Foundation Design Equations Summary

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1.0 INTRODUCTION

This document presents a summary of commonly applied engineering equations for the design of shallow and deep foundations.

2.0 FOUNDATION DESIGN EQUATIONS SUMMARY

Definitions of variables are as follows:-

Allowable (safe) net effective bearing capacity, q_{fnet}'
Allowable (safe) net bearing capacity, q_{fnet}
Gross effective bearing capacity, q_f'
Gross bearing capacity, q_f
Net (effective) working pressure, q_{wnet}'
Effective surcharge above founding level, p_0'
Total surcharge above founding level, p_0
Standard penetration test, SPT, N
Factor of safety, FOS
Water table, WT
Depth of water table from ground level, z_u
Depth of foundation founding level from ground level, D
Width of foundation, B
Length of foundation, L
Influence factor, $I_s = f_s.f_d$
Shape and rigidity factor, f_s
Depth factor, f_d
SLS pile axial compression capacity, $N_{cap,pile,comp,sls}$
Base effective bearing capacity, Q_b'
Gross effective bearing capacity, $q_f'(z=L-L_0)$
Shaft effective friction capacity, Q_s'
Average shaft effective stress, τ_a'
Pile weight minus soil weight removed, F_{pile}
Combined base effective bearing and shaft effective friction capacity, P_f'
Overall pile effective capacity for vertical (compressive) load, P_{cap}

Foundation Type	Structural Capacity	Geotechnical Capacity			Geotechnical Settlement		
		Cohesionless Soils	**Cohesive Soils**	**Rocks**	**Cohesionless Soils**	**Cohesive Soils**	**Rocks**
Pad	**ULS**	**Empirical**	**Empirical**	**Empirical**	**Elastic**	**Elastic**	**Elastic**
	Excluding soil-structure interaction, the pad footing is designed to resist the ULS pressure stemming from the ULS column loads. Note that the DL of the pad is NOT included in the analysis.	$q_{fnet}' \approx k.30N/FOS = k.10N$, k = 0.5 if WT above depth of B	$q_{fnet} \approx k.42.6N/FOS = k.14.2N$, k = 0.67 if WT above ground level	$q_{fnet}' \approx k.30N/FOS = k.10N$, k = 1.0 if WT above depth of B	$\delta = q_{wnet}'.B.(1-\nu^2).I_s/E$ $\nu = 0.15\text{-}0.25$ $I_s = f_s.f_d$ $f_s = 1.12(L/B)^{0.39}$ *Flexible Rectangular* $f_s = 0.90(L/B)^{0.38}$ *Rigid Rectangular* $f_s = 1.0$ *Flexible Circular* $f_s = 0.79$ *Rigid Circular* $f_d = 1-0.08(D/B).[1+(4/3).(B/L)]$ $E = 1000N$ *Normally Consolidated* $E = 2000N$ *Over Consolidated*	$\delta = q_{wnet}'.B.(1-\nu^2).I_s/E$ $\nu = 0.30\text{-}0.50$ $I_s = f_s.f_d$ $f_s = 1.12(L/B)^{0.39}$ *Flexible Rectangular* $f_s = 0.90(L/B)^{0.38}$ *Rigid Rectangular* $f_s = 1.0$ *Flexible Circular* $f_s = 0.79$ *Rigid Circular* $f_d = 1-0.08(D/B).[1+(4/3).(B/L)]$ $E = 200S_u$	$\delta = q_{wnet}'.(B/E).I_p.F_B.F_D$
		Terzaghi	**Terzaghi**	**Terzaghi**	**Burland and Burbidge**	**Elastic and 1D Consolidation**	
		$q_{fnet}' = (q_f'-p_0')/FOS$ $q_f' = s_c.d_c.N_{c,strip}.c' + s_q.d_q.N_{q,strip}.p_0' + s_\gamma.d_\gamma.N_{\gamma,strip}.B/2.\gamma'$ $s_c=(s_q.N_q-1)/(N_q-1)$ $d_c=1+0.4\tan^{-1}(D/B)$ *Prandtl*, $N_{c,strip} = (N_{q,strip}-1).\cot\phi'$ $s_q=1+(B'/L')\sin\phi'$ $d_q=1+2\tan\phi'(1-\sin\phi')^2.\tan^{-1}(D/B')$ *Reissner*, $N_{q,strip} = e^{\pi\tan\phi'}.\tan^2(45°+\phi'/2)$ $s_\gamma=1-0.3(B'/L')$ $d_\gamma=1.0$ *Hansen*, $N_{\gamma,strip} = 2.0(N_{q,strip}-1).\tan\phi'$	$q_{fnet} = (q_f-p_0)/FOS$ $q_f = s_c.d_c.N_{c,strip}.S_u + p_0$ $s_c = 1+0.2(B/L)$ $d_c = 1+(0.053D/B)^{0.5}$ for $D/B \leq 4.0$ *Skempton*, $N_{c,strip} = (2+\pi)$	$q_{fnet}' = (q_f'-p_0')/FOS$ $q_f' = s_c.d_c.N_{c,strip}.c' + s_q.d_q.N_{q,strip}.p_0' + s_\gamma.d_\gamma.N_{\gamma,strip}.B/2.\gamma'$ $s_c=(s_q.N_q-1)/(N_q-1)$ $d_c=1+0.4\tan^{-1}(D/B)$ *Tomlinson*, $N_{c,strip}$ $s_q=1+(B'/L')\sin\phi'$ $d_q=1+2\tan\phi'(1-\sin\phi')^2.\tan^{-1}(D/B')$ *Tomlinson*, $N_{q,strip}$ $s_\gamma=1-0.3(B'/L')$ $d_\gamma=1.0$ *Tomlinson*, $N_{\gamma,strip}$	$\delta = 1.71q_{wnet}'.B^{0.7}/N^{1.4}$	*Rectangular* $\delta = \Sigma\Delta\delta = \Sigma[m_v.\Delta\sigma_v'.\Delta H]$ $\Delta\sigma_v' = 4.q_{wnet}'.I_\sigma$ $m = (B/2)/z$ $n = (L/2)/z$ *Circular* $\delta = \Sigma\Delta\delta = \Sigma[m_v.\Delta\sigma_v'.\Delta H]$ $\Delta\sigma_v' = 1.q_{wnet}'.I_\sigma$	

Foundation Type	Structural Capacity	Geotechnical Capacity			Geotechnical Settlement		
		Cohesionless Soils	**Cohesive Soils**	**Rocks**	**Cohesionless Soils**	**Cohesive Soils**	**Rocks**
Strip	**ULS**	**Empirical**	**Empirical**	**Empirical**	**Elastic**	**Elastic**	**Elastic**
	… as that for pads	$q_{fnet}' \approx k.21N/FOS = k.7N$, k = 0.5 if WT above depth of B	$q_{fnet} \approx k.35.5N/FOS = k.11.8N$, k = 0.67 if WT above ground level	$q_{fnet}' \approx k.21N/FOS = k.7N$, k = 1.0 if WT above depth of B	*… as that for pads*	*… as that for pads*	*… as that for pads*
		Terzaghi	**Terzaghi**	**Terzaghi**	**Burland and Burbidge**	**Elastic and 1D Consolidation**	
		… as that for pads	*… as that for pads*	*… as that for pads*	*… as that for pads*	*… as that for pads*	

Foundation Type	Structural Capacity	Geotechnical Capacity			Geotechnical Settlement		
		Cohesionless Soils	Cohesive Soils	Rocks	Cohesionless Soils	Cohesive Soils	Rocks
Raft	**ULS**	**Empirical**	**Empirical**	**Empirical**	**Elastic**	**Elastic**	**Elastic**
	Excluding soil-structure interaction, raft designed as series of pad footings, strip footings, multi-column footings, combined footings and strap footings culminating in an inverted flat slab (in the case of a solid raft) or an inverted one- or two-way spanning slab (in the case of a stripped raft) to resist the ULS pressure stemming from the ULS column loads. Note that as with the pad, strip, multi-column and combined footings the DL of the raft is NOT included in the inverted flat, one- or two-way spanning slab analysis. *Including soil-structure interaction, raft analysed and designed to the ULS column loads with soil stiffness modelled beneath the raft as springs based on the modulus of the subgrade reaction over the pressure bulb, each sub-soil layer contributing a spring stiffness connected in series.*	*… as that for pads*	*… as that for pads*	*… as that for pads*	*… as that for pads*	*… as that for pads*	*… as that for pads*
	SLS	**Terzaghi**	**Terzaghi**	**Terzaghi**	**Burland and Burbidge**	**Elastic and 1D Consolidation**	
	Including soil-structure interaction, raft analysed to the SLS column loads with soil stiffness modelled beneath the raft as springs based on the modulus of the subgrade reaction over the pressure bulb, each sub-soil layer contributing a spring stiffness connected in series. Raft stiffness modified to limit angular distortion to distance/350.	*… as that for pads*	*… as that for pads*	*… as that for pads*	*… as that for pads*	*… as that for pads*	

Foundation Type	Structural Capacity	Geotechnical Capacity			Geotechnical Settlement		
		Cohesionless Soils	Cohesive Soils	Rocks	Cohesionless Soils	Cohesive Soils	Rocks
Piled Raft ***(note that the piled raft may be a solid raft or a stripped one- or two-way spanning raft)***	**ULS**	**Empirical**	**Empirical**	**Empirical**	**Elastic**	**Elastic**	**Elastic**
	Including soil-structure interaction, piled raft analysed and designed to the ULS column loads with soil stiffness modelled beneath the piled raft, along and beneath the piles as springs based on the modulus of the subgrade reaction over the pressure bulb, each sub-soil layer contributing a spring stiffness connected in series.	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*
	SLS	**Terzaghi**	**Terzaghi**	**Terzaghi**	**Burland and Burbidge / Empirical**	**Elastic and 1D Consolidation / Empirical**	
	Including soil-structure interaction, piled raft analysed to the SLS column loads with soil stiffness modelled beneath the piled raft, along and beneath the piles as springs based on the modulus of the subgrade reaction over the pressure bulb, each sub-soil layer contributing a spring stiffness connected in series. Raft stiffness, pile size, pile spacing and pile depth modified to limit angular distortion to distance/350.	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	*… as that for pads and piles to their respective stiffness ratios*	

Foundation Type	Structural Capacity	Geotechnical Capacity			Geotechnical Settlement		
		Cohesionless Soils	**Cohesive Soils**	**Rocks**	**Cohesionless Soils**	**Cohesive Soils**	**Rocks**
Pile Cap and Pile ***(note that the pile cap may be disconnected individual pile caps, connected solid slab or a connected stripped one- or two-way spanning slab)***	**ULS**	**Empirical**	**Empirical**	**Empirical**	**Empirical**	**Empirical**	**Empirical**
	Pile cap designed employing well proportioned span to depth truss analogy method and sufficient pile cap and pile rebar anchorages. *Solid or stripped one- or two-way spanning slab designed to suspend between the pile points.*	P_{cap} = MIN ($Q_b'/3.0 + Q_s'/1.5$, $P_f'/2.0$)-F_{pile} $Q_b' = (\pi D_b^2/4 \text{ or } D_b^2).q_f'(z=L-L_0)$ $q_f'(z=L-L_0)=250.N(z=L-L_0)$ $(<=q_{flimit}'(z=L-L_0))$ $Q_s' = (\pi D \text{ or } 4D).(L-L_0).\tau_a'$ $\tau_a'=[\tau_a'(z=0)+\tau_a'(z=L-L_0)]/2$ $\tau_a'(z=0)=2.0.N(z=0)$ $(<=\tau_{alimit}'(z))$ $\tau_a'(z=L-L_0) = 2.0.N(z=L-L_0)$ $(<=\tau_{alimit}'(z))$ $F_{pile} = A_{ps}.L.(\rho_c-\gamma_{dry})$ $P_f' = Q_b' + Q_s'$	*… as that for cohesionless soils*	*… as that for cohesionless soils*	$d = z_b+z_s$ $z_b = z_{bc}.(z_b/z_{bc})$ $z_{bc} = 5\%.(D_b)$ z_b/z_{bc} $z_s = z_{sc}.(z_s/z_{sc})$ z_{sc} z_s/z_{sc}	*… as that for cohesionless soils*	*… as that for cohesionless soils*
	SLS	**Terzaghi**	**Terzaghi**	**Terzaghi**			
	Precast driven square RC pile or insitu bored circular RC pile, $N_{cap,pile,comp,sls} = 0.25f_{cu}.A_{ps}$ *Precast (pretensioned spun) driven circular RC pile,* $N_{cap,pile,comp,sls} = 0.25(f_{cu}-f_{pe}).A_p$ *Insitu bored circular RC pile (API Micropile),* $N_{cap,pile,comp,sls}$ $=f_{y,API}.A_{API}/2.0$ (reinforcement only) $=0.5f_{y,API}.(A_{API}+A_{c,API}.E_c/E_s)/2.0$ (composite section (strain compatibility)) $=(0.91f_{y,API}.A_{API}+0.45f_{cu}.A_{c,API})/2.0$ (concrete filled CHS)	P_{cap} = MIN ($Q_b'/3.0 + Q_s'/1.5$, $P_f'/2.0$)-F_{pile} $Q_b' = (\pi D_b^2/4 \text{ or } D_b^2).q_f'(z=L-L_0)$ $q_f'(z=L-L_0)= s_c.d_c.N_{c,strip}.c'+$ $s_q.d_q.N_{q,strip}.\sigma_v'(z=L-L_0)+$ $s_\gamma.d_\gamma.N_{\gamma,strip}.D_b/2.\gamma'$ $(<=q_{flimit}'(z=L-L_0))$ $s_c=(s_q.N_q-1)/(N_q-1)$ $d_c=1+0.4\tan^{-1}((L_c+L)/D_b)$ *Prandtl*, $N_{c,strip} = (N_{q,strip}-1).\cot\phi'$ $s_q=1+(D_b/D_b)\sin\phi'$ $d_q=1+2\tan\phi'(1-\sin\phi')^2.\tan^{-1}((L_c+L)/D_b)$ *Reissner*, $N_{q,strip} = e^{\pi\tan\phi'}.\tan^2(45°+\phi'/2)$ $s_\gamma=1-0.3(D_b/D_b)$ $d_\gamma=1.0$ *Hansen*, $N_{\gamma,strip} = 2.0(N_{q,strip}-1).\tan\phi'$ $Q_s' = (\pi D \text{ or } 4D).(L-L_0).\tau_a'$ $\tau_a'=[\tau_a'(z=0)+\tau_a'(z=L-L_0)]/2$ $\tau_a'(z=0)= K_s.\tan\delta'.\sigma_v'(z=0)$ $(<=\tau_{alimit}'(z))$ $\tau_a'(z=L-L_0) = K_s.\tan\delta'.\sigma_v'(z=L-L_0)$ $(<=\tau_{alimit}'(z))$ $\tau_a' = \sigma_h'.\tan\delta' = K_s\sigma_v'.\tan\delta'$ $K_s.\tan\delta' = k_{Ks}.K_0.\tan\delta' = k_{Ks}.(1-\sin\phi').\tan\delta'$ $F_{pile} = A_{ps}.L.(\rho_c-\gamma_{dry})$ $P_f' = Q_b' + Q_s'$	P_{cap} = MIN ($Q_b/3.0 + Q_s/1.5$, $P_f/2.0$)-F_{pile} $Q_b = (\pi D_b^2/4 \text{ or } D_b^2).q_f(z=L-L_0)$ $q_f(z=L-L_0)= N_c.S_u(z=L-L_0)$ $(<=q_{flimit}(z=L-L_0))$ $N_c = 9.0$ $Q_s = (\pi D \text{ or } 4D).(L-L_0).S_a$ $S_a=[S_a(z=0)+S_a(z=L-L_0)]/2$ $S_a(z=0) = F.\alpha.S_u(z=0)$ $(<=S_{alimit}(z))$ $S_a(z=L-L_0) = F.\alpha.S_u(z=L-L_0)$ $(<=S_{alimit}(z))$ $F_{pile} = A_{ps}.L.(\rho_c-\gamma_{dry})$ $P_f = Q_b + Q_s$	P_{cap} = MIN ($Q_b'/3.0 + Q_s'/1.5$, $P_f'/2.0$)-F_{pile} $Q_b' = (\pi D_b^2/4 \text{ or } D_b^2).q_f'(z=L-L_0)$ $q_f'(z=L-L_0)= s_c.d_c.N_{c,strip}.c'+$ $s_q.d_q.N_{q,strip}.\sigma_v'(z=L-L_0)+$ $s_\gamma.d_\gamma.N_{\gamma,strip}.D_b/2.\gamma'$ $(<=q_{flimit}'(z=L-L_0))$ $s_c=(s_q.N_q-1)/(N_q-1)$ $d_c=1+0.4\tan^{-1}((L_c+L)/D_b)$ *Kulhawy and Goodman*, $N_{c,strip} = 2N_\phi^{1/2}(N_\phi+1)$, $N_\phi=\tan^2(45°+\phi/2)$ $s_q=1+(D_b/D_b)\sin\phi'$ $d_q=1+2\tan\phi'(1-\sin\phi')^2.\tan^{-1}((L_c+L)/D_b)$ *Kulhawy and Goodman*, $N_{q,strip} = N_\phi^2$, $N_\phi=\tan^2(45°+\phi/2)$ $s_\gamma=1-0.3(D_b/D_b)$ $d_\gamma=1.0$ *Kulhawy and Goodman*, $N_{\gamma,strip} = N_\phi^{1/2}(N_\phi^2-1)$, $N_\phi=\tan^2(45°+\phi/2)$ $Q_s' = (\pi D \text{ or } 4D).(L-L_0).\tau_a'$ $\tau_a'=[\tau_a'(z=0)+\tau_a'(z=L-L_0)]/2$ $\tau_a'(z=0)= K_s.\tan\delta'.\sigma_v'(z=0)$ $(<=\tau_{alimit}'(z))$ $\tau_a'(z=L-L_0) = K_s.\tan\delta'.\sigma_v'(z=L-L_0)$ $(<=\tau_{alimit}'(z))$ $\tau_a' = \sigma_h'.\tan\delta' = K_s\sigma_v'.\tan\delta'$ $K_s.\tan\delta' = k_{Ks}.K_0.\tan\delta' = k_{Ks}.(1-\sin\phi').\tan\delta'$ $F_{pile} = A_{ps}.L.(\rho_c-\gamma_{dry})$ $P_f' = Q_b' + Q_s'$			