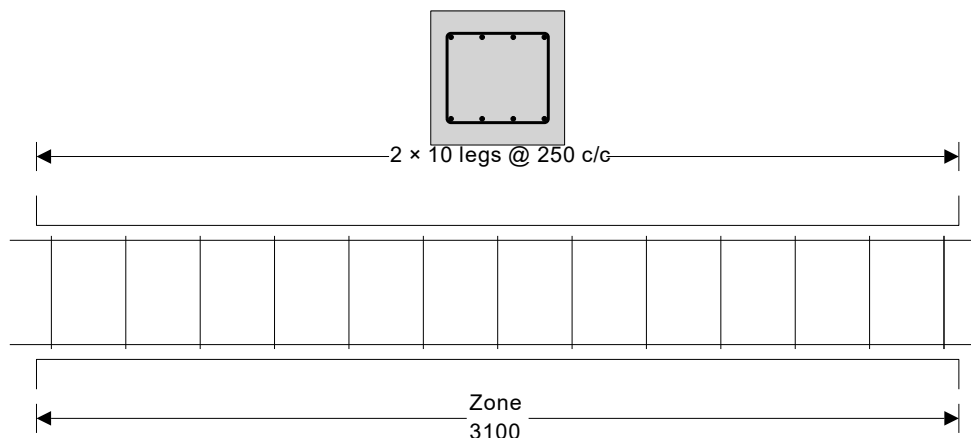
PASS - Actual bar spacing exceeds minimum allowable

Shear design



Zone 3100
Span 4

Shear resistance
Elastic shear force



Angle of comp. shear strut for maximum shear

$$\theta_{\text{max}} = 45 \text{ deg}$$

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Strength reduction factor - cl.6.2.3(3)

$$v_1 = 0.6 \times (1 - f_{ck} / 250 \text{ N/mm}^2) = \mathbf{0.533}$$

Compression chord coefficient - cl.6.2.3(3)

$$\alpha_{cw} = \mathbf{1.00}$$

Minimum area of shear reinforcement - exp.9.5N

$$A_{sv,min} = 0.08 \text{ N/mm}^2 \times b \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} / f_{yk} = \mathbf{381 \text{ mm}^2/\text{m}}$$

Section in shear - section 6.2

Design shear force at support

$$V_{Ed,max} = \max(\text{abs}(V_{z2,max}), \text{abs}(V_{z2,red,max})) = \mathbf{109 \text{ kN}}$$

Min lever arm in shear zone

$$z = \mathbf{344 \text{ mm}}$$

Maximum design shear resistance - exp.6.9

$$V_{Rd,max} = \alpha_{cw} \times b \times z \times v_1 \times f_{cwd} / (\cot(\theta_{max}) + \tan(\theta_{max})) = \mathbf{770 \text{ kN}}$$

PASS - Design shear force at support is less than maximum design shear resistance

Design shear force within zone

$$V_{Ed} = \mathbf{109 \text{ kN}}$$

Design shear stress

$$v_{Ed} = V_{Ed} / (b \times z) = \mathbf{0.707 \text{ N/mm}^2}$$

Angle of concrete compression strut - cl.6.2.3

$$\theta = \min(\max(0.5 \times \text{Asin}(\min(2 \times v_{Ed} / (\alpha_{cw} \times f_{cwd} \times v_1), 1)), 21.8 \text{ deg}), 45 \text{ deg}) = \mathbf{21.8 \text{ deg}}$$

Area of shear reinforcement required - exp.6.8

$$A_{sv,des} = V_{Ed} \times b / (f_{yd} \times \cot(\theta)) = \mathbf{293 \text{ mm}^2/\text{m}}$$

Area of shear reinforcement required

$$A_{sv,req} = \max(A_{sv,min}, A_{sv,des}) = \mathbf{381 \text{ mm}^2/\text{m}}$$

Shear reinforcement provided

$$2 \times 10 \text{ legs @ } 250 \text{ c/c}$$

Area of shear reinforcement provided

$$A_{sv,prov} = \mathbf{628 \text{ mm}^2/\text{m}}$$

PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing - exp.9.6N

$$s_{vl,max} = 0.75 \times d = \mathbf{271 \text{ mm}}$$

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum