Summary

Cantilever wall, stem height 4 m, base 2.75 m wide. Overall: ALL CHECKS PASS.

Check	Result
Stability, static	PASS
Stability, earthquake (Av down)	PASS
Stem: 12 mm @ 140	PASS
Toe: 10 mm @ 120	PASS
Heel: 10 mm @ 140	PASS
Durability: M25, covers 50 / 50 mm, moderate exposure	PASS

1 Inputs

Item	Value	Item	Value
Stem height h	4.000 m	Concrete grade	M25
Stem thickness top / base	200 / 375 mm	Steel grade	Fe 500
Base thickness	375 mm	Cover earth face / other	50 / 50 mm
Toe / heel	0.950 / 1.425 m	Bars available	8, 10, 12, 16, 20, 25, 28, 32 mm
Base width B	2.750 m	Backfill γ / γsat	18 / 20 kN/m³
Foundation depth	1.00 m	Angle of internal friction φ	30°
Backfill slope β	0°	Safe bearing capacity	150 kN/m²
Wall length	10 m	Base friction μ	0.5
Surcharge	0 kN/m²	Water table depth	none
FS overturning / sliding	2 / 1.4	Seismic zone / I	III / 1
Partial load factor	1.5 static, 1.2 seismic	Seismic load case	runs
Shear key (width × depth)	none	Filling over the toe (OB-4)	soil 625 mm at 18 kN/m³, not counted

Note: IS 456 cl. 20.1 requires a factor of safety of at least 1.4 against overturning; this design uses 2 as entered.

1.1 Durability (IS 456 cl. 8.2, 26.4, 35.3.2)

Requirement	Required	Provided	Result
Exposure (IS 456 Table 3)	earth faces moderate, front face moderate	governing: moderate	
Minimum grade (Table 5)	M25	M25	PASS
Maximum free w/c ratio (Table 5)	0.5	site control	
Minimum cement content (Table 5)	300 kg/m³	site control	
Cover, earth face (Table 16, cl. 26.4.2.2)	50 mm	50 mm	PASS
Cover, other faces (Table 16, cl. 26.4.2.2)	50 mm	50 mm	PASS
Crack width limit (cl. 35.3.2)	0.2 mm	see section 5	

2 Codes referred

Code	Used for
IS 456:2000	Plain and reinforced concrete: limit state design, cover, detailing
IS 1893 (Part 1):2016	Seismic zones and zone factors

Code	Used for
IS 1893 (Part 3):2014	Earthquake design of retaining walls (bridges and retaining walls)
IS 14458 (Part 1):1998	Retaining walls for hill areas: guidelines, drainage
IS 6403:1981	Bearing capacity of shallow foundations
IS 1904:1986	Design and construction of foundations in soils
IS 875 (Part 2):1987	Imposed loads (surcharge)
IS 1786:2008	High strength deformed steel bars
IS 2502:1963	Bending and fixing of bars (bar bending schedule)
SP 16:1980 / SP 34:1987	Design aids and handbook on concrete reinforcement and detailing

3 Earth pressure

Rankine active coefficient Ka = (1 − sin φ)/(1 + sin φ) = (1 − sin 30°)/(1 + sin 30°) = 0.3333
Height on the vertical plane through the heel H' = 4.375 m
Pressure diagram: earth Ka·γ·z. Integrated numerically (Simpson's rule).
Total horizontal thrust P = 57.42 kN/m acting at 1.458 m above the base underside.

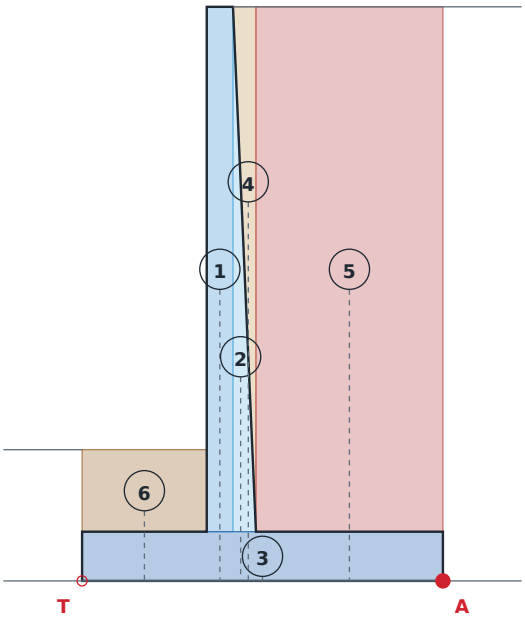
Earthquake

Zone III: seismic load case required (IS 1893 Part 3).
Ah = (Z/2)·I = 0.0800; Av = (2/3)·Ah = 0.0533 (IS 1893 Part 1 Table 3 zone factor; R = 1, Sa/g = 1 for a rigid wall). Soil increment at 0.5·H', surcharge increment at 0.66·H' (IS 1893 Part 3).

Quantity	Av down (+)	Av up (−)
Kae (Mononobe-Okabe, δ = 0)	0.3860	0.3803
Dynamic increment ΔPae, soil, at 0.5·H' (kN/m)	5.52	11.58

4 Stability (service loads)

Loads and lever arms about A (normal load case)



Each numbered area is a vertical load of the table below; the dashed line drops to the base where it acts. Its lever arm x is measured from A, the heel end of the base underside (LA-0). The wall tips about T, the toe tip, so the overturning check uses the lever about T, B − x.

4.1 Static load case

No.	Vertical (gravity) loads	W (kN/m)	x from A (m)	W·x about A	B − x, about T (m)	W·(B − x) about T	Resisting
1	Stem (rectangle)	20.00	1.700	34.00	1.050	21.00	yes
2	Stem (taper)	8.75	1.542	13.49	1.208	10.57	yes
3	Base slab	25.78	1.375	35.45	1.375	35.45	yes
4	Soil over stem taper	6.30	1.483	9.35	1.267	7.98	yes
5	Soil over heel	102.60	0.712	73.10	2.038	209.05	yes
6	Overburden over toe: soil	10.69	2.275	24.31	0.475	5.08	no

No.	Vertical (gravity) loads	W (kN/m)	x from A (m)	W·x about A	B − x, about T (m)	W·(B − x) about T	Resisting
	Total of the resisting loads	163.43		165.39		M_R = 284.05	

Lateral loads	P (kN/m)	Height above base (m)	Moment (kN·m/m)
Active thrust (earth, water, surcharge)	57.42	1.458	83.74

Overturning is about T, the edge the wall tips about: M_R = Σ W·(B − x) of the resisting loads = 284.05 kN·m/m; M_O = Σ P·height. The resultant acts x_r = 1.570 m from A (B/2 = 1.375 m), so e = x_r − B/2 = 0.195 m towards the toe.

Check	Achieved	Required	Result
Overturning (IS 456 cl. 20.1)	3.39	≥ 2.00	PASS
Sliding μ(ΣV − U)/ΣH (IS 456 cl. 20.2)	1.42	≥ 1.40	PASS
Eccentricity e (no tension)	0.195 m	≤ B/6 = 0.458 m	PASS
Max base pressure (IS 6403)	90.3 kN/m²	≤ 150.0 kN/m²	PASS
Min base pressure	36.3 kN/m²	≥ 0	PASS

4.2 Seismic load case (IS 1893 Part 3), governing direction: earthquake (Av down)

No.	Vertical (gravity) loads	W (kN/m)	x from A (m)	W·x about A	B − x, about T (m)	W·(B − x) about T	Resisting
1	Stem (rectangle)	18.93	1.700	32.19	1.050	19.88	yes
2	Stem (taper)	8.28	1.542	12.77	1.208	10.01	yes
3	Base slab	24.41	1.375	33.56	1.375	33.56	yes
4	Soil over stem taper	5.96	1.483	8.85	1.267	7.55	yes
5	Soil over heel	97.13	0.712	69.20	2.038	197.90	yes
6	Overburden over toe: soil	10.69	2.275	24.31	0.475	5.08	no
	Total of the resisting loads	154.71		156.57		M_R = 268.90	

Lateral loads	P (kN/m)	Height above base (m)	Moment (kN·m/m)
Active thrust (earth, water, surcharge)	57.42	1.458	83.74
Earthquake increment of thrust	5.52	2.188	12.08
Inertia: Stem (rectangle)	1.60	2.375	3.80
Inertia: Stem (taper)	0.70	1.708	1.20
Inertia: Base slab	2.06	0.188	0.39
Inertia: Soil over stem taper	0.50	3.042	1.53
Inertia: Soil over heel	8.21	2.375	19.49

Overturning is about T, the edge the wall tips about: M_R = Σ W·(B − x) of the resisting loads = 268.90 kN·m/m; M_O = Σ P·height. The resultant acts x_r = 1.833 m from A (B/2 = 1.375 m), so e = x_r − B/2 = 0.458 m towards the toe.

Check	Achieved	Required	Result
Overturning (IS 456 cl. 20.1)	2.20	≥ 1.50	PASS
Sliding μ(ΣV − U)/ΣH (IS 456 cl. 20.2)	1.02	≥ 1.00	PASS
Eccentricity e (no tension)	0.458 m	≤ B/6 = 0.458 m	PASS
Max base pressure (IS 6403)	120.2 kN/m²	≤ 199.5 kN/m²	PASS
Min base pressure	0.1 kN/m²	≥ 0	PASS

5 Reinforcement design (IS 456 limit state)

M25, Fe 500. Strip width b = 1000 mm. Mu,lim = 0.36·fck·b·xu,max·(d − 0.42·xu,max) (Annex G); Ast from Mu = 0.87·fy·Ast·d·(1 − Ast·fy/(b·d·fck)) (Annex G-1.1); minimum 0.12 % (cl. 26.5.2.1); spacing ≤ 3d and 300 mm (cl. 26.3.3); τc from Table 19 with k (cl. 40.2.1.1); Ld = φ·0.87·fy/(4·τbd) (cl. 26.2.1). Crack width (Annex F) under the static service moment Ms: cracked section with m = Es/(Ec/(1 + θ)), Ec = 5000√fck (cl. 6.2.3.1), θ = 1.6 (cl. 6.2.5.1); fs = Ms/(As·(d − x/3)); εm = ε1 − b(h − x)²/(3·Es·As·(d − x)); w = 3·acr·εm/(1 + 2(acr − cmin)/(h − x)), acr midway between bars. Limit 0.2 mm (cl. 35.3.2); the bar spacing is closed until the limit is met.

Quantity	Stem	Toe	Heel
Tension face	earth face	bottom face	top face
Governing combination	earthquake (1.2)	earthquake (1.2)	earthquake (1.2)
D / d (mm)	375 / 319	375 / 320	375 / 320
Mu (kN·m/m)	104.99	52.52	73.75
Mu,lim (kN·m/m)	339.90	342.03	342.03
Ast required (mm²/m)	797	450	549
Bars provided	12 mm @ 140	10 mm @ 120	10 mm @ 140
Ast provided (mm²/m)	808	654	561
Vu (kN/m)	72.00	102.68	85.77
τv / k·τc (N/mm²)	0.226 / 0.362	0.321 / 0.328	0.268 / 0.308
Ld (mm)	583	485	485
Distribution steel	8 mm @ 110	8 mm @ 110	8 mm @ 110
Ms service (kN·m/m)	64.00	33.72	36.28
fs service (N/mm²)	274	176	219
Crack width / limit (mm)	0.196 / 0.2	0.031 / 0.2	0.052 / 0.2
Result	PASS	PASS	PASS

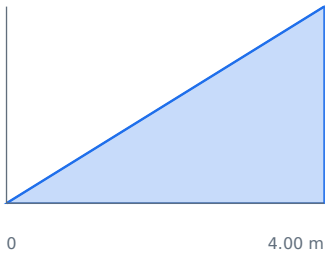
5.1 Member diagrams and worked calculations

Each member is a cantilever measured from its free end to its support. Diagrams are for service loads, per metre run; the design values are the factored values in the steps below (specs 10-diagrams-calcs.md).

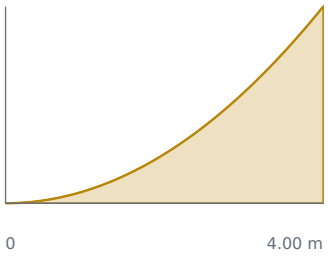
5.1.1 Stem (tension face: earth face; length L = 4.000 m, x = depth below the top of the backfill (m))

Static load case: Horizontal earth pressure

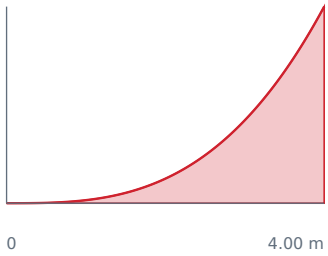
Load w (kN/m²)
at support: 24.00 kN/m²



Shear V (kN/m)
at support: 48.00 kN/m

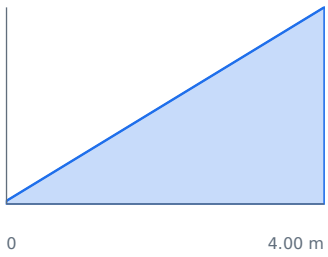


Moment M (kN·m/m)
at support: 64.00 kN·m/m

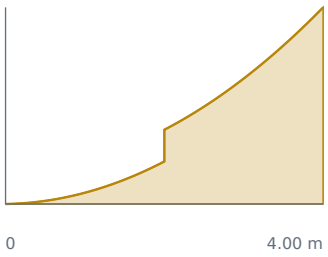


Lateral loads (kN/m²): Earth pressure: 24.00 at the support, largest 24.00.
Seismic load case (IS 1893 Part 3): Horizontal earth pressure + inertia

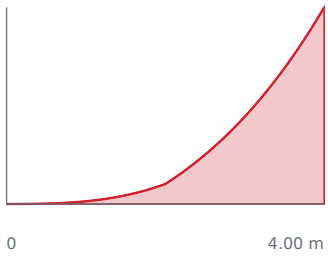
Load w (kN/m²)
at support: 24.75 kN/m²



Shear V (kN/m)
at support: 59.98 kN/m



Moment M (kN·m/m)
at support: 87.49 kN·m/m



Lateral loads (kN/m²): Earth pressure: 24.00 at the support, largest 24.00; Inertia of the stem (seismic): 0.75 at the support, largest 0.75.
Point load 9.68 kN/m at x = 2.000 m: Earthquake increment, soil (0.5·h above base)

Step	Formula	Working	Result	IS clause
	Loads and forces			
L1	Active earth pressure coefficient Ka = (1 − sin φ)/(1 + sin φ); sloping backfill: Ka = cos β·(cos β − √(cos²β − cos²φ))/(cos β + √(cos²β − cos²φ))	Ka = (1 − sin φ)/(1 + sin φ) = (1 − sin 30°)/(1 + sin 30°) = 0.3333	0.3333	Rankine; spec EP-1, EP-2, EP-8
L2	Pressure ordinates on the stem σ'(z) = Σ γ·Δz (γsat − γw below the water table); p = Ka·(σ' + q) + γw·(z − zw)	q = 0 kN/m²; z = 0.000 m: σ' = 0.00 kN/m², p = 0.00 kN/m²; z = 4.000 m: σ' = 72.00 kN/m², p = 24.00 kN/m²	p at the base = 24.00 kN/m²	spec EP-4, EP-5, EP-8
LSG 1	Earth pressure, segment 1 (z = 0.000 to 4.000 m) F = w_a·Δx + ½(w_b − w_a)·Δx; lever arm to the support = L − centroid; M = Σ F·arm	w_a = 0.00, w_b = 24.00 kN/m²; Δx = 4.000 m; rectangle 0.00 × 4.000 = 0.00 kN/m, lever arm 2.000 m; triangle ½ × (24.00 − 0.00) × 4.000 = 48.00 kN/m, lever arm 1.333 m; M = 0.00 × 2.000 + 48.00 × 1.333 = 64.00 kN·m/m	F = 48.00 kN/m, M = 64.00 kN·m/m	spec EP-6, EP-7

Step	Formula	Working	Result	IS clause
LS-V	Shear at the base of the stem, static (Vs) Vs = cos β·Σ F	Vs = 1.0000 × 48.00 = 48.00 kN/m	Vs = 48.00 kN/m	spec EP-7, RC-1
LS-M	Moment at the base of the stem, static (Ms) Ms = cos β·Σ M	Ms = 1.0000 × 64.00 = 64.00 kN·m/m	Ms = 64.00 kN·m/m	spec EP-7, RC-1
LE1	Seismic coefficients Ah = (Z/2)·I·(Sa/g), Sa/g = 1; Av = (2/3)·Ah	Zone III: Ah = (0.160/2) × 1 = 0.0800; Av = 2/3 × 0.0800 = 0.0533	Ah = 0.0800, Av = 0.0533	IS 1893 Part 1; spec SE-2, SE-3
LE2	Backfill used for the earthquake increment γ_eq = dry weight of the layers/h; φ_eq = thickness-weighted φ; Pa = ½·Ka·γ_eq·h²	γ_eq = 18.00 kN/m³, φ_eq = 30.00°, Ka = 0.3333, Pa = ½ × 0.3333 × 18.00 × 4.000² = 48.00 kN/m	Pa = 48.00 kN/m	spec SE-5, SE-7 (A-16)
LE3	Earthquake increments of the soil and surcharge thrust (Mononobe-Okabe, δ = 0) Kae = cos²(φ − ψ)/[cos²ψ·(1 + √(sin φ·sin(φ − ψ − i)/(cos ψ·cos i)))²], ψ = atan(Ah/(1 − Av)); dP = ½·γ·h²·(1 − Av)·Kae − Pa; dQ = q·h·((1 − Av)·Kae − Ka)	Av down (0.0533): Kae = 0.3860; dP = ½ × 18.00 × 4.000² × (1 − 0.0533) × 0.3860 − 48.00 = 4.62 kN/m; dQ = 0 × 4.000 × ((1 − 0.0533) × 0.3860 − 0.3333) = 0.00 kN/m; moment dP × 0.5h + dQ × 0.66h = 9.23 kN·m/m; Av up (−0.0533): Kae = 0.3803; dP = ½ × 18.00 × 4.000² × (1 + 0.0533) × 0.3803 − 48.00 = 9.68 kN/m; dQ = 0 × 4.000 × ((1 + 0.0533) × 0.3803 − 0.3333) = 0.00 kN/m; moment dP × 0.5h + dQ × 0.66h = 19.36 kN·m/m; the direction with the larger moment governs	dP = 9.68 kN/m at 0.5h, dQ = 0.00 kN/m at 0.66h	IS 1893 Part 3; spec SE-4, SE-5
LE4	Inertia of the stem rectangle Ah·γc·t_top·h at h/2; triangle Ah·γc·(t_base − t_top)·h/2 at h/3 above the base	rectangle 0.0800 × 25 × 0.200 × 4.000 = 1.60 kN/m at 2.000 m; triangle 0.0800 × 25 × (0.375 − 0.200) × 4.000/2 = 0.70 kN/m at 1.333 m	inertia = 2.30 kN/m, moment 4.13 kN·m/m	spec SE-6
LE-V	Shear at the base of the stem, earthquake (Ve) Ve = Vs + dP + dQ + inertia	Ve = 48.00 + 9.68 + 0.00 + 2.30 = 59.98 kN/m	Ve = 59.98 kN/m	spec SE-5, SE-6
LE-M	Moment at the base of the stem, earthquake (Me) Me = Ms + dP·0.5h + dQ·0.66h + inertia moments	Me = 64.00 + 9.68 × 2.000 + 0.00 × 2.640 + 4.13 = 87.49 kN·m/m	Me = 87.49 kN·m/m	spec SE-5, SE-6
	Forces			
F1	Service moment and shear at the support, Static load case Ms = M(L), Vs = V(L) (the diagrams; equal to the hand totals LS-M, LS-V above)	Ms = 64.00 kN·m/m, Vs = 48.00 kN/m	Ms = 64.00 kN·m/m, Vs = 48.00 kN/m	Statics (specs EP-4..EP-8, RC-2)
F2	Service moment and shear at the support, Seismic load case (IS 1893 Part 3) Me = M(L), Ve = V(L) (static loads + SE-5, SE-6 increments)	Me = 87.49 kN·m/m, Ve = 59.98 kN/m	Me = 87.49 kN·m/m, Ve = 59.98 kN/m	IS 1893 Part 3; spec SE-5, SE-6
F3	Design (factored) moment Mu = γf·M, γf = 1.5 (static), 1.2 (with earthquake); the larger governs	static: 1.5 × 64.00 = 96.00; earthquake: 1.2 × 87.49 = 104.99	Mu = 104.99 kN·m/m (earthquake (1.2))	IS 456 Table 18 (cl. 36.4)

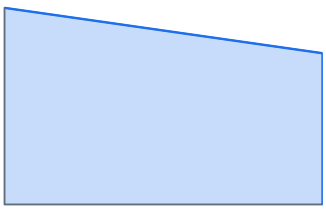
Step	Formula	Working	Result	IS clause
F4	Design (factored) shear Vu = γf·V, larger of the two combinations	static: 1.5 × 48.00 = 72.00; earthquake: 1.2 × 59.98 = 71.98	Vu = 72.00 kN/m	IS 456 Table 18 (cl. 36.4)
	Section			
S1	Effective depth (1 m wide strip) d = D − cover − φ/2	d = 375 − 50 − 12/2 = 319.0 mm	d = 319.0 mm	IS 456 cl. 26.4, 26.4.2.2
	Flexure			
B1	Limiting moment of resistance Mu,lim = 0.36·(xu,max/d)·[1 − 0.42·(xu,max/d)]·fck·b·d²	xu,max/d = 0.46 (Fe 500); Mu,lim = 0.36 × 0.46 × (1 − 0.42 × 0.46) × 25 × 1000 × 319.0² = 339.90 kN·m/m	Mu,lim = 339.90 kN·m/m	IS 456 cl. 38.1, Annex G
B2	Singly reinforced section check Mu ≤ Mu,lim	104.99 ≤ 339.90	OK	IS 456 cl. 38.1
B3	Tension steel for flexure Ast = 0.5·(fck/fy)·[1 − √(1 − 4.6·Mu/(fck·b·d²))]·b·d	Ast = 0.5 × (25/500) × [1 − √(1 − 4.6 × 104991820/(25 × 1000 × 319.0²)] × 1000 × 319.0 = 796.80 mm²/m	Ast = 796.80 mm²/m	IS 456 Annex G, cl. G-1.1(b)
B4	Minimum tension steel Ast,min = 0.0012·b·D (HYSD bars)	Ast,min = 0.0012 × 1000 × 375 = 450.00 mm²/m	Ast,min = 450.00 mm²/m	IS 456 cl. 26.5.2.1
B5	Steel required Ast,req = max(Ast, Ast,min)	max(796.80, 450.00) = 796.80 mm²/m	Ast,req = 796.80 mm²/m	IS 456 cl. 26.5.2.1, Annex G
B6	Bar diameter and spacing s = 1000·Aφ/Ast,req (rounded down to 10 mm) ≤ min(3d, 300 mm); then closed up until the crack width passes	φ = 12 mm, Aφ = π × 12²/4 = 113.10 mm²; s = 1000 × 113.10/796.80 → 140 mm; s,max = min(3 × 319.0, 300) = 300 mm; chosen s = 140 mm	12 mm @ 140 mm c/c	IS 456 cl. 26.3.3(b)
B7	Steel provided Ast,prov = 1000·Aφ/s; pt = 100·Ast,prov/(b·d)	Ast,prov = 1000 × 113.10/140 = 807.84 mm²/m; pt = 100 × 807.84/(1000 × 319.0) = 0.253 %	Ast,prov = 807.84 mm²/m	IS 456 cl. 26.5.2.1
	Shear			
V1	Nominal shear stress τv = Vu/(b·d)	τv = 72.00 × 1000/(1000 × 319.0) = 0.226 N/mm²	τv = 0.226 N/mm²	IS 456 cl. 40.1
V2	Permissible shear stress without stirrups τc,allow = k·τc; τc from Table 19 at pt and fck, k from cl. 40.2.1.1 for slab depth D	pt = 0.253 %, M25: τc = 0.362 N/mm²; D = 375 mm: k = 1.00; τc,allow = 1.00 × 0.362 = 0.362 N/mm²	τc,allow = 0.362 N/mm²	IS 456 Table 19, cl. 40.2.1.1
V3	Shear check τv ≤ k·τc	0.226 ≤ 0.362	OK, no shear reinforcement needed	IS 456 cl. 40.2.1
	Development length			
D1	Development length of main bars Ld = φ·0.87·fy/(4·τbd), τbd for deformed bars (1.6 × plain-bar value)	τbd = 2.24 N/mm² (M25); Ld = 12 × 0.87 × 500/(4 × 2.24) = 583 mm	Ld = 583 mm	IS 456 cl. 26.2.1.1
	Distribution steel			
X1	Distribution (secondary) steel Ast,dist = 0.0012·b·D; s ≤ min(5d, 450 mm)	Ast,dist = 0.0012 × 1000 × 375 = 450.00 mm²/m; 8 mm bars @ 110 mm give 456.96 mm²/m	8 mm @ 110 mm c/c	IS 456 cl. 26.5.2.1, 26.3.3(b)
	Crack width			

Step	Formula	Working	Result	IS clause
C1	Surface crack width under service moment (static) m = Es/(Ec/(1+θ)); ½·b·x² = m·Ast·(d − x); fs = Ms/[Ast·(d − x/3)]; εm = ε1 − b(h−x)²/[3·Es·Ast·(d−x)]; acr = √[(s/2)² + (cmin+φ/2)²] − φ/2; w = 3·acr·εm/[1 + 2(acr − cmin)/(h − x)]	Ms = 64.00 kN·m/m; m = 20.80; x = 88.1 mm; fs = 273.5 N/mm²; εm = 0.000964; acr = 83.6 mm; w = 0.196 mm	w = 0.196 mm	IS 456 Annex F (cl. 35.3.2)
C2	Crack width check w ≤ limit	0.196 ≤ 0.20 mm	OK	IS 456 cl. 35.3.2
	Curtailment			
CU1	Curtailment of the main bars alternate bars are stopped where the other half is enough	half of the steel (404 mm²/m) is below the minimum 450 mm²/m (cl. 26.5.2.1)	not curtailed: half of the steel (404 mm²/m) is below the minimum 450 mm²/m (cl. 26.5.2.1)	IS 456 cl. 26.2.3
	Result			
R1	Member result All checks must pass	12 mm @ 140 mm c/c (earth face), distribution 8 mm @ 110 mm	All checks pass	IS 456

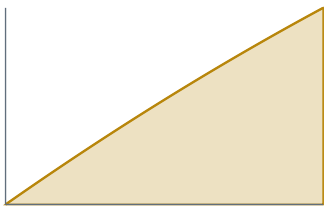
5.1.2 Toe (tension face: bottom face; length L = 0.950 m, x = distance from the toe tip (m))

Static load case: Upward base pressure − self-weight

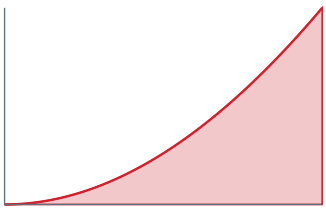
Load w (kN/m²)
at support: 62.29 kN/m²



Shear V (kN/m)
at support: 68.03 kN/m

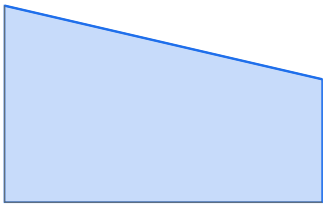


Moment M (kN·m/m)
at support: 33.72 kN·m/m

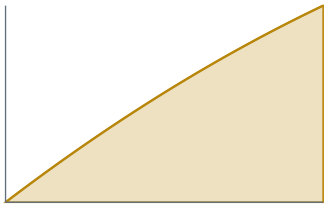


Vertical (gravity) loads (kN/m²): Base pressure (upward): 71.66 at the support, largest 90.31; Self-weight of the toe (downward): -9.38 at the support, largest -9.38.
Seismic load case (IS 1893 Part 3): Upward base pressure − self-weight

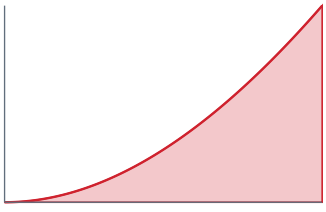
Load w (kN/m²)
at support: 69.33 kN/m²



Shear V (kN/m)
at support: 85.57 kN/m



Moment M (kN·m/m)
at support: 43.77 kN·m/m



Vertical (gravity) loads (kN/m²): Base pressure (upward): 78.71 at the support, largest 120.19; Self-weight of the toe (downward): -9.38 at the support, largest -9.38.

Step	Formula	Working	Result	IS clause
	Loads and forces			

Step	Formula	Working	Result	IS clause
BP1	Base pressure (static): net vertical load $\Sigma V = \Sigma W - U$	$\Sigma V = 174.12 - 0.00 = 174.12$ kN/m	$\Sigma V = 174.12$ kN/m	IS 456 cl. 20; spec ST-5
BP2	Base pressure (static): moment of the vertical loads about the toe $\Sigma M_V = \Sigma W \cdot x$	$\Sigma M_V = 289.13$ kN·m/m	$\Sigma M_V = 289.13$ kN·m/m	IS 456 cl. 20; spec ST-5
BP3	Base pressure (static): overturning moment about the toe $M_O = \Sigma H \cdot h + U \cdot x_u$	$M_O = 83.74 + 0.00 \times 0.000 = 83.74$ kN·m/m	$M_O = 83.74$ kN·m/m	IS 456 cl. 20; spec ST-5
BP4	Base pressure (static): position of the resultant $x_r = (\Sigma M_V - M_O)/\Sigma V$	$x_r = (289.13 - 83.74)/174.12 = 1.180$ m	$x_r = 1.180$ m from the toe	IS 456 cl. 20; spec ST-5
BP5	Base pressure (static): eccentricity $e = B/2 - x_r$; middle third: $\lvert e \rvert \le B/6$	$e = 2.750/2 - 1.180 = 0.195$ m; $B/6 = 0.458$ m	$e = 0.195$ m (inside the middle third)	IS 456 cl. 20; spec ST-5
BP6	Base pressure (static): at the toe $q = \Sigma V/B \cdot (1 \pm 6e/B)$, larger value on the side of the resultant	$q(\text{toe}) = 90.31$ kN/m², $q(\text{heel}) = 36.32$ kN/m² ($\Sigma V/B = 63.32$, $6e/B = 0.426$)	$q(\text{toe}) = 90.31$ kN/m²	IS 456 cl. 20; spec ST-5
BP7	Base pressure (static): at the heel $q = \Sigma V/B \cdot (1 \pm 6e/B)$, larger value on the side of the resultant	$q(\text{heel}) = 36.32$ kN/m²	$q(\text{heel}) = 36.32$ kN/m²	IS 456 cl. 20; spec ST-5
BQ1	Base pressure (earthquake): net vertical load $\Sigma V = \Sigma W - U$	$\Sigma V = 165.40 - 0.00 = 165.40$ kN/m	$\Sigma V = 165.40$ kN/m	IS 456 cl. 20; spec ST-5
BQ2	Base pressure (earthquake): moment of the vertical loads about the toe $\Sigma M_V = \Sigma W \cdot x$	$\Sigma M_V = 273.98$ kN·m/m	$\Sigma M_V = 273.98$ kN·m/m	IS 456 cl. 20; spec ST-5
BQ3	Base pressure (earthquake): overturning moment about the toe $M_O = \Sigma H \cdot h + U \cdot x_u$	$M_O = 122.23 + 0.00 \times 0.000 = 122.23$ kN·m/m	$M_O = 122.23$ kN·m/m	IS 456 cl. 20; spec ST-5
BQ4	Base pressure (earthquake): position of the resultant $x_r = (\Sigma M_V - M_O)/\Sigma V$	$x_r = (273.98 - 122.23)/165.40 = 0.917$ m	$x_r = 0.917$ m from the toe	IS 456 cl. 20; spec ST-5
BQ5	Base pressure (earthquake): eccentricity $e = B/2 - x_r$; middle third: $\lvert e \rvert \le B/6$	$e = 2.750/2 - 0.917 = 0.458$ m; $B/6 = 0.458$ m	$e = 0.458$ m (inside the middle third)	IS 456 cl. 20; spec ST-5
BQ6	Base pressure (earthquake): at the toe $q = \Sigma V/B \cdot (1 \pm 6e/B)$, larger value on the side of the resultant	$q(\text{toe}) = 120.19$ kN/m², $q(\text{heel}) = 0.10$ kN/m² ($\Sigma V/B = 60.15$, $6e/B = 0.998$)	$q(\text{toe}) = 120.19$ kN/m²	IS 456 cl. 20; spec ST-5
BQ7	Base pressure (earthquake): at the heel $q = \Sigma V/B \cdot (1 \pm 6e/B)$, larger value on the side of the resultant	$q(\text{heel}) = 0.10$ kN/m²	$q(\text{heel}) = 0.10$ kN/m²	IS 456 cl. 20; spec ST-5

Step	Formula	Working	Result	IS clause
L1	Slab self-weight on the toe w = γc·D	w = 25 × 0.375 = 9.38 kN/m²	w = 9.38 kN/m²	IS 875 Part 1; spec RC-2
LSG 1	Net upward load on the toe (static), segment 1 (x from the toe tip = 0.000 to 0.950 m) F = w_a·Δx + ½(w_b − w_a)·Δx; lever arm to the support = L − centroid; M = Σ F·arm	w_a = 80.94, w_b = 62.29 kN/m²; Δx = 0.950 m; rectangle 80.94 × 0.950 = 76.89 kN/m, lever arm 0.475 m; triangle ½ × (62.29 − 80.94) × 0.950 = −8.86 kN/m, lever arm 0.317 m; M = 76.89 × 0.475 + −8.86 × 0.317 = 33.72 kN·m/m	F = 68.03 kN/m, M = 33.72 kN·m/m	spec RC-2
LS-V	Shear at the support, static (Vs) V = Σ F	V = 68.03 kN/m (soil over the toe ignored, A-19)	V = 68.03 kN/m	spec RC-2
LS-M	Moment at the support, static (Ms) M = Σ F·lever arm	M = 33.72 kN·m/m (soil over the toe ignored, A-19)	M = 33.72 kN·m/m	spec RC-2
LEG 1	Net upward load on the toe (earthquake), segment 1 (x from the toe tip = 0.000 to 0.950 m) F = w_a·Δx + ½(w_b − w_a)·Δx; lever arm to the support = L − centroid; M = Σ F·arm	w_a = 110.82, w_b = 69.33 kN/m²; Δx = 0.950 m; rectangle 110.82 × 0.950 = 105.28 kN/m, lever arm 0.475 m; triangle ½ × (69.33 − 110.82) × 0.950 = −19.71 kN/m, lever arm 0.317 m; M = 105.28 × 0.475 + −19.71 × 0.317 = 43.77 kN·m/m	F = 85.57 kN/m, M = 43.77 kN·m/m	spec RC-2
LE-V	Shear at the support, earthquake (Vs) V = Σ F	V = 85.57 kN/m (soil over the toe ignored, A-19)	V = 85.57 kN/m	spec RC-2
LE-M	Moment at the support, earthquake (Ms) M = Σ F·lever arm	M = 43.77 kN·m/m (soil over the toe ignored, A-19)	M = 43.77 kN·m/m	spec RC-2
	Forces			
F1	Service moment and shear at the support, Static load case Ms = M(L), Vs = V(L) (the diagrams; equal to the hand totals LS-M, LS-V above)	Ms = 33.72 kN·m/m, Vs = 68.03 kN/m	Ms = 33.72 kN·m/m, Vs = 68.03 kN/m	Statics (specs EP-4..EP-8, RC-2)
F2	Service moment and shear at the support, Seismic load case (IS 1893 Part 3) Me = M(L), Ve = V(L) (static loads + SE-5, SE-6 increments)	Me = 43.77 kN·m/m, Ve = 85.57 kN/m	Me = 43.77 kN·m/m, Ve = 85.57 kN/m	IS 1893 Part 3; spec SE-5, SE-6
F3	Design (factored) moment Mu = γf·M, γf = 1.5 (static), 1.2 (with earthquake); the larger governs	static: 1.5 × 33.72 = 50.58; earthquake: 1.2 × 43.77 = 52.52	Mu = 52.52 kN·m/m (earthquake (1.2))	IS 456 Table 18 (cl. 36.4)
F4	Design (factored) shear Vu = γf·V, larger of the two combinations	static: 1.5 × 68.03 = 102.05; earthquake: 1.2 × 85.57 = 102.68	Vu = 102.68 kN/m	IS 456 Table 18 (cl. 36.4)
	Section			
S1	Effective depth (1 m wide strip) d = D − cover − φ/2	d = 375 − 50 − 10/2 = 320.0 mm	d = 320.0 mm	IS 456 cl. 26.4, 26.4.2.2
	Flexure			
B1	Limiting moment of resistance Mu,lim = 0.36·(xu,max/d)·[1 − 0.42·(xu,max/d)]·fck·b·d²	xu,max/d = 0.46 (Fe 500); Mu,lim = 0.36 × 0.46 × (1 − 0.42 × 0.46) × 25 × 1000 × 320.0² = 342.03 kN·m/m	Mu,lim = 342.03 kN·m/m	IS 456 cl. 38.1, Annex G

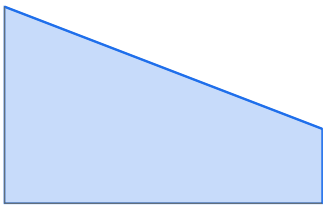
Step	Formula	Working	Result	IS clause
B2	Singly reinforced section check Mu ≤ Mu,lim	52.52 ≤ 342.03	OK	IS 456 cl. 38.1
B3	Tension steel for flexure Ast = 0.5·(fck/fy)·[1 − √(1 − 4.6·Mu/(fck·b·d²))]·b·d	Ast = 0.5 × (25/500) × [1 − √(1 − 4.6 × 52519515/(25 × 1000 × 320.0²)] × 1000 × 320.0 = 386.84 mm²/m	Ast = 386.84 mm²/m	IS 456 Annex G, cl. G-1.1(b)
B4	Minimum tension steel Ast,min = 0.0012·b·D (HYSD bars)	Ast,min = 0.0012 × 1000 × 375 = 450.00 mm²/m	Ast,min = 450.00 mm²/m	IS 456 cl. 26.5.2.1
B5	Steel required Ast,req = max(Ast, Ast,min)	max(386.84, 450.00) = 450.00 mm²/m	Ast,req = 450.00 mm²/m	IS 456 cl. 26.5.2.1, Annex G
B6	Bar diameter and spacing s = 1000·Aφ/Ast,req (rounded down to 10 mm) ≤ min(3d, 300 mm); then closed up until the crack width passes	φ = 10 mm, Aφ = π × 10²/4 = 78.54 mm²; s = 1000 × 78.54/450.00 → 170 mm; s,max = min(3 × 320.0, 300) = 300 mm; chosen s = 120 mm	10 mm @ 120 mm c/c	IS 456 cl. 26.3.3(b)
B7	Steel provided Ast,prov = 1000·Aφ/s; pt = 100·Ast,prov/(b·d)	Ast,prov = 1000 × 78.54/120 = 654.50 mm²/m; pt = 100 × 654.50/(1000 × 320.0) = 0.205 %	Ast,prov = 654.50 mm²/m	IS 456 cl. 26.5.2.1
	Shear			
V1	Nominal shear stress τv = Vu/(b·d)	τv = 102.68 × 1000/(1000 × 320.0) = 0.321 N/mm²	τv = 0.321 N/mm²	IS 456 cl. 40.1
V2	Permissible shear stress without stirrups τc,allow = k·τc; τc from Table 19 at pt and fck, k from cl. 40.2.1.1 for slab depth D	pt = 0.205 %, M25: τc = 0.328 N/mm²; D = 375 mm: k = 1.00; τc,allow = 1.00 × 0.328 = 0.328 N/mm²	τc,allow = 0.328 N/mm²	IS 456 Table 19, cl. 40.2.1.1
V3	Shear check τv ≤ k·τc	0.321 ≤ 0.328	OK, no shear reinforcement needed	IS 456 cl. 40.2.1
	Development length			
D1	Development length of main bars Ld = φ·0.87·fy/(4·τbd), τbd for deformed bars (1.6 × plain-bar value)	τbd = 2.24 N/mm² (M25); Ld = 10 × 0.87 × 500/(4 × 2.24) = 485 mm	Ld = 485 mm	IS 456 cl. 26.2.1.1
	Distribution steel			
X1	Distribution (secondary) steel Ast,dist = 0.0012·b·D; s ≤ min(5d, 450 mm)	Ast,dist = 0.0012 × 1000 × 375 = 450.00 mm²/m; 8 mm bars @ 110 mm give 456.96 mm²/m	8 mm @ 110 mm c/c	IS 456 cl. 26.5.2.1, 26.3.3(b)
	Crack width			
C1	Surface crack width under service moment (static) m = Es/(Ec/(1+θ)); ½·b·x² = m·Ast·(d − x); fs = Ms/[Ast·(d − x/3)]; εm = ε1 − b(h−x)²/[3·Es·Ast·(d−x)]; acr = √[(s/2)² + (cmin+φ/2)²] − φ/2; w = 3·acr·εm/[1 + 2(acr − cmin)/(h − x)]	Ms = 33.72 kN·m/m; m = 20.80; x = 80.7 mm; fs = 175.8 N/mm²; εm = 0.000159; acr = 76.4 mm; w = 0.031 mm	w = 0.031 mm	IS 456 Annex F (cl. 35.3.2)
C2	Crack width check w ≤ limit	0.031 ≤ 0.20 mm	OK	IS 456 cl. 35.3.2
	Curtailment			

Step	Formula	Working	Result	IS clause
CU1	Curtailment of the main bars alternate bars are stopped where the other half is enough	half of the steel (327 mm²/m) is below the minimum 450 mm²/m (cl. 26.5.2.1)	not curtailed: half of the steel (327 mm²/m) is below the minimum 450 mm²/m (cl. 26.5.2.1)	IS 456 cl. 26.2.3
	Result			
R1	Member result All checks must pass	10 mm @ 120 mm c/c (bottom face), distribution 8 mm @ 110 mm	All checks pass	IS 456

5.1.3 Heel (tension face: top face; length L = 1.425 m, x = distance from the heel tip (m))

Static load case: Downward load − upward base pressure

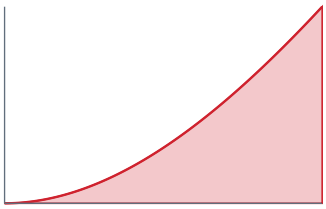
Load w (kN/m²)
at support: 17.08 kN/m²



Shear V (kN/m)
at support: 44.27 kN/m

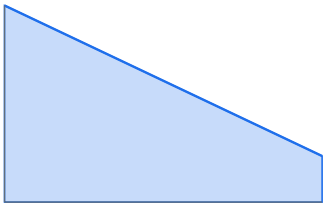


Moment M (kN·m/m)
at support: 36.28 kN·m/m

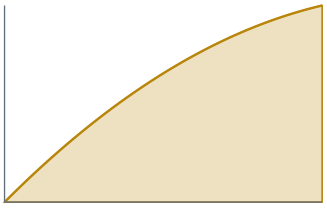


Vertical (gravity) loads (kN/m²): Soil, slope and surcharge on the heel (downward): 72.00 at the support, largest 72.00; Self-weight of the heel (downward): 9.38 at the support, largest 9.38; Base pressure and uplift (upward): -64.30 at the support, largest -64.30.
Seismic load case (IS 1893 Part 3): Downward load − upward base pressure

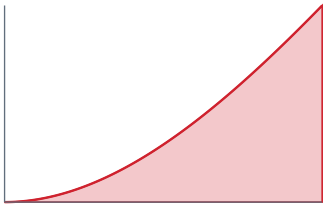
Load w (kN/m²)
at support: 19.05 kN/m²



Shear V (kN/m)
at support: 71.48 kN/m



Moment M (kN·m/m)
at support: 61.46 kN·m/m



Vertical (gravity) loads (kN/m²): Soil, slope and surcharge on the heel (downward): 72.00 at the support, largest 72.00; Self-weight of the heel (downward): 9.38 at the support, largest 9.38; Base pressure and uplift (upward): -62.33 at the support, largest -62.33.

Step	Formula	Working	Result	IS clause
	Loads and forces			
BP1	Base pressure (static): net vertical load ΣV = Σ W − U	ΣV = 174.12 − 0.00 = 174.12 kN/m	ΣV = 174.12 kN/m	IS 456 cl. 20; spec ST-5
BP2	Base pressure (static): moment of the vertical loads about the toe ΣM_V = Σ W·x	ΣM_V = 289.13 kN·m/m	ΣM_V = 289.13 kN·m/m	IS 456 cl. 20; spec ST-5
BP3	Base pressure (static): overturning moment about the toe M_O = Σ H·h + U·x_u	M_O = 83.74 + 0.00 × 0.000 = 83.74 kN·m/m	M_O = 83.74 kN·m/m	IS 456 cl. 20; spec ST-5

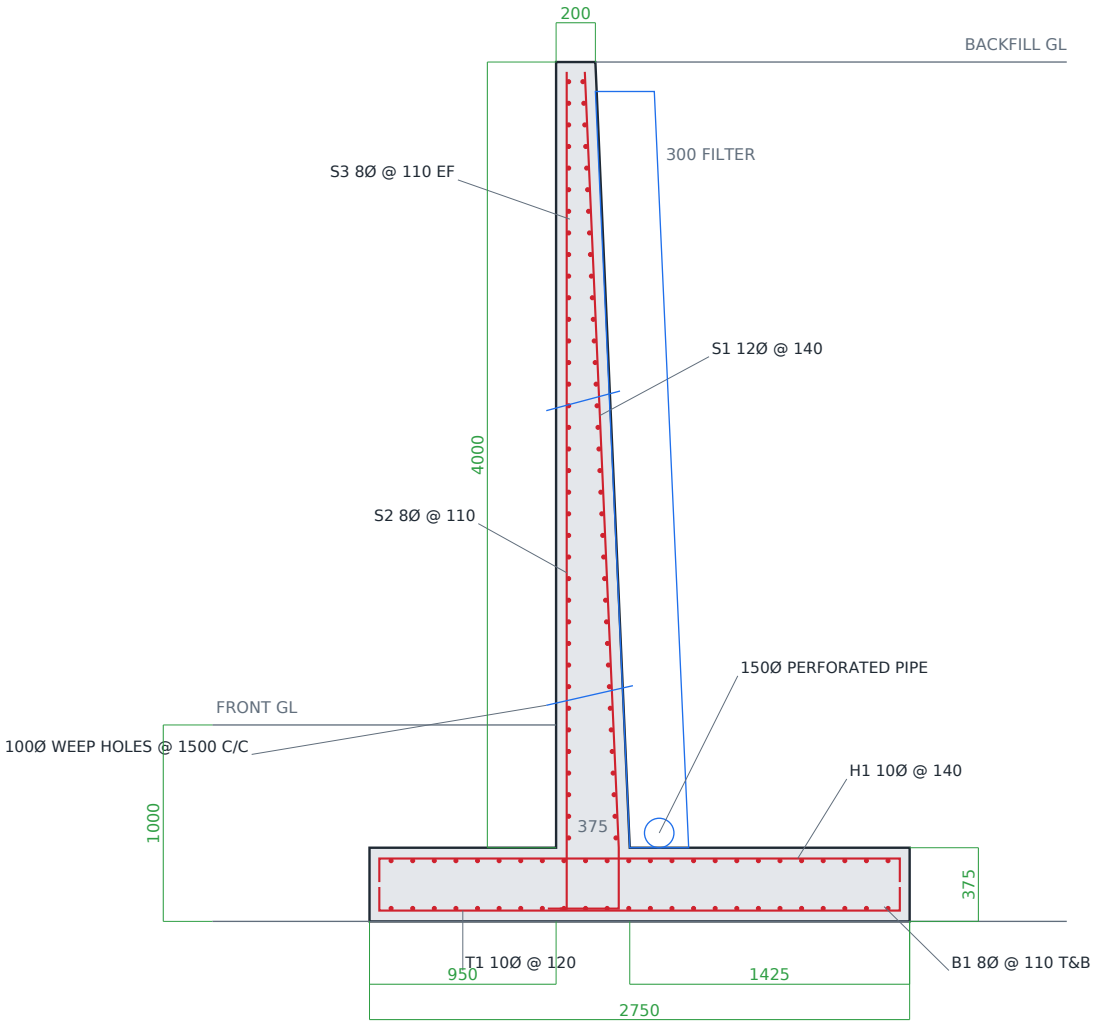
Step	Formula	Working	Result	IS clause
BP4	Base pressure (static): position of the resultant x_r = (ΣM_V − M_O)/ΣV	x_r = (289.13 − 83.74)/174.12 = 1.180 m	x_r = 1.180 m from the toe	IS 456 cl. 20; spec ST-5
BP5	Base pressure (static): eccentricity e = B/2 − x_r; middle third: |e| ≤ B/6	e = 2.750/2 − 1.180 = 0.195 m; B/6 = 0.458 m	e = 0.195 m (inside the middle third)	IS 456 cl. 20; spec ST-5
BP6	Base pressure (static): at the toe q = ΣV/B·(1 ± 6e/B), larger value on the side of the resultant	q(toe) = 90.31 kN/m², q(heel) = 36.32 kN/m² (ΣV/B = 63.32, 6e/B = 0.426)	q(toe) = 90.31 kN/m²	IS 456 cl. 20; spec ST-5
BP7	Base pressure (static): at the heel q = ΣV/B·(1 ± 6e/B), larger value on the side of the resultant	q(heel) = 36.32 kN/m²	q(heel) = 36.32 kN/m²	IS 456 cl. 20; spec ST-5
BQ1	Base pressure (earthquake): net vertical load ΣV = Σ W − U	ΣV = 165.40 − 0.00 = 165.40 kN/m	ΣV = 165.40 kN/m	IS 456 cl. 20; spec ST-5
BQ2	Base pressure (earthquake): moment of the vertical loads about the toe ΣM_V = Σ W·x	ΣM_V = 273.98 kN·m/m	ΣM_V = 273.98 kN·m/m	IS 456 cl. 20; spec ST-5
BQ3	Base pressure (earthquake): overturning moment about the toe M_O = Σ H·h + U·x_u	M_O = 122.23 + 0.00 × 0.000 = 122.23 kN·m/m	M_O = 122.23 kN·m/m	IS 456 cl. 20; spec ST-5
BQ4	Base pressure (earthquake): position of the resultant x_r = (ΣM_V − M_O)/ΣV	x_r = (273.98 − 122.23)/165.40 = 0.917 m	x_r = 0.917 m from the toe	IS 456 cl. 20; spec ST-5
BQ5	Base pressure (earthquake): eccentricity e = B/2 − x_r; middle third: |e| ≤ B/6	e = 2.750/2 − 0.917 = 0.458 m; B/6 = 0.458 m	e = 0.458 m (inside the middle third)	IS 456 cl. 20; spec ST-5
BQ6	Base pressure (earthquake): at the toe q = ΣV/B·(1 ± 6e/B), larger value on the side of the resultant	q(toe) = 120.19 kN/m², q(heel) = 0.10 kN/m² (ΣV/B = 60.15, 6e/B = 0.998)	q(toe) = 120.19 kN/m²	IS 456 cl. 20; spec ST-5
BQ7	Base pressure (earthquake): at the heel q = ΣV/B·(1 ± 6e/B), larger value on the side of the resultant	q(heel) = 0.10 kN/m²	q(heel) = 0.10 kN/m²	IS 456 cl. 20; spec ST-5
L1	Soil column over the heel w_soil = Σ γ·Δz (γsat below the water table)	w_soil = 4.000 × 18 = 72.00 kN/m²	w_soil = 72.00 kN/m²	spec EP-10
L2	Other downward loads on the heel slope wedge = γ_top·rise/2; surcharge q; self-weight γc·D	wedge = 18 × 0.000/2 = 0.00; q = 0; self-weight = 25 × 0.375 = 9.38 kN/m²	9.38 kN/m²	spec RC-2
L3	Total downward load on the heel w_down = soil + wedge + surcharge + self-weight	w_down = 72.00 + 0.00 + 0.00 + 9.38 = 81.38 kN/m²	w_down = 81.38 kN/m²	spec RC-2

Step	Formula	Working	Result	IS clause
LSG 1	Net downward load on the heel (static), segment 1 (x from the heel tip = 0.000 to 1.425 m) F = w_a·Δx + ½(w_b − w_a)·Δx; lever arm to the support = L − centroid; M = Σ F·arm	w_a = 45.06, w_b = 17.08 kN/m²; Δx = 1.425 m; rectangle 45.06 × 1.425 = 64.20 kN/m, lever arm 0.713 m; triangle ½ × (17.08 − 45.06) × 1.425 = −19.93 kN/m, lever arm 0.475 m; M = 64.20 × 0.713 + −19.93 × 0.475 = 36.28 kN·m/m	F = 44.27 kN/m, M = 36.28 kN·m/m	spec RC-2
LS-V	Shear at the support, static (Vs) V = Σ F	V = 44.27 kN/m (downward − base pressure − uplift)	V = 44.27 kN/m	spec RC-2
LS-M	Moment at the support, static (Ms) M = Σ F·lever arm	M = 36.28 kN·m/m (downward − base pressure − uplift)	M = 36.28 kN·m/m	spec RC-2
LEG 1	Net downward load on the heel (earthquake), segment 1 (x from the heel tip = 0.000 to 1.425 m) F = w_a·Δx + ½(w_b − w_a)·Δx; lever arm to the support = L − centroid; M = Σ F·arm	w_a = 81.28, w_b = 19.05 kN/m²; Δx = 1.425 m; rectangle 81.28 × 1.425 = 115.82 kN/m, lever arm 0.713 m; triangle ½ × (19.05 − 81.28) × 1.425 = −44.34 kN/m, lever arm 0.475 m; M = 115.82 × 0.713 + −44.34 × 0.475 = 61.46 kN·m/m	F = 71.48 kN/m, M = 61.46 kN·m/m	spec RC-2
LE-V	Shear at the support, earthquake (Vs) V = Σ F	V = 71.48 kN/m (downward − base pressure − uplift)	V = 71.48 kN/m	spec RC-2
LE-M	Moment at the support, earthquake (Ms) M = Σ F·lever arm	M = 61.46 kN·m/m (downward − base pressure − uplift)	M = 61.46 kN·m/m	spec RC-2
	Forces			
F1	Service moment and shear at the support, Static load case Ms = M(L), Vs = V(L) (the diagrams; equal to the hand totals LS-M, LS-V above)	Ms = 36.28 kN·m/m, Vs = 44.27 kN/m	Ms = 36.28 kN·m/m, Vs = 44.27 kN/m	Statics (specs EP-4..EP-8, RC-2)
F2	Service moment and shear at the support, Seismic load case (IS 1893 Part 3) Me = M(L), Ve = V(L) (static loads + SE-5, SE-6 increments)	Me = 61.46 kN·m/m, Ve = 71.48 kN/m	Me = 61.46 kN·m/m, Ve = 71.48 kN/m	IS 1893 Part 3; spec SE-5, SE-6
F3	Design (factored) moment Mu = γf·M, γf = 1.5 (static), 1.2 (with earthquake); the larger governs	static: 1.5 × 36.28 = 54.42; earthquake: 1.2 × 61.46 = 73.75	Mu = 73.75 kN·m/m (earthquake (1.2))	IS 456 Table 18 (cl. 36.4)
F4	Design (factored) shear Vu = γf·V, larger of the two combinations	static: 1.5 × 44.27 = 66.41; earthquake: 1.2 × 71.48 = 85.77	Vu = 85.77 kN/m	IS 456 Table 18 (cl. 36.4)
	Section			
S1	Effective depth (1 m wide strip) d = D − cover − φ/2	d = 375 − 50 − 10/2 = 320.0 mm	d = 320.0 mm	IS 456 cl. 26.4, 26.4.2.2
	Flexure			
B1	Limiting moment of resistance Mu,lim = 0.36·(xu,max/d)·[1 − 0.42·(xu,max/d)]·fck·b·d²	xu,max/d = 0.46 (Fe 500); Mu,lim = 0.36 × 0.46 × (1 − 0.42 × 0.46) × 25 × 1000 × 320.0² = 342.03 kN·m/m	Mu,lim = 342.03 kN·m/m	IS 456 cl. 38.1, Annex G
B2	Singly reinforced section check Mu ≤ Mu,lim	73.75 ≤ 342.03	OK	IS 456 cl. 38.1

Step	Formula	Working	Result	IS clause
B3	Tension steel for flexure Ast = 0.5·(fck/fy)·[1 − √(1 − 4.6·Mu/(fck·b·d²))]·b·d	Ast = 0.5 × (25/500) × [1 − √(1 − 4.6 × 73750473/(25 × 1000 × 320.0²)] × 1000 × 320.0 = 548.91 mm²/m	Ast = 548.91 mm²/m	IS 456 Annex G, cl. G-1.1(b)
B4	Minimum tension steel Ast,min = 0.0012·b·D (HYSD bars)	Ast,min = 0.0012 × 1000 × 375 = 450.00 mm²/m	Ast,min = 450.00 mm²/m	IS 456 cl. 26.5.2.1
B5	Steel required Ast,req = max(Ast, Ast,min)	max(548.91, 450.00) = 548.91 mm²/m	Ast,req = 548.91 mm²/m	IS 456 cl. 26.5.2.1, Annex G
B6	Bar diameter and spacing s = 1000·Aφ/Ast,req (rounded down to 10 mm) ≤ min(3d, 300 mm); then closed up until the crack width passes	φ = 10 mm, Aφ = π × 10²/4 = 78.54 mm²; s = 1000 × 78.54/548.91 → 140 mm; s,max = min(3 × 320.0, 300) = 300 mm; chosen s = 140 mm	10 mm @ 140 mm c/c	IS 456 cl. 26.3.3(b)
B7	Steel provided Ast,prov = 1000·Aφ/s; pt = 100·Ast,prov/(b·d)	Ast,prov = 1000 × 78.54/140 = 561.00 mm²/m; pt = 100 × 561.00/(1000 × 320.0) = 0.175 %	Ast,prov = 561.00 mm²/m	IS 456 cl. 26.5.2.1
	Shear			
V1	Nominal shear stress τv = Vu/(b·d)	τv = 85.77 × 1000/(1000 × 320.0) = 0.268 N/mm²	τv = 0.268 N/mm²	IS 456 cl. 40.1
V2	Permissible shear stress without stirrups τc,allow = k·τc; τc from Table 19 at pt and fck, k from cl. 40.2.1.1 for slab depth D	pt = 0.175 %, M25: τc = 0.308 N/mm²; D = 375 mm: k = 1.00; τc,allow = 1.00 × 0.308 = 0.308 N/mm²	τc,allow = 0.308 N/mm²	IS 456 Table 19, cl. 40.2.1.1
V3	Shear check τv ≤ k·τc	0.268 ≤ 0.308	OK, no shear reinforcement needed	IS 456 cl. 40.2.1
	Development length			
D1	Development length of main bars Ld = φ·0.87·fy/(4·τbd), τbd for deformed bars (1.6 × plain-bar value)	τbd = 2.24 N/mm² (M25); Ld = 10 × 0.87 × 500/(4 × 2.24) = 485 mm	Ld = 485 mm	IS 456 cl. 26.2.1.1
	Distribution steel			
X1	Distribution (secondary) steel Ast,dist = 0.0012·b·D; s ≤ min(5d, 450 mm)	Ast,dist = 0.0012 × 1000 × 375 = 450.00 mm²/m; 8 mm bars @ 110 mm give 456.96 mm²/m	8 mm @ 110 mm c/c	IS 456 cl. 26.5.2.1, 26.3.3(b)
	Crack width			
C1	Surface crack width under service moment (static) m = Es/(Ec/(1+θ)); ½·b·x² = m·Ast·(d − x); fs = Ms/[Ast·(d − x/3)]; εm = ε1 − b(h−x)²/[3·Es·Ast·(d−x)]; acr = √[(s/2)² + (cmin+φ/2)²] − φ/2; w = 3·acr·εm/[1 + 2(acr − cmin)/(h − x)]	Ms = 36.28 kN·m/m; m = 20.80; x = 75.5 mm; fs = 219.3 N/mm²; εm = 0.000254; acr = 84.0 mm; w = 0.052 mm	w = 0.052 mm	IS 456 Annex F (cl. 35.3.2)
C2	Crack width check w ≤ limit	0.052 ≤ 0.20 mm	OK	IS 456 cl. 35.3.2
	Curtailment			

Step	Formula	Working	Result	IS clause
CU1	Curtailment of the main bars alternate bars are stopped where the other half is enough	half of the steel (280 mm²/m) is below the minimum 450 mm²/m (cl. 26.5.2.1)	not curtailed: half of the steel (280 mm²/m) is below the minimum 450 mm²/m (cl. 26.5.2.1)	IS 456 cl. 26.2.3
	Result			
R1	Member result All checks must pass	10 mm @ 140 mm c/c (top face), distribution 8 mm @ 110 mm	All checks pass	IS 456

6 Section and reinforcement



7 Bar bending schedule (IS 2502, SP 34)

For the full wall length of 10 m. Cutting length deducts 2φ per 90° bend. Unit weight φ²/162 kg/m. Bars longer than the 12 m stock are lapped with Ls = max(Ld, 30φ) (IS 456 cl. 26.2.5.1(c)); the lap length is in the cutting length and the description says where (LP-2 to LP-4).

Mark	Description	Ø	Shape	a / b / c (mm)	Cut length (mm)	Nos	Total (m)	kg
S1	Stem main, earth face, vertical	12	L	4263 / 300	4539	71	322.3	286.5
S2	Stem front face, vertical	8	L	4267 / 96	4347	91	395.6	156.3
S3	Stem horizontal distribution, both faces	8	straight	9900	9900	72	712.8	281.6
H1	Base top main (heel), across base	10	U	120 / 2650 / 120	2850	71	202.3	124.9
T1	Base bottom main (toe), across base	10	U	120 / 2650 / 120	2850	83	236.6	146.0
B1	Base distribution along wall, top and bottom	8	straight	9900	9900	50	495.0	195.6
	Total 8 mm							633.4
	Total 10 mm							270.9
	Total 12 mm							286.5
	Grand total							1190.8

8 Quantities

Item	Per metre run	Wall length 10 m	Rate (₹)	Amount (₹)
Concrete (m³)	2.181	21.81	6,500	141,781
Reinforcement (kg), from BBS	119.1	1191	70	83,357
Formwork (m²)	8.75	87.5	450	39,375
Total				264,514

Rates are placeholders (assumption A-9) until the firm's rates are entered.

8.1 Base slab alternatives

Same stem, toe, heel and thickness at the stem face; the tip thickness is the cheapest (25 mm steps, at least 0.20 m and half the base thickness) that passes stability, flexure and shear at every section of the projections (spec 13-base-profiles.md).

Base slab	Tip thickness toe / heel (mm)	Concrete (m³/m)	Steel (kg/m)	Cost index (₹/m)	Saving
Uniform	—	2.181	73.6	23,267	—
Tapered	200 / 275	2.027	73.6	22,149	4.8 %
Stepped	200 / 275	2.027	73.6	22,264	4.3 %

9 Assumptions to verify

A-1 Ah = (Z/2)·I with R = 1, Sa/g = 1 (confirmed); Av = 2/3·Ah.
A-2 Earthquake soil increment acts at 0.5·H, surcharge increment at 0.66·H (IS 1893 Part 3, confirmed).
A-3 Wall friction δ = 0 in Rankine and Mononobe-Okabe (conservative).
A-4 Soil over the toe is not counted as resisting by default (conservative; can be switched on).
A-5 Earthquake factors of safety: overturning 1.5, sliding 1.0 (confirmed, editable).
A-6 Safe bearing capacity increased by 33 % in the earthquake case (IS 1893 Part 1 Table 1 ties the permitted increase to soil type; edit if the soil report says otherwise).
A-7 Shear checked at the face of the support (conservative).

A-8 Option quantities without laps (approximate); the bar bending schedule includes laps (LP-2).
A-9 Cost rates are placeholders until the firm's rates are entered.
A-10 Drainage layout per common practice (to verify against IS 14458 Part 1).
A-11 Stem bar anchorage by IS 456 cl. 26.2.1 and 26.2.2.1(b): leg = max(Ld − straight length in the base − 8φ, 300 mm); base main bars with 12φ end legs.
A-12 Crack width with long-term modulus Ec/(1 + θ), θ = 1.6 (IS 456 cl. 6.2.5.1), under the static service moment, at the surface midway between bars.
A-13 Shear key: Rankine Kp (δ = 0) with the backfill φ and γ for the foundation soil, dry, acting over the key depth only; the soil above the base underside gives no passive resistance itself but its weight presses on the wedge (p = Kp·γ·Df at the top of the key); full passive resistance counted.
A-14 PCC overburden 24 kN/m³ (plain concrete, IS 456 cl. 19.2.1).
A-15 Both cover inputs include a base slab face, so each is at least 50 mm (IS 456 cl. 26.4.2.2).
A-16 Layered backfill, earthquake: Mononobe-Okabe on an equivalent single soil over H' (γ = dry weight/H', φ = thickness-weighted mean); static pressure is exact layer by layer.
A-17 With layers, the soil inputs γ, φ, SBC and friction describe the foundation / front soil.
A-18 Active thrust by Rankine theory on the vertical plane through the heel end, parallel to the slope; no trial-wedge check (to verify against IS 14458 Part 1).
A-19 Soil over the toe is ignored in the toe design (conservative).
A-20 Rigid base with linear soil pressure; toe, heel, stem and shear key are cantilevers fixed at their supports.
A-21 Partial load factors 1.5 (static) and 1.2 (with earthquake) applied to the service forces; the larger governs.
A-22 Water: one water table depth on the retained side, linear uplift between toe and heel heads, no drainage credit.
A-23 Passive resistance in front of the toe counted only when a reduction factor is given (PF-1); the shear key as A-13.
A-24 Surcharge is uniform; it adds to bearing pressure but does not resist overturning or sliding.
A-25 Optimiser grid and limits (steps, base width 0.4H to 1.0H, etc.) are design choices; every option must pass all checks.
A-26 Drawing label overlap is checked with an approximate text box (automatic check only).
A-27 Defaults chosen by the owner: φ 30°, no default seismic zone (chosen by the user, D-69), overturning factor 2.0 (IS 456 cl. 20.1 asks 1.4); options A least steel, B least concrete, C least cost.
A-28 Curtailment: alternate bars stopped short of the free end (extension d or 12φ, cl. 26.2.3.2(c) option iii).
A-29 Profiled base: extra soil over a thinner toe tip is not counted (conservative).
A-30 Profiled base: underside flat, top surface slopes or steps; tips at least 0.20 m and half the face thickness (confirmed).
A-31 Profiled base: top bars follow the top surface, bottom bars flat; bend deduction proportional to the angle.
A-32 Toe and heel checked at 40 stations plus the stem face, d from the face, the cut-off and a step, with the steel actually present after curtailment (a failure withdraws the curtailment).
A-33 Profiled base: inertia heights of the toe and heel parts taken as half the mean thickness.
A-34 Base comparison: tips in 25 mm steps, toe tip then heel tip, cheapest cost index.
A-35 Option search: the shortest heel that passes is found by bisection (stability improves with the heel length).
A-36 Trial or licensed output is one server-wide setting until accounts and licences are designed.
A-37 A sign-up starts a 14-day trial with watermarked output; after it the account behaves as an anonymous visitor.
A-38 Bar sizes: 8, 10, 12, 16, 20, 25, 28 and 32 mm (IS 1786 nominal sizes); the smallest size that keeps the spacing at or above the closest spacing allowed (100 mm by default) is used.
A-39 Passive resistance in front of the toe is added to the sliding resistance only, not to overturning.
A-40 Water pressure on the front face is not counted as resisting; the front water level changes only the uplift and the passive unit weight.
A-41 Below the front water level the passive unit weight is γ + (γsat − γ) − γw of each soil.
A-42 No design within base width 1.0H: the search widens the base width to 1.5H once and says so.

A-43 Spare: achieved ÷ required at least 1.5; counterfort hint above 8 m of stem.
A-44 Lap at a low-moment section: factored moment at most 50 % of the resistance of the full set.
A-45 Input limits that are not code values (wall height up to 15 m, surcharge up to 200 kN/m², safety factors up to 5) only catch typing mistakes.
A-46 L-shaped wall, first proportions: heel 0.65·H, base max(0.30 m, H/12) (practice values; the search decides the final sizes).
A-47 Inverted wall, first proportions: toe 0.70·H, base max(0.30 m, H/10), shear key H/5 deep under the stem (practice values; the search decides the final sizes).
A-48 Drawing: PCC levelling course M10, 100 mm thick, projecting 100 mm beyond the base; excavation working space 300 mm on each side beyond the PCC (practice, not a code value).