The Masters School Innovation and Entrepreneurship Center

Retaining Wall Calculations

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Prepared for

Ms. Jennifer Olson, AIA, LEED AP

Marvel Architects, PLLC

New York, NY 10013

Prepared by

Silman

32 Old Slip, 10th Floor

New York, NY 10005

Silman Project #19856

Wall 101

The following calculations represent the design for the cantilever retaining wall with a maximum retained soil height of 6’-6”.

RETAINING WALL ANALYSIS

In accordance with International Building Code 2015

Tedds calculation version 2.9.07

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **6.5** ft
Stem thickness	t_{stem} = **12** in
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **150** pcf
Toe length	l_{toe} = **1** ft
Heel length	l_{heel} = **2.5** ft
Base thickness	t_{base} = **12** in
Base density	γ_{base} = **150** pcf
Height of retained soil	h_{ret} = **6.5** ft
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** ft

Retained soil properties

Soil type	Very dense well graded sand
Moist density	γ_{mr} = **130** pcf
Saturated density	γ_{sr} = **130** pcf
Effective angle of internal resistance	ϕ_r = **30** deg
Effective wall friction angle	δ_r = **15** deg

Base soil properties

Soil type	Very Dense well graded sand
Soil density	γ_b = **130** pcf
Cohesion	c_b = **0** psf
Effective angle of internal resistance	ϕ_b = **30** deg
Effective wall friction angle	δ_b = **15** deg
Effective base friction angle	δ_{bb} = **30** deg
Allowable bearing pressure	$P_{bearing}$ = **4000** psf

Loading details

Live surcharge load	$Surcharge_L$ = **100** psf

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	Section Wall 101 - 6'-6" Retainined height				Sheet no./rev. 2	
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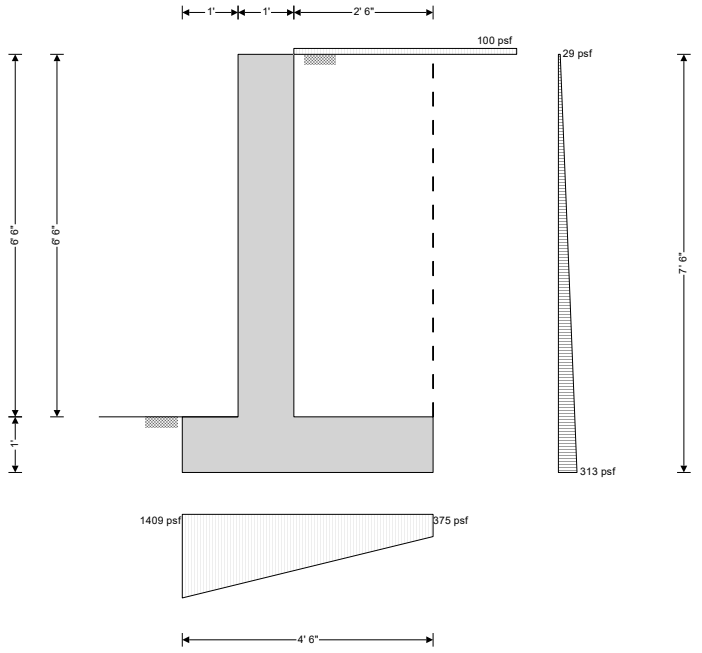

General arrangement

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel}$ = **4.5** ft
Moist soil height	$h_{moist} = h_{soil}$ = **6.5** ft
Length of surcharge load	$l_{sur} = l_{heel}$ = **2.5** ft
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2$ = **3.25** ft
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **7.5** ft
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2$ = **3.75** ft
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem}$ = **6.5** ft^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2$ = **1.5** ft
Area of wall base	$A_{base} = l_{base} \times t_{base}$ = **4.5** ft^2
- Distance to vertical component	$x_{base} = l_{base} / 2$ = **2.25** ft
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel}$ = **16.25** ft^2
- Distance to vertical component	$x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist}$ = **3.25** ft
- Distance to horizontal component	$x_{moist\_h} = h_{eff} / 3$ = **2.5** ft

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi_r)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_r) \times [1 + \sqrt{[\sin(\phi_r + \delta_r) \times \sin(\phi_r - \beta) / (\sin(\alpha - \delta_r) \times \sin(\alpha + \beta))]}]^2)$ = **0.301**
Passive pressure coefficient	$K_P = \sin(90 - \phi_b)^2 / (\sin(90 + \delta_b) \times [1 - \sqrt{[\sin(\phi_b + \delta_b) \times \sin(\phi_b) / (\sin(90 + \delta_b))]}]^2)$ = **4.977**

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Silman 32 Old Slip 10th floor New York, NY 10005	Retaining Wall					
	Section				Sheet no./rev.	
	Wall 101 - 6'-6" Retainined height				3	
	Calc. by	Date	Chk'd by	Date	App'd by	Date
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From IBC 2015 cl.1807.2.3 Safety factor

Load combination 1 — 1.0 × Dead + 1.0 × Live + 1.0 × Lateral earth

Sliding check

Vertical forces on wall

Wall stem — $F_{stem} = A_{stem} \times \gamma_{stem}$ = **975** plf

Wall base — $F_{base} = A_{base} \times \gamma_{base}$ = **675** plf

Moist retained soil — $F_{moist\_v} = A_{moist} \times \gamma_{mr}$ = **2113** plf

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **3763** plf

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_r) \times Surcharge_L \times h_{eff}$ = **218** plf

Moist retained soil — $F_{moist\_h} = K_A \times \cos(\delta_r) \times \gamma_{mr} \times h_{eff}^2 / 2$ = **1065** plf

Total — $F_{total\_h} = F_{sur\_h} + F_{moist\_h}$ = **1283** plf

Check stability against sliding

Base soil resistance — $F_{exc\_h} = K_P \times \cos(\delta_b) \times \gamma_b \times (h_{pass} + h_{base})^2 / 2$ = **312** plf

Base friction — $F_{friction} = F_{total\_v} \times \tan(\delta_{bb})$ = **2172** plf

Resistance to sliding — $F_{rest} = F_{exc\_h} + F_{friction}$ = **2485** plf

Factor of safety — $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.937** > 1.5

PASS - Factor of safety against sliding is adequate

Overturning check

Vertical forces on wall

Wall stem — $F_{stem} = A_{stem} \times \gamma_{stem}$ = **975** plf

Wall base — $F_{base} = A_{base} \times \gamma_{base}$ = **675** plf

Moist retained soil — $F_{moist\_v} = A_{moist} \times \gamma_{mr}$ = **2113** plf

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **3763** plf

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_r) \times Surcharge_L \times h_{eff}$ = **218** plf

Moist retained soil — $F_{moist\_h} = K_A \times \cos(\delta_r) \times \gamma_{mr} \times h_{eff}^2 / 2$ = **1065** plf

Base soil — $F_{exc\_h} = -K_P \times \cos(\delta_b) \times \gamma_b \times (h_{pass} + h_{base})^2 / 2$ = **-312** plf

Total — $F_{total\_h} = F_{sur\_h} + F_{moist\_h} + F_{exc\_h}$ = **970** plf

Overturning moments on wall

Surcharge load — $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h}$ = **819** lb_ft/ft

Moist retained soil — $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h}$ = **2661** lb_ft/ft

Total — $M_{total\_OT} = M_{sur\_OT} + M_{moist\_OT}$ = **3480** lb_ft/ft

Restoring moments on wall

Wall stem — $M_{stem\_R} = F_{stem} \times x_{stem}$ = **1462** lb_ft/ft

Wall base — $M_{base\_R} = F_{base} \times x_{base}$ = **1519** lb_ft/ft

Moist retained soil — $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **6866** lb_ft/ft

Base soil — $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h}$ = **104** lb_ft/ft

Total — $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R}$ = **9951** lb_ft/ft

Check stability against overturning

Factor of safety — $FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **2.859** > 1.5

PASS - Factor of safety against overturning is adequate

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = A_{stem} \times \gamma_{stem} =$ **975** plf
Wall base	$F_{base} = A_{base} \times \gamma_{base} =$ **675** plf
Surcharge load	$F_{sur\_v} = Surcharge_L \times l_{heel} =$ **250** plf
Moist retained soil	$F_{moist\_v} = A_{moist} \times \gamma_{mr} =$ **2113** plf
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{sur\_v} + F_{moist\_v} =$ **4013** plf

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_r) \times Surcharge_L \times h_{eff} =$ **218** plf
Moist retained soil	$F_{moist\_h} = K_A \times \cos(\delta_r) \times \gamma_{mr} \times h_{eff}^2 / 2 =$ **1065** plf
Base soil	$F_{pass\_h} = -K_P \times \cos(\delta_b) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 =$ **-312** plf
Total	$F_{total\_h} = \max(F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{total\_v} \times \tan(\delta_{bb}), 0\ plf) =$ **0** plf

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem} =$ **1462** lb_ft/ft
Wall base	$M_{base} = F_{base} \times x_{base} =$ **1519** lb_ft/ft
Surcharge load	$M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} =$ **-6** lb_ft/ft
Moist retained soil	$M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} =$ **4204** lb_ft/ft
Base soil	$M_{pass} = -F_{pass\_h} \times x_{pass\_h} =$ **104** lb_ft/ft
Total	$M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} + M_{pass} =$ **7283** lb_ft/ft

Check bearing pressure

Distance to reaction	$\bar{x} = M_{total} / F_{total\_v} =$ **1.815** ft
Eccentricity of reaction	$e = \bar{x} - l_{base} / 2 =$ **-0.435** ft
Loaded length of base	$l_{load} = l_{base} =$ **4.5** ft
Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{base} \times (1 - 6 \times e / l_{base}) =$ **1409** psf
Bearing pressure at heel	$q_{heel} = F_{total\_v} / l_{base} \times (1 + 6 \times e / l_{base}) =$ **375** psf
Factor of safety	$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) =$ **2.84**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

RETAINING WALL DESIGN

In accordance with ACI 318-14

Tedds calculation version 2.9.07

Concrete details

Compressive strength of concrete	$f'_c =$ **4000** psi
Concrete type	Normal weight

Reinforcement details

Yield strength of reinforcement	$f_y =$ **60000** psi
Modulus of elasticity or reinforcement	$E_s =$ **29000000** psi

Cover to reinforcement

Front face of stem	$c_{sf} =$ **2.25** in
Rear face of stem	$c_{sr} =$ **2.25** in
Top face of base	$c_{bt} =$ **2** in

Bottom face of base c_{bb} = **3** in

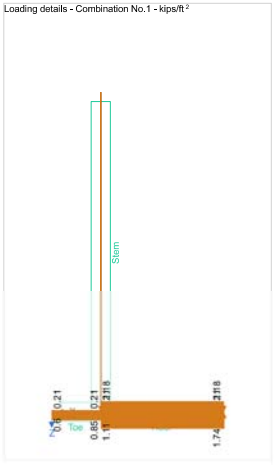
From IBC 2015 cl.1605.2.1 Basic load combinations

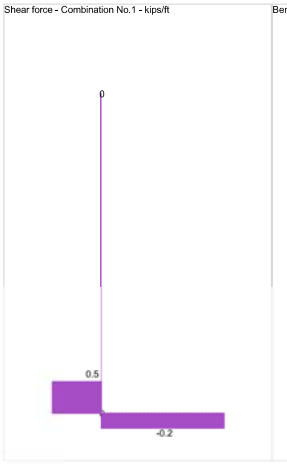
Load combination no.1 1.4 × Dead

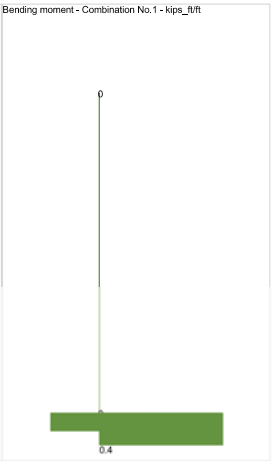
Load combination no.2 1.2 × Dead + 1.6 × Live + 1.6 × Lateral earth

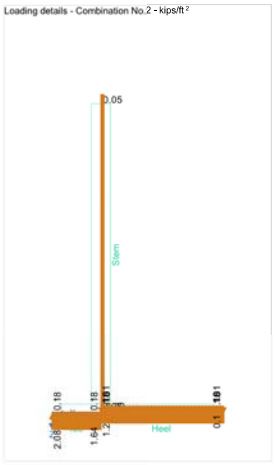
Load combination no.3 1.2 × Dead + 1.0 × Earthquake + 1.0 × Live + 1.6 × Lateral earth

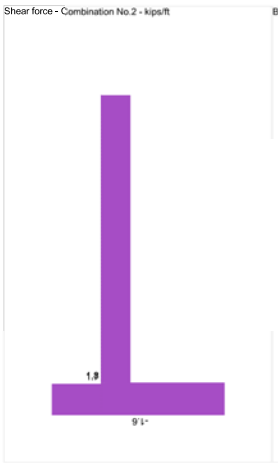
Load combination no.4 0.9 × Dead + 1.0 × Earthquake + 1.6 × Lateral earth

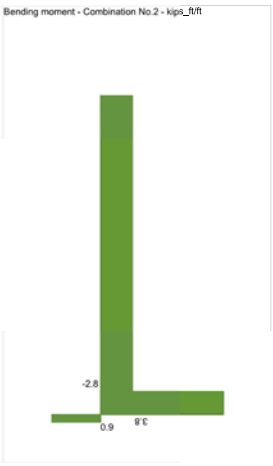












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	Section Wall 101 - 6'-6" Retainined height			Sheet no./rev. 6	
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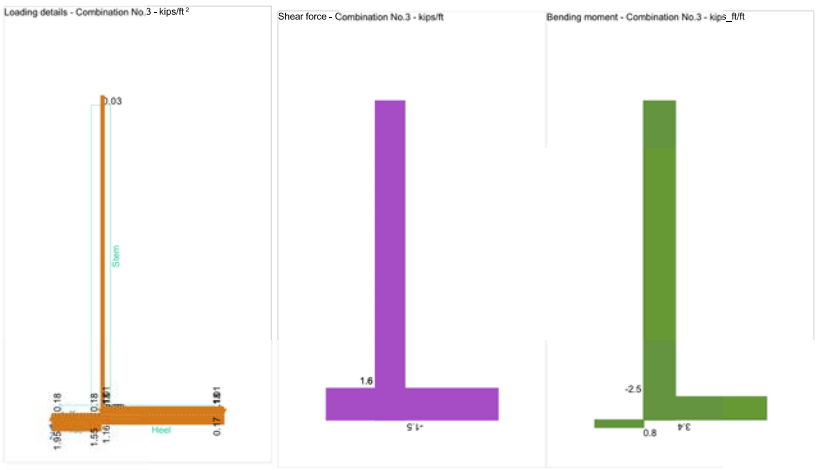
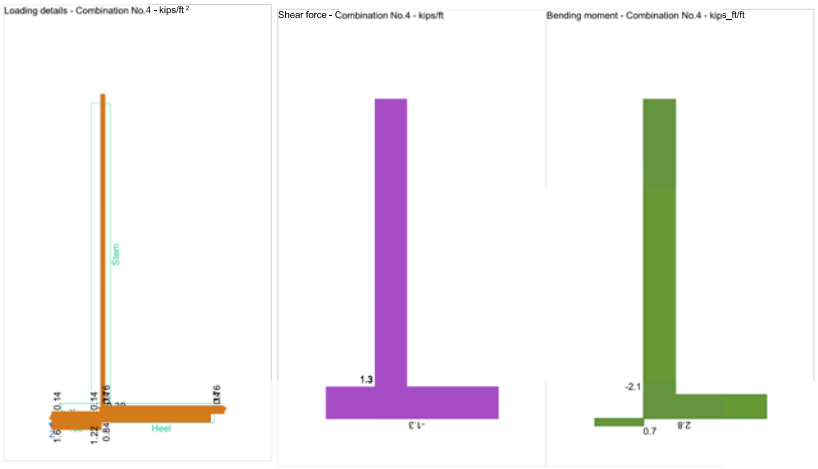




Check stem design at base of stem

Depth of section	h = **12** in

Rectangular section in flexure - Section 22.3

Design bending moment combination 2	M = **3756** lb_ft/ft
Depth of tension reinforcement	d = h - c_{sr} - ϕ_{sr} / 2 = **9.5** in
Compression reinforcement provided	No.4 bars @ 12" c/c
Area of compression reinforcement provided	$A_{sf,prov} = \pi \times \phi_{sf}^2 / (4 \times s_{sf})$ = **0.196** in²/ft
Tension reinforcement provided	No.4 bars @ 12" c/c
Area of tension reinforcement provided	$A_{sr,prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **0.196** in²/ft
Maximum reinforcement spacing - cl.11.7.2	s_{max} = min(18 in, 3 × h) = **18** in

PASS - Reinforcement is adequately spaced

Depth of compression block	$a = A_{sr.prov} \times f_y / (0.85 \times f'_c)$ = **0.289** in
Neutral axis factor - cl.22.2.2.4.3	$\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85)$ = **0.85**
Depth to neutral axis	$c = a / \beta_1$ = **0.34** in
Strain in reinforcement	$\varepsilon_t = 0.003 \times (d - c) / c$ = **0.080896**
	Section is in the tension controlled zone
Strength reduction factor	$\phi_f = \min(\max(0.65 + (\varepsilon_t - 0.002) \times (250 / 3), 0.65), 0.9)$ = **0.9**
Nominal flexural strength	$M_n = A_{sr.prov} \times f_y \times (d - a / 2)$ = **9185** lb_ft/ft
Design flexural strength	$\phi M_n = \phi_f \times M_n$ = **8266** lb_ft/ft
	$M / \phi M_n$ = **0.454**
	PASS - Design flexural strength exceeds factored bending moment
By iteration, reinforcement required by analysis	$A_{sr.des}$ = **0.088** in^2/ft
Minimum area of reinforcement - cl.9.6.1.3	$A_{sr.mod} = 4 \times A_{sr.des} / 3$ = **0.118** in^2/ft
	PASS - Area of reinforcement provided is greater than minimum area of reinforcement required

Rectangular section in shear - Section 22.5

Design shear force	V = **1582** lb/ft
Concrete modification factor - cl.19.2.4	λ = **1**
Nominal concrete shear strength - eqn.22.5.5.1	$V_c = 2 \times \lambda \times \sqrt{(f'_c \times 1\ psi)} \times d$ = **14420** lb/ft
Strength reduction factor	ϕ_s = **0.75**
Design concrete shear strength - cl.11.5.1.1	$\phi V_c = \phi_s \times V_c$ = **10815** lb/ft
	$V / \phi V_c$ = **0.146**
	PASS - No shear reinforcement is required

Horizontal reinforcement parallel to face of stem

Minimum area of reinforcement - cl.11.6.1	$A_{sx.req} = 0.002 \times t_{stem}$ = **0.288** in^2/ft
Transverse reinforcement provided	No.4 bars @ 12" c/c each face
Area of transverse reinforcement provided	$A_{sx.prov} = 2 \times \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **0.393** in^2/ft
	PASS - Area of reinforcement provided is greater than area of reinforcement required

Check base design at toe

Depth of section	h = **12** in

Rectangular section in flexure - Section 22.3

Design bending moment combination 2	M = **878** lb_ft/ft
Depth of tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2$ = **8.688** in
Compression reinforcement provided	No.5 bars @ 12" c/c
Area of compression reinforcement provided	$A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt})$ = **0.307** in^2/ft
Tension reinforcement provided	No.5 bars @ 12" c/c
Area of tension reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **0.307** in^2/ft
Maximum reinforcement spacing - cl.7.7.2.3	$s_{max} = \min(18\ in, 3 \times h)$ = **18** in
	PASS - Reinforcement is adequately spaced
Depth of compression block	$a = A_{bb.prov} \times f_y / (0.85 \times f'_c)$ = **0.451** in
Neutral axis factor - cl.22.2.2.4.3	$\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85)$ = **0.85**
Depth to neutral axis	$c = a / \beta_1$ = **0.531** in
Strain in reinforcement	$\varepsilon_t = 0.003 \times (d - c) / c$ = **0.046101**
	Section is in the tension controlled zone

Silman 32 Old Slip 10th floor New York, NY 10005	Project Retaining Wall				Job Ref.	
	Section Wall 101 - 6'-6" Retainined height				Sheet no./rev. 8	
	Calc. by B	Date	Chk'd by	Date	App'd by	Date

Strength reduction factor	$\phi_f = \min(\max(0.65 + (\varepsilon_t - 0.002) \times (250 / 3), 0.65), 0.9) =$ **0.9**
Nominal flexural strength	$M_n = A_{bb.prov} \times f_y \times (d - a / 2) =$ **12980** lb_ft/ft
Design flexural strength	$\phi M_n = \phi_f \times M_n =$ **11682** lb_ft/ft
	$M / \phi M_n =$ **0.075**
	PASS - Design flexural strength exceeds factored bending moment
By iteration, reinforcement required by analysis	$A_{bb.des} =$ **0.023** in^2/ft
Minimum area of reinforcement - cl.7.6.1.1	$A_{bb.min} = 0.0018 \times h =$ **0.259** in^2/ft
	PASS - Area of reinforcement provided is greater than minimum area of reinforcement required
Rectangular section in shear - Section 22.5	
Design shear force	V = **1683** lb/ft
Concrete modification factor - cl.19.2.4	$\lambda =$ **1**
Nominal concrete shear strength - eqn.22.5.5.1	$V_c = 2 \times \lambda \times \sqrt{(f'_c \times 1\ psi)} \times d =$ **13187** lb/ft
Strength reduction factor	$\phi_s =$ **0.75**
Design concrete shear strength - cl.7.6.3.1	$\phi V_c = \phi_s \times V_c =$ **9890** lb/ft
	$V / \phi V_c =$ **0.170**
	PASS - No shear reinforcement is required
Check base design at heel	
Depth of section	h = **12** in
Rectangular section in flexure - Section 22.3	
Design bending moment combination 2	M = **2768** lb_ft/ft
Depth of tension reinforcement	$d = h - c_{bt} - \phi_{bt} / 2 =$ **9.688** in
Compression reinforcement provided	No.5 bars @ 12" c/c
Area of compression reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **0.307** in^2/ft
Tension reinforcement provided	No.5 bars @ 12" c/c
Area of tension reinforcement provided	$A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) =$ **0.307** in^2/ft
Maximum reinforcement spacing - cl.7.7.2.3	$s_{max} = \min(18\ in, 3 \times h) =$ **18** in
	PASS - Reinforcement is adequately spaced
Depth of compression block	$a = A_{bt.prov} \times f_y / (0.85 \times f'_c) =$ **0.451** in
Neutral axis factor - cl.22.2.2.4.3	$\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**
Depth to neutral axis	$c = a / \beta_1 =$ **0.531** in
Strain in reinforcement	$\varepsilon_t = 0.003 \times (d - c) / c =$ **0.051753**
	Section is in the tension controlled zone
Strength reduction factor	$\phi_f = \min(\max(0.65 + (\varepsilon_t - 0.002) \times (250 / 3), 0.65), 0.9) =$ **0.9**
Nominal flexural strength	$M_n = A_{bt.prov} \times f_y \times (d - a / 2) =$ **14514** lb_ft/ft
Design flexural strength	$\phi M_n = \phi_f \times M_n =$ **13063** lb_ft/ft
	$M / \phi M_n =$ **0.212**
	PASS - Design flexural strength exceeds factored bending moment
By iteration, reinforcement required by analysis	$A_{bt.des} =$ **0.064** in^2/ft
Minimum area of reinforcement - cl.7.6.1.1	$A_{bt.min} = 0.0018 \times h =$ **0.259** in^2/ft
	PASS - Area of reinforcement provided is greater than minimum area of reinforcement required
Rectangular section in shear - Section 22.5	
Design shear force	V = **1755** lb/ft

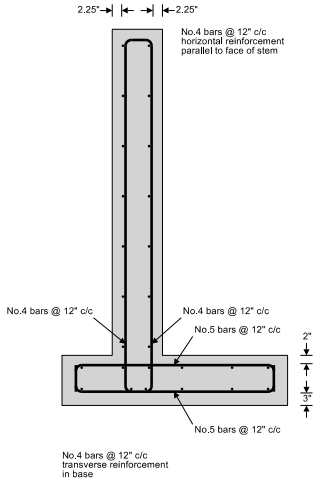
Concrete modification factor - cl.19.2.4	λ = **1**
Nominal concrete shear strength - eqn.22.5.5.1	$V_c = 2 \times \lambda \times \sqrt{(f'_c \times 1\ psi)} \times d$ = **14705** lb/ft
Strength reduction factor	ϕ_s = **0.75**
Design concrete shear strength - cl.7.6.3.1	$\phi V_c = \phi_s \times V_c$ = **11028** lb/ft
	$V / \phi V_c$ = **0.159**

PASS - No shear reinforcement is required

Transverse reinforcement parallel to base

Minimum area of reinforcement - cl.76.1.1	$A_{bx.req} = 0.0018 \times t_{base}$ = **0.259** in^2/ft
Transverse reinforcement provided	No.4 bars @ 12" c/c each face
Area of transverse reinforcement provided	$A_{bx.prov} = 2 \times \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **0.393** in^2/ft

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



Reinforcement details

Wall 102

The following calculations represent the design for the cantilever retaining wall with a maximum retained soil height of 12’-6”.

Tekla Tedds
Silman
32 Old Slip 10th floor
New York, NY 10005

Project				Job Ref.	
Retaining Wall					
Section				Sheet no./rev.	
Wall 102 - 12'-6" Retainined height				1	
Calc. by	Date	Chk'd by	Date	App'd by	Date
B					

RETAINING WALL ANALYSIS

In accordance with International Building Code 2015

Tedds calculation version 2.9.07

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **12.5** ft
Stem thickness	t_{stem} = **12** in
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **150** pcf
Toe length	l_{toe} = **1.5** ft
Heel length	l_{heel} = **4.5** ft
Base thickness	t_{base} = **12** in
Base density	γ_{base} = **150** pcf
Height of retained soil	h_{ret} = **12.5** ft
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** ft

Retained soil properties

Soil type	Very dense well graded sand
Moist density	γ_{mr} = **130** pcf
Saturated density	γ_{sr} = **130** pcf
Effective angle of internal resistance	ϕ_r = **30** deg
Effective wall friction angle	δ_r = **15** deg

Base soil properties

Soil type	Very Dense well graded sand
Soil density	γ_b = **130** pcf
Cohesion	c_b = **0** psf
Effective angle of internal resistance	ϕ_b = **30** deg
Effective wall friction angle	δ_b = **15** deg
Effective base friction angle	δ_{bb} = **30** deg
Allowable bearing pressure	$P_{bearing}$ = **4000** psf

Loading details

Live surcharge load	$Surcharge_L$ = **100** psf

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Silman
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Project				Job Ref.	
Retaining Wall					
Section				Sheet no./rev.	
Wall 102 - 12'-6" Retainined height				2	
Calc. by	Date	Chk'd by	Date	App'd by	Date
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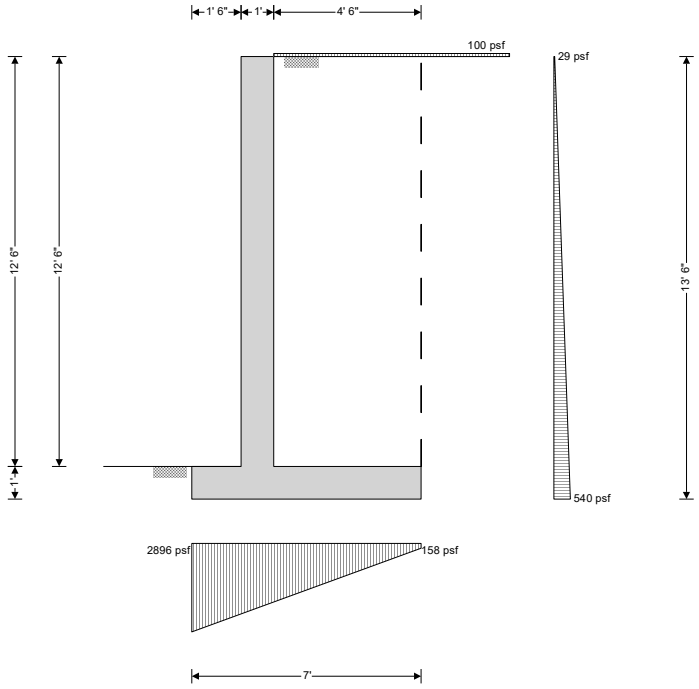


General arrangement

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel}$ = **7** ft
Moist soil height	$h_{moist} = h_{soil}$ = **12.5** ft
Length of surcharge load	$l_{sur} = l_{heel}$ = **4.5** ft
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2$ = **4.75** ft
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **13.5** ft
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2$ = **6.75** ft
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem}$ = **12.5** ft^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2$ = **2** ft
Area of wall base	$A_{base} = l_{base} \times t_{base}$ = **7** ft^2
- Distance to vertical component	$x_{base} = l_{base} / 2$ = **3.5** ft
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel}$ = **56.25** ft^2
- Distance to vertical component	$x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist}$ = **4.75** ft
- Distance to horizontal component	$x_{moist\_h} = h_{eff} / 3$ = **4.5** ft

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi_r)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_r) \times [1 + \sqrt{[\sin(\phi_r + \delta_r) \times \sin(\phi_r - \beta) / (\sin(\alpha - \delta_r) \times \sin(\alpha + \beta))]}]^2)$ = **0.301**
Passive pressure coefficient	$K_P = \sin(90 - \phi_b)^2 / (\sin(90 + \delta_b) \times [1 - \sqrt{[\sin(\phi_b + \delta_b) \times \sin(\phi_b) / (\sin(90 + \delta_b))]}]^2)$ = **4.977**

From IBC 2015 cl.1807.2.3 Safety factor

Load combination 1 — 1.0 × Dead + 1.0 × Live + 1.0 × Lateral earth

Sliding check

Vertical forces on wall

Wall stem — $F_{stem} = A_{stem} \times \gamma_{stem}$ = **1875** plf

Wall base — $F_{base} = A_{base} \times \gamma_{base}$ = **1050** plf

Moist retained soil — $F_{moist\_v} = A_{moist} \times \gamma_{mr}$ = **7313** plf

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **10238** plf

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_r) \times Surcharge_L \times h_{eff}$ = **393** plf

Moist retained soil — $F_{moist\_h} = K_A \times \cos(\delta_r) \times \gamma_{mr} \times h_{eff}^2 / 2$ = **3449** plf

Total — $F_{total\_h} = F_{sur\_h} + F_{moist\_h}$ = **3842** plf

Check stability against sliding

Base soil resistance — $F_{exc\_h} = K_P \times \cos(\delta_b) \times \gamma_b \times (h_{pass} + h_{base})^2 / 2$ = **312** plf

Base friction — $F_{friction} = F_{total\_v} \times \tan(\delta_{bb})$ = **5911** plf

Resistance to sliding — $F_{rest} = F_{exc\_h} + F_{friction}$ = **6223** plf

Factor of safety — $FoS_{sl} = F_{rest} / F_{total\_h}$ = **1.62** > 1.5

PASS - Factor of safety against sliding is adequate

Overturning check

Vertical forces on wall

Wall stem — $F_{stem} = A_{stem} \times \gamma_{stem}$ = **1875** plf

Wall base — $F_{base} = A_{base} \times \gamma_{base}$ = **1050** plf

Moist retained soil — $F_{moist\_v} = A_{moist} \times \gamma_{mr}$ = **7313** plf

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **10238** plf

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_r) \times Surcharge_L \times h_{eff}$ = **393** plf

Moist retained soil — $F_{moist\_h} = K_A \times \cos(\delta_r) \times \gamma_{mr} \times h_{eff}^2 / 2$ = **3449** plf

Base soil — $F_{exc\_h} = -K_P \times \cos(\delta_b) \times \gamma_b \times (h_{pass} + h_{base})^2 / 2$ = **-312** plf

Total — $F_{total\_h} = F_{sur\_h} + F_{moist\_h} + F_{exc\_h}$ = **3530** plf

Overturning moments on wall

Surcharge load — $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h}$ = **2653** lb_ft/ft

Moist retained soil — $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h}$ = **15520** lb_ft/ft

Total — $M_{total\_OT} = M_{sur\_OT} + M_{moist\_OT}$ = **18174** lb_ft/ft

Restoring moments on wall

Wall stem — $M_{stem\_R} = F_{stem} \times x_{stem}$ = **3750** lb_ft/ft

Wall base — $M_{base\_R} = F_{base} \times x_{base}$ = **3675** lb_ft/ft

Moist retained soil — $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **34734** lb_ft/ft

Base soil — $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h}$ = **104** lb_ft/ft

Total — $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} + M_{exc\_R}$ = **42264** lb_ft/ft

Check stability against overturning

Factor of safety — $FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **2.326** > 1.5

Silman 32 Old Slip 10th floor New York, NY 10005	Project Retaining Wall				Job Ref.	
	Section Wall 102 - 12'-6" Retainined height				Sheet no./rev. 4	
	Calc. by B	Date	Chk'd by	Date	App'd by	Date

PASS - Factor of safety against overturning is adequate

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = A_{stem} \times \gamma_{stem} =$ **1875** plf
Wall base	$F_{base} = A_{base} \times \gamma_{base} =$ **1050** plf
Surcharge load	$F_{sur\_v} = Surcharge_L \times l_{heel} =$ **450** plf
Moist retained soil	$F_{moist\_v} = A_{moist} \times \gamma_{mr} =$ **7313** plf
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{sur\_v} + F_{moist\_v} =$ **10688** plf

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_r) \times Surcharge_L \times h_{eff} =$ **393** plf
Moist retained soil	$F_{moist\_h} = K_A \times \cos(\delta_r) \times \gamma_{mr} \times h_{eff}^2 / 2 =$ **3449** plf
Base soil	$F_{pass\_h} = -K_P \times \cos(\delta_b) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 =$ **-312** plf
Total	$F_{total\_h} = \max(F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{total\_v} \times \tan(\delta_{bb}), 0\ plf) =$ **0** plf

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem} =$ **3750** lb_ft/ft
Wall base	$M_{base} = F_{base} \times x_{base} =$ **3675** lb_ft/ft
Surcharge load	$M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} =$ **-516** lb_ft/ft
Moist retained soil	$M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} =$ **19214** lb_ft/ft
Base soil	$M_{pass} = -F_{pass\_h} \times x_{pass\_h} =$ **104** lb_ft/ft
Total	$M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} + M_{pass} =$ **26228** lb_ft/ft

Check bearing pressure

Distance to reaction	$\bar{x} = M_{total} / F_{total\_v} =$ **2.454** ft
Eccentricity of reaction	$e = \bar{x} - l_{base} / 2 =$ **-1.046** ft
Loaded length of base	$l_{load} = l_{base} =$ **7** ft
Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{base} \times (1 - 6 \times e / l_{base}) =$ **2896** psf
Bearing pressure at heel	$q_{heel} = F_{total\_v} / l_{base} \times (1 + 6 \times e / l_{base}) =$ **158** psf
Factor of safety	$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) =$ **1.381**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

RETAINING WALL DESIGN

In accordance with ACI 318-14

Tedds calculation version 2.9.07

Concrete details

Compressive strength of concrete	$f'_c =$ **4000** psi
Concrete type	Normal weight

Reinforcement details

Yield strength of reinforcement	$f_y =$ **60000** psi
Modulus of elasticity or reinforcement	$E_s =$ **29000000** psi

Cover to reinforcement

Front face of stem	$c_{sf} =$ **2.25** in
Rear face of stem	$c_{sr} =$ **2.25** in
Top face of base	$c_{bt} =$ **2** in

Bottom face of base c_{bb} = **3** in

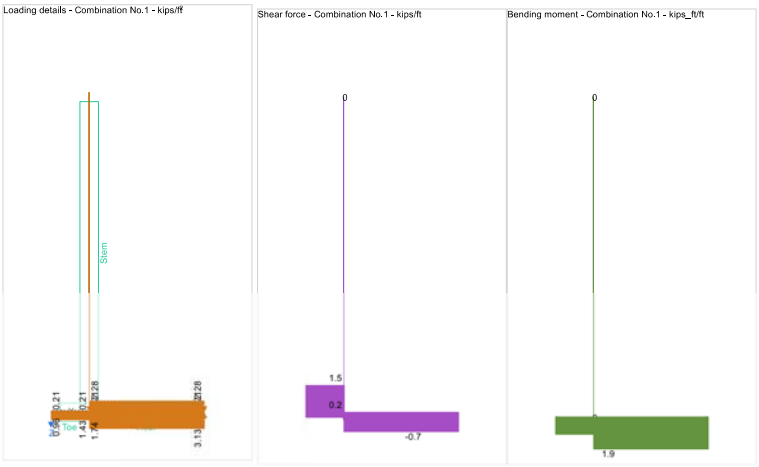
From IBC 2015 cl.1605.2.1 Basic load combinations

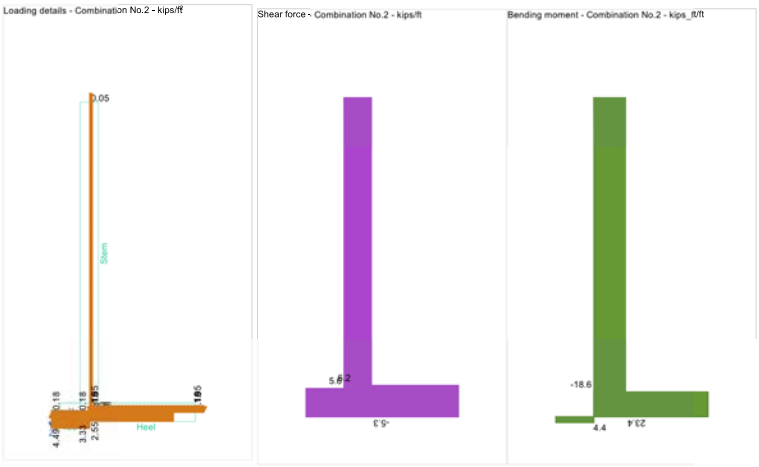
Load combination no.1 1.4 × Dead

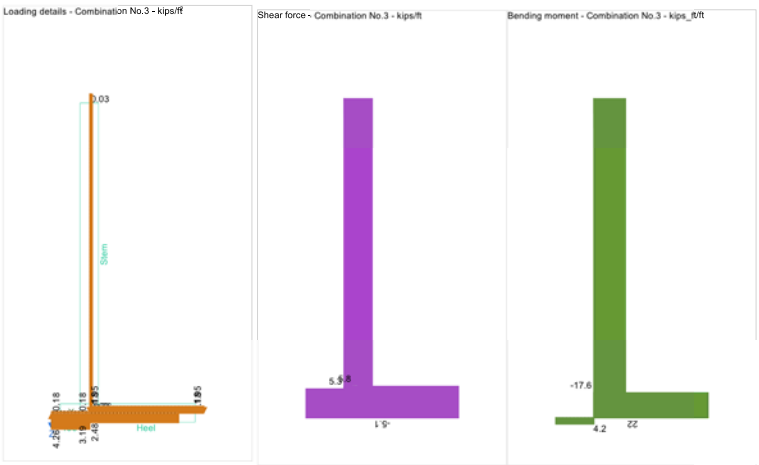
Load combination no.2 1.2 × Dead + 1.6 × Live + 1.6 × Lateral earth

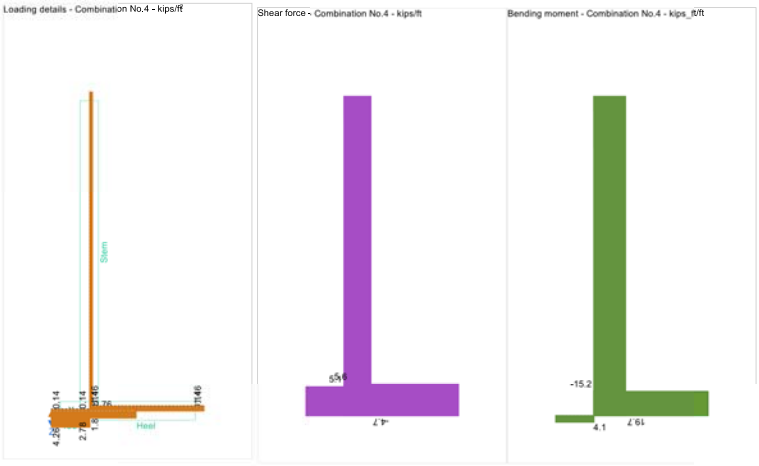
Load combination no.3 1.2 × Dead + 1.0 × Earthquake + 1.0 × Live + 1.6 × Lateral earth

Load combination no.4 0.9 × Dead + 1.0 × Earthquake + 1.6 × Lateral earth









Check stem design at base of stem

Depth of section	h = **12** in

Rectangular section in flexure - Section 22.3

Design bending moment combination 2	M = **23352** lb_ft/ft
Depth of tension reinforcement	d = h - c_{sr} - ϕ_{sr} / 2 = **9.313** in
Compression reinforcement provided	No.4 bars @ 12" c/c
Area of compression reinforcement provided	$A_{sf.prov} = \pi \times \phi_{sf}^2 / (4 \times s_{sf})$ = **0.196** in^2/ft
Tension reinforcement provided	No.7 bars @ 12" c/c
Area of tension reinforcement provided	$A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **0.601** in^2/ft
Maximum reinforcement spacing - cl.11.7.2	s_{max} = min(18 in, 3 × h) = **18** in
	PASS - Reinforcement is adequately spaced
Depth of compression block	$a = A_{sr.prov} \times f_y / (0.85 \times f'_c)$ = **0.884** in

Neutral axis factor - cl.22.2.2.4.3	$\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**
Depth to neutral axis	$c = a / \beta_1 =$ **1.04** in
Strain in reinforcement	$\varepsilon_t = 0.003 \times (d - c) / c =$ **0.023854**
	Section is in the tension controlled zone
Strength reduction factor	$\phi_f = \min(\max(0.65 + (\varepsilon_t - 0.002) \times (250 / 3), 0.65), 0.9) =$ **0.9**
Nominal flexural strength	$M_n = A_{sr.prov} \times f_y \times (d - a / 2) =$ **26670** lb_ft/ft
Design flexural strength	$\phi M_n = \phi_f \times M_n =$ **24003** lb_ft/ft
	$M / \phi M_n =$ **0.973**
	PASS - Design flexural strength exceeds factored bending moment
By iteration, reinforcement required by analysis	$A_{sr.des} =$ **0.584** in²/ft
Minimum area of reinforcement - cl.9.6.1.2	$A_{sr.min} = \max(3 \times \sqrt{(f'_c \times 1\ psi)}, 200\ psi) \times d / f_y =$ **0.373** in²/ft
	PASS - Area of reinforcement provided is greater than minimum area of reinforcement required
Rectangular section in shear - Section 22.5	
Design shear force	V = **5313** lb/ft
Concrete modification factor - cl.19.2.4	$\lambda =$ **1**
Nominal concrete shear strength - eqn.22.5.5.1	$V_c = 2 \times \lambda \times \sqrt{(f'_c \times 1\ psi)} \times d =$ **14135** lb/ft
Strength reduction factor	$\phi_s =$ **0.75**
Design concrete shear strength - cl.11.5.1.1	$\phi V_c = \phi_s \times V_c =$ **10602** lb/ft
	$V / \phi V_c =$ **0.501**
	PASS - No shear reinforcement is required
Horizontal reinforcement parallel to face of stem	
Minimum area of reinforcement - cl.11.6.1	$A_{sx.req} = 0.002 \times t_{stem} =$ **0.288** in²/ft
Transverse reinforcement provided	No.4 bars @ 12" c/c each face
Area of transverse reinforcement provided	$A_{sx.prov} = 2 \times \pi \times \phi_{sx}^2 / (4 \times s_{sx}) =$ **0.393** in²/ft
	PASS - Area of reinforcement provided is greater than area of reinforcement required
Check base design at toe	
Depth of section	h = **12** in
Rectangular section in flexure - Section 22.3	
Design bending moment combination 2	M = **4415** lb_ft/ft
Depth of tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2 =$ **8.563** in
Compression reinforcement provided	No.7 bars @ 12" c/c
Area of compression reinforcement provided	$A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) =$ **0.601** in²/ft
Tension reinforcement provided	No.7 bars @ 12" c/c
Area of tension reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **0.601** in²/ft
Maximum reinforcement spacing - cl.7.7.2.3	$s_{max} = \min(18\ in, 3 \times h) =$ **18** in
	PASS - Reinforcement is adequately spaced
Depth of compression block	$a = A_{bb.prov} \times f_y / (0.85 \times f'_c) =$ **0.884** in
Neutral axis factor - cl.22.2.2.4.3	$\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**
Depth to neutral axis	$c = a / \beta_1 =$ **1.04** in
Strain in reinforcement	$\varepsilon_t = 0.003 \times (d - c) / c =$ **0.021691**
	Section is in the tension controlled zone
Strength reduction factor	$\phi_f = \min(\max(0.65 + (\varepsilon_t - 0.002) \times (250 / 3), 0.65), 0.9) =$ **0.9**

Nominal flexural strength	$M_n = A_{bb.prov} \times f_y \times (d - a / 2) =$ **24415** lb_ft/ft
Design flexural strength	$\phi M_n = \phi_f \times M_n =$ **21973** lb_ft/ft
	$M / \phi M_n =$ **0.201**
	PASS - Design flexural strength exceeds factored bending moment
By iteration, reinforcement required by analysis	$A_{bb.des} =$ **0.116** in^2/ft
Minimum area of reinforcement - cl.7.6.1.1	$A_{bb.min} = 0.0018 \times h =$ **0.259** in^2/ft
	PASS - Area of reinforcement provided is greater than minimum area of reinforcement required

Rectangular section in shear - Section 22.5

Design shear force	V = **5595** lb/ft
Concrete modification factor - cl.19.2.4	$\lambda =$ **1**
Nominal concrete shear strength - eqn.22.5.5.1	$V_c = 2 \times \lambda \times \sqrt{(f'_c \times 1\ psi)} \times d =$ **12997** lb/ft
Strength reduction factor	$\phi_s =$ **0.75**
Design concrete shear strength - cl.7.6.3.1	$\phi V_c = \phi_s \times V_c =$ **9748** lb/ft
	$V / \phi V_c =$ **0.574**
	PASS - No shear reinforcement is required

Check base design at heel

Depth of section	h = **12** in

Rectangular section in flexure - Section 22.3

Design bending moment combination 2	M = **18581** lb_ft/ft
Depth of tension reinforcement	$d = h - c_{bt} - \phi_{bt} / 2 =$ **9.563** in
Compression reinforcement provided	No.7 bars @ 12" c/c
Area of compression reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **0.601** in^2/ft
Tension reinforcement provided	No.7 bars @ 12" c/c
Area of tension reinforcement provided	$A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) =$ **0.601** in^2/ft
Maximum reinforcement spacing - cl.7.7.2.3	$s_{max} = \min(18\ in, 3 \times h) =$ **18** in
	PASS - Reinforcement is adequately spaced
Depth of compression block	$a = A_{bt.prov} \times f_y / (0.85 \times f'_c) =$ **0.884** in
Neutral axis factor - cl.22.2.2.4.3	$\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**
Depth to neutral axis	$c = a / \beta_1 =$ **1.04** in
Strain in reinforcement	$\varepsilon_t = 0.003 \times (d - c) / c =$ **0.024575**
	Section is in the tension controlled zone
Strength reduction factor	$\phi_f = \min(\max(0.65 + (\varepsilon_t - 0.002) \times (250 / 3), 0.65), 0.9) =$ **0.9**
Nominal flexural strength	$M_n = A_{bt.prov} \times f_y \times (d - a / 2) =$ **27421** lb_ft/ft
Design flexural strength	$\phi M_n = \phi_f \times M_n =$ **24679** lb_ft/ft
	$M / \phi M_n =$ **0.753**
	PASS - Design flexural strength exceeds factored bending moment
By iteration, reinforcement required by analysis	$A_{bt.des} =$ **0.447** in^2/ft
Minimum area of reinforcement - cl.7.6.1.1	$A_{bt.min} = 0.0018 \times h =$ **0.259** in^2/ft
	PASS - Area of reinforcement provided is greater than minimum area of reinforcement required

Rectangular section in shear - Section 22.5

Design shear force	V = **6150** lb/ft
Concrete modification factor - cl.19.2.4	$\lambda =$ **1**

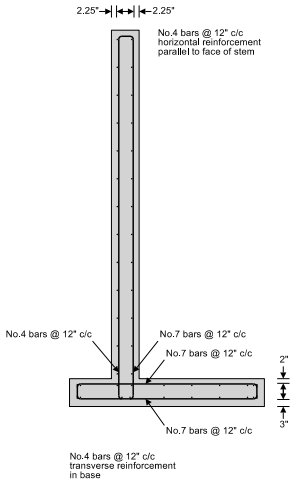
Nominal concrete shear strength - eqn.22.5.5.1	$V_c = 2 \times \lambda \times \sqrt{(f'_c \times 1\ psi)} \times d =$ **14515** lb/ft
Strength reduction factor	$\phi_s =$ **0.75**
Design concrete shear strength - cl.7.6.3.1	$\phi V_c = \phi_s \times V_c =$ **10886** lb/ft
	$V / \phi V_c =$ **0.565**

PASS - No shear reinforcement is required

Transverse reinforcement parallel to base

Minimum area of reinforcement - cl.76.1.1	$A_{bx.req} = 0.0018 \times t_{base} =$ **0.259** in^2/ft
Transverse reinforcement provided	No.4 bars @ 12" c/c each face
Area of transverse reinforcement provided	$A_{bx.prov} = 2 \times \pi \times \phi_{bx}^2 / (4 \times s_{bx}) =$ **0.393** in^2/ft

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



Reinforcement details