DOWNDRAG ANALYSIS (FELLENIUS UNIFIED METHOD)

Project:	Sample Project	**Number:**	DD-2026-007
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1. INPUT PARAMETERS

Parameter	Symbol	Value	Unit
Pile length	L	18.00	m
Pile diameter	D	0.610	m
Pile perimeter	P	1.916	m
Pile cross-sectional area	A_p	0.292247	m^2
Pile Young's modulus	E	200000000	kPa
Pile unit weight	γ_{pile}	24.0	kN/m^3
Dead load at pile head	Q_{dead}	500.0	kN
Fill thickness	H_{fill}	2.00	m
Fill unit weight	γ_{fill}	20.0	kN/m^3
Settlement trigger	$Source$	Fill placement (2.0 m @ 20 kN/m^3)	
Structural capacity	P_r	2000.0	kN
Groundwater depth	GWT	1.00	m

1. SOIL PROFILE

Soil Layer Definition

#	Top (m)	Bottom (m)	Description	Type	γ (kN/m^3)	Strength	S
1	0.0	5.0	Settling fill / soft clay	Cohesive	17.0	c_u = 25.0 kPa, α = 1.00	
2	5.0	10.0	Stiff clay (not settling)	Cohesive	18.0	c_u = 60.0 kPa, α = 1.00	
3	10.0	20.0	Dense sand bearing layer	Cohesionless	19.5	φ = 35.0°, β = 0.30	

1. NEUTRAL PLANE LOCATION & DRAGLOAD

Force Equilibrium (Neutral Plane)

$$Attheneutralplanedepthz_{np} : Q_{dead} + W_{pile}(0 \to z_{np}) + Dragload(0 \to z_{np}) = R_{toe} + R_{shaft}(z_{np} \to L)$$

$$LoadfromtopatNP = ResistancefromtipatNPQ_{dead} + pileweight + neg.friction = toe + pos.friction$$

z_{np} = **18.00** m

Fellenius (2004), unified neutral plane method

NP at 18.00 m (100% of pile length)

Force Components at the Neutral Plane

Component	Value (kN)	Description
Q_dead	500.0	Applied dead load at pile head
Pile weight to NP	126.3	γ_pile × A_p × z_np = 24.0 × 0.292247 × 18.00
Dragload	1382.8	Negative skin friction above NP
Max pile load	2009.1	Q_dead + pile weight + dragload

Maximum Axial Load at Neutral Plane

$$Q_{np} = Q_{dead} + W_{pile}(0 \to z_{np}) + Q_{nf}$$

$$Q_{np} = 500.0 + 126.3 + 1382.8$$

Q_{np} = **2009.1** kN

Fellenius (2004); UFC 3-220-20, Eq. 6-80

1. RESISTANCE BELOW NEUTRAL PLANE

Positive Shaft Resistance Below NP

$$R_s = \Sigma[f_s(z) \times P \times \Delta z] forz > z_{np}$$

$$Sumofpositiveskinfrictionfromz_{np}topiletip$$

R_s = **0.0** kN

Toe Bearing Resistance

$$R_t = N_t \times q_t \times A_{tip}(cohesionless) or N_c \times c_u \times A_{tip}(cohesive)$$

R_t = **4895.6** kN

Fellenius (1991); UFC 3-220-20

Total Resistance Below NP

$$R_{total} = R_s + R_t$$

$$R_{total} = 0.0 + 4895.6$$

R_{total} = **4895.6** kN

1. SETTLEMENT AT THE NEUTRAL PLANE

Elastic Shortening of Pile (above NP)

$$\delta_e = \Sigma[Q_{avg} \times \Delta z/(A_p \times E)] for z = 0 to z_{np}$$

$$AE = 0.292247 \times 200000000 = 58,449,331 kN$$

δ_e = **0.38** mm

Toe Settlement (bearing stratum compression)

$$Equivalent footing B' = D, influence depth = 3 \times D.2V : 1H stress distribution below pile tip (UFC Eq 6-51).$$

$$B' = 0.610 m$$

δ_{toe} = **0.00** mm

UFC 3-220-20, Eqs 6-49 through 6-51

Pile Settlement at Neutral Plane

$$\delta_{pile} = \delta_e + \delta_{toe}$$

$$\delta_{pile} = 0.38 + 0.00$$

$\delta_{pile} =$ 0.38 mm

Soil Settlement at Neutral Plane

$$S_{soil}(z_{np}) = cumulative1 - Dconsolidationsettlementfromsettlinglayers, accumulatedbottom - up.$$

$$Interpolatedfromsoilsettlementprofileatz_{np}$$

$S_{soil}(z_{np}) =$ 0.00 mm

UFC 3-220-20, Eq. 6-53 (clay), Eq. 6-54 (sand)

Settlement Summary

Component	Value (mm)	Description
Elastic shortening	0.38	Pile compression above NP
Toe settlement	0.00	Bearing stratum compression below tip
Pile settlement	0.38	δ_e + δ_toe
Soil settlement at NP	0.00	From consolidation of settling layers

Settlement compatibility: pile and soil settlements should be approximately equal at the neutral plane.

1. LIMIT STATE CHECKS

Structural Limit State (UFC Eq 6-80)

$$LRFDDemand = 1.25 \times Q_{dead} + 1.10 \times (Q_{np} - Q_{dead})Demand \leq P_r(factoredstructuralresistance)$$

$$Demand = 1.25 \times 500.0 + 1.10 \times (2009.1 - 500.0)$$

$Demand =$ 2285.0 kN

UFC 3-220-20, Eq. 6-80

FAIL Structural capacity check (UFC Eq 6-80)

$LRFDdemand$ = 2284.9974001863156 kN $>$ P_r = 2000.0 kN (D/C = 1.14)

Geotechnical Limit State

$$Q_{dead} \leq R_{total}(positive friction + toe) Dragload is NOT included—it cancels at the neutral plane.$$

$$Q_{dead} = 500.0kN vs R_{total} = 4895.6kN$$

Q_{dead}/R_{total} = **0.102**

Fellenius (2004); AASHTO 10.7.3.7

Dragload cancels in geotechnical equilibrium per Fellenius unified method.

PASS Geotechnical capacity check (Q_dead vs R_total)

Q_{dead} = 500.0 kN $\leq$ R_{total} = 4895.5581781718265 kN (D/C = 0.10)

1. FIGURES

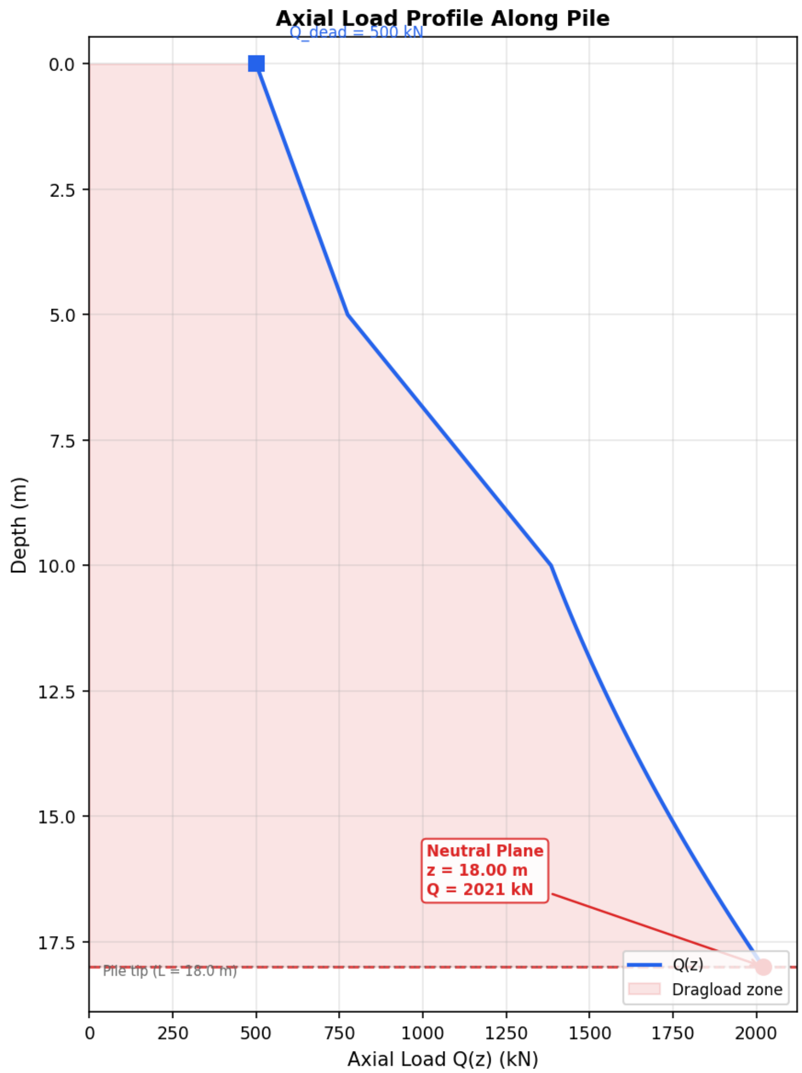

Figure 1: *

Figure 1: Axial load distribution along the pile. Neutral plane at z = 18.00 m (Q_max = 2009.1 kN).

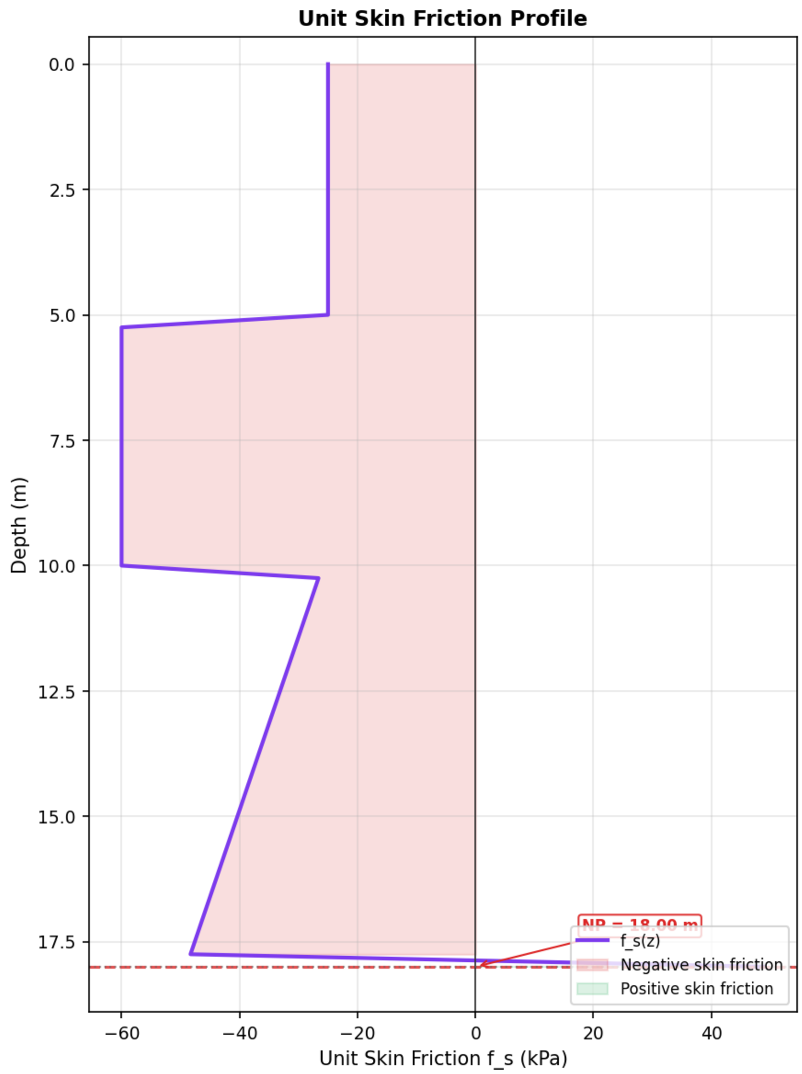

Figure 2: *
Figure 2: Unit skin friction along the pile. Negative above NP (18.00 m), positive below.

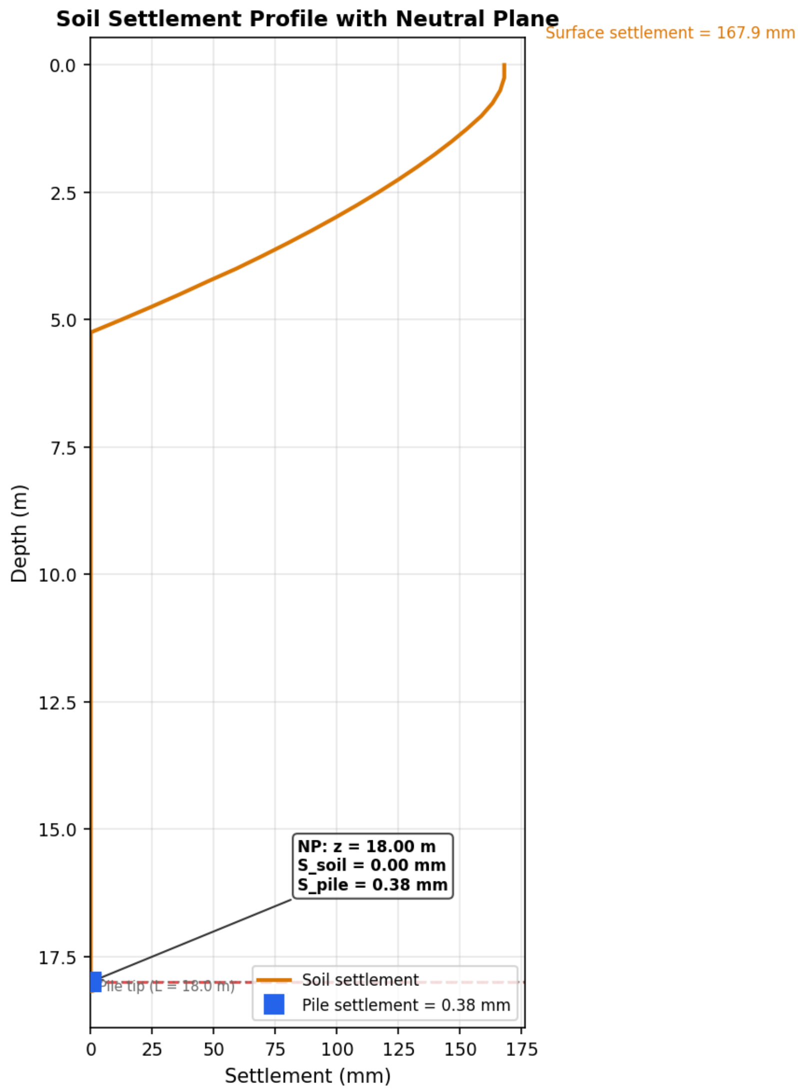

Figure 3: *
Figure 3: Soil settlement profile along the pile depth. Soil settlement at NP = 0.00 mm, pile settlement = 0.38 mm.

1. REFERENCES

1. Fellenius, B.H. (2006). "Results of static loading tests on driven piles." Geotechnical News Magazine.
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3. UFC 3-220-20, 16 Jan 2025. "Geotechnical Engineering." Chapter 6: Deep Foundations.
4. AASHTO LRFD Bridge Design Specifications, 9th Ed. (2020). Section 10.7.3.7: Downdrag.
5. Fellenius, B.H. (1991). "Pile foundations." Chapter 13 in Foundation Engineering Handbook, 2nd Ed. Van Nostrand Reinhold.

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