Numerical evaluation of sheet pile wall stability with varying anchor depths and soil properties.

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Abstract:

This research explores how varying anchor depths affect the behaviour of anchored retaining systems in different ground conditions, including sand, stiff clay, completely weathered siltstone, highly weathered sandstone, and layered soils. Using numerical analysis Plaxis-3D, key factors such as displacement, anchor force, bending moment, and factor of safety (FOS) were examined for anchor depths ranging from 2 m to 6 m. The findings reveal that an anchor depth of around 4 meters provides the most efficient performance in stiff and semi-rocky materials, offering high stability and optimal force mobilization with minimal structural demand. In contrast, sandy and layered soils showed increased horizontal displacement and reduced FOS at greater depths, suggesting that deeper anchoring in such soils can lead to reduced efficiency. The study concludes that anchor depth must be carefully matched to soil type, as both shallow and overly deep installations can lead to suboptimal performance. These insights are intended to support more effective and economical design of anchored systems across a range of geotechnical settings.

Key words: Ground anchor, Sand**,** completely weathered siltstone, highly weathered sandstone, Plaxis-3D, Displacement, Bending Moment, Anchor Force and Factor of Safety.

1. Introduction:

In geotechnical engineering, the construction of deep excavations and waterfront structures often requires the use of retaining systems capable of withstanding significant lateral earth pressures. Sheet pile walls are one such popular and cost-effective method for earth retention. These vertical structural members are driven into the ground to retain soil and water and are extensively used in ports, basements, bridge abutments, and deep foundation works. However, when the depth of excavation increases or the lateral loads are substantial, additional supports such as ground anchors are often provided to improve wall performance and stability.

Ground anchors transfer the lateral forces from the sheet pile wall into deeper, more stable soil layers, thereby reducing wall deflection, bending moments, and the potential for failure. The depth at which these anchors are installed commonly known as anchor depth significantly influences the mechanical response of the wall. Anchors installed too shallow may not develop enough resistance, whereas those installed too deep may not be efficient or economical. Hence, determining the optimum anchor depth is essential for the safe and economic design of anchored sheet pile walls.

2. Literature review

The literature review highlights that optimal anchor inclination 10–30° and spacing is 0.5H, along with appropriate prestress levels, effectively reduce wall displacement, bending moments, and shear forces, while multiple anchors enhance stability in deeper excavations. Soil properties such as cohesion and friction angle, as well as groundwater levels, play a critical role, with groundwater lowering significantly improving the factor of safety. Numerical tools like PLAXIS 2D/3D provide accurate results aligning with field data, offering better insights than traditional analytical methods. Structural parameters including wall stiffness, anchor length, and bond length must be optimized since excessive stiffness or prestress can increase internal forces. Additionally, seismic and reliability studies emphasize the importance of optimized anchor layouts, site-specific validation, and probabilistic analyses for safe and cost-effective designs.

3.Methodology

Anchored sheet pile wall is analyzed manually and using finite element analysis by PLAXIS 3D. Five different systems of anchored sheet pile wall are analyzed with following variable parameters.

Depth of anchor, D_a = 2m, 3m, 4m, 5m and 6m

Soil profile: i) Sandy soil: γ_d=17 kN/m^3, γ_{sat}=20 kN/m^3, E=20000 kN/m^2, c=13 kN/m^2, Φ=28.1°, ν=0.3

ii) Stiff clay: γ_d=18.5 kN/m^3, γ_{sat} =22 kN/m^3, E=65000 kN/m^2, c=85 kN/m^2, Φ=0°, ν=0.3

iii) Completely weathered silt stone: γ_d =20 kN/m^3, γ_{sat} =20 kN/m^3, E=100000 kN/m^2, c=50 kN/m^2, Φ=45°, ν=0.3

iv) Highly weathered sand stone: γ_d =20.5 kN/m^3, γ_{sat} =20.5 kN/m^3, E=150000 kN/m^2, c=120 kN/m^2, Φ=45°, ν=0.3

v) Two layered soil profile with sand followed stiff clay

Sandy soil: γ_d=17 kN/m^3, γ_{sat}=20 kN/m^3, E=20000 kN/m^2, c=13 kN/m^2, Φ=28.1°, ν=0.3.

Stiff clay: γ_d=18.5 kN/m^3, γ_{sat} =22 kN/m^3, E=65000 kN/m^2, c=85 kN/m^2, Φ=0°, ν=0.3

Definition sketch:

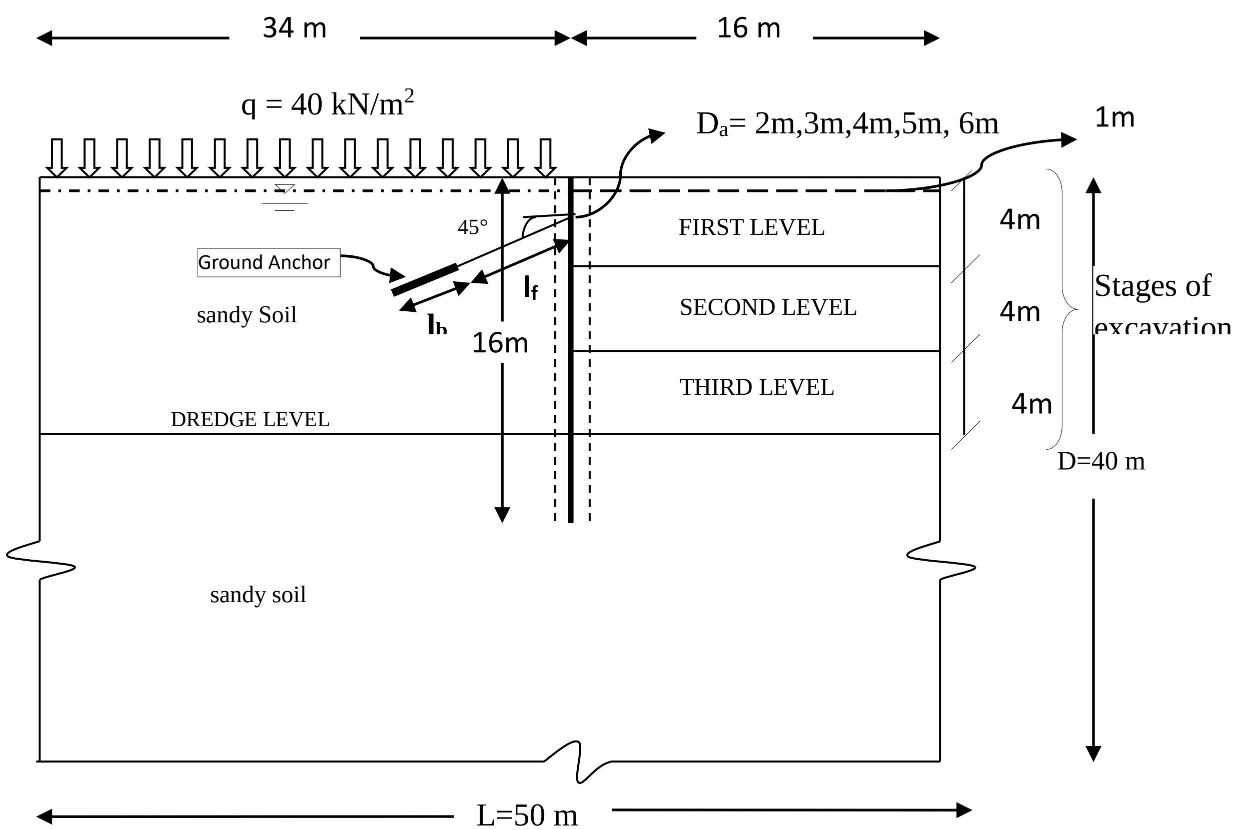


Fig.1 Cross-section of a sheet pile wall in sandy soil

For the soil profiles mentioned the section has to be modelled as shown in Fig.1 explains the cross section of a sheet pile wall in sandy soil.

Material properties of the model

The properties of the Pile, Node-to-Node anchor and embedded beam considered for the analysis are mentioned Table 1, Table 2 and Table 3 respectively.

Table 1: Properties of the pile

Parameter	Name	Value	Unit
Type of Behaviour	Material Type	Elasto-plastic	-
Equivalent thickness	d	0.8	m
Weight	W	19.2	kN/m/m
Poisson's ratio	ν	0.15	-
Young's Modulus	E_{ref}	25×10^6	kN/m^2
Rigidity Modulus	G	13.04×10^6	kN/m^2
Yield Stress	σ_y	3200	kN/m^2
Unit Weight	γ	24	kN/m^3

Table 2: Properties of Node-to-Node anchor

Parameter	Name	Value	unit
Type of Behavior	Material Type	Elasto-plastic	-
Normal Stiffness	EA	2×10^5	kN
Spacing out of	L_S	2.5	m

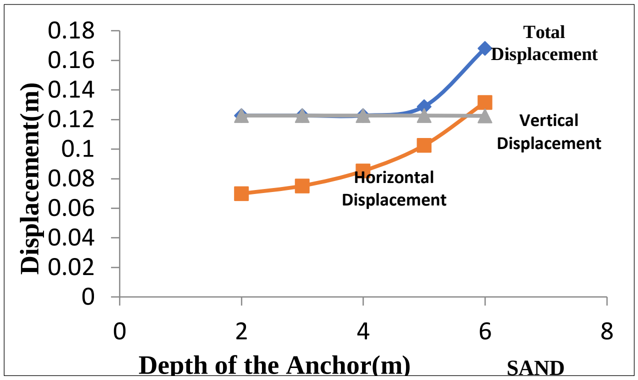
Maximum Force	$F_{max,comp}$	1.1×10^{15}	kN
	$F_{max,tens}$	1.1×10^{15}	kN

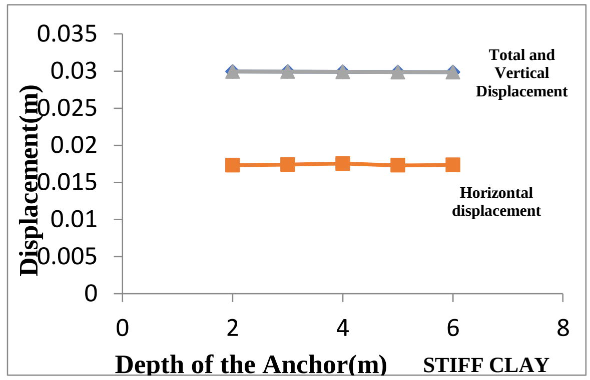
Table 3: properties of embedded beam

Parameter	**Name**	**Grout**	**Unit**
Young's Modulus	E	3×10^7	kN/m^2
Unit Weight	γ	24	kN/m^3
Beam Type	-	Predefined	-
Predefined Beam Type	-	Massive Circular Beam	-
Diameter	-	0.14	m
Axial Skin Resistance	Type	Linear	-
Skin Resistance at the top of the embedded beam	$T_{skin,start,max}$	200	kN/m
Skin Resistance at the bottom of the embedded beam	$T_{skin,end,max}$	0.0	kN/m
Base Resistance	F_{max}	0.0	kN

4. Results and Discussion

For sand

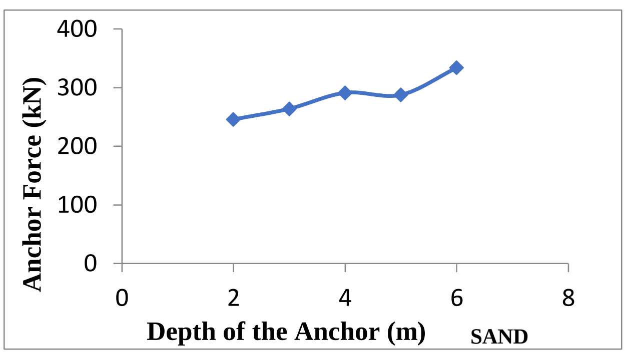


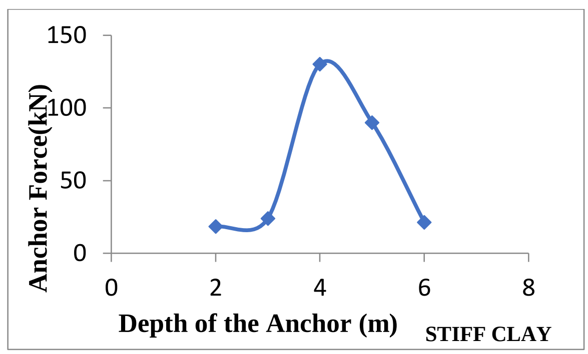


(a) **(b)**

Fig.4.1 (a) Displacement vs depth of anchor (b) Displacement Vs depth of anchor

As per the Fig.4.1 (a), it shows that in sandy soils, horizontal and total displacement increases sharply with deeper anchors reducing stability and from Fig.4.1 (b) explains that in stiff clay, displacement remains almost constant, showing minimal sensitivity to anchor depth.

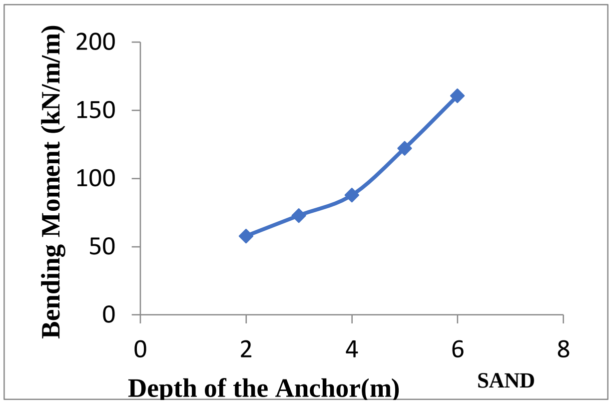


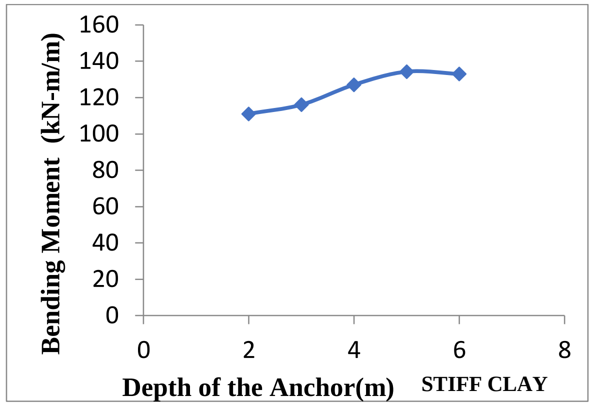


(a) **(b)**

Fi.4.2 (a) Anchor force vs depth of anchor (b) Anchor force vs depth of anchor

It is clear that from the Fi.4.2 (a), in sand, anchor force steadily increases with depth reaching higher values up to 330 KN whereas Fig.4.2 (b) explains that in stiff clay, anchor force peaks sharply around 4m about 130 kN and then decreases, unlike the continuous increase in sand.

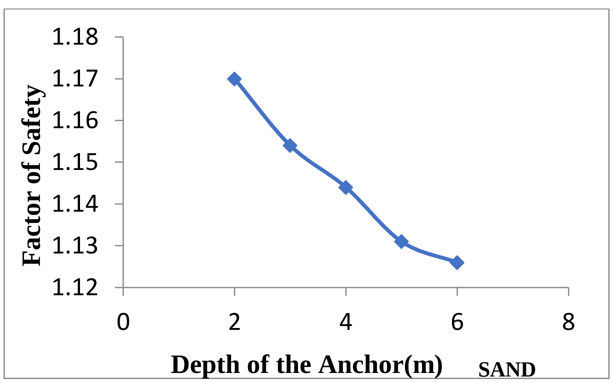


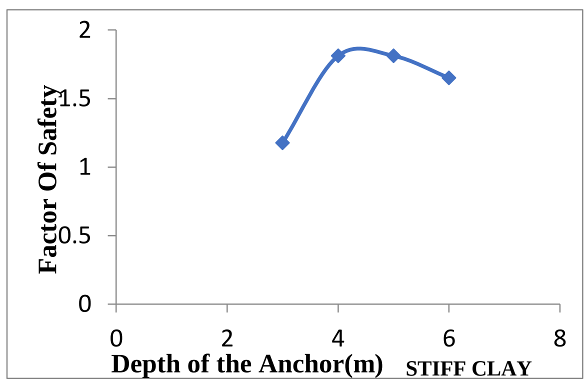


(a) (b)

Fig.4.3 (a) Bending moment vs anchor depth (b) Bending moment vs anchor depth

The graph shown in Fig.4.3 (a) explains that in sand, the bending moment increases steeply with anchor depth, reaching much higher values but from Fig.4.3 (b) shows that in stiff clay, the bending moment rises initially but then levels off, showing less sensitivity to depth.





(a) (b)

Fig.4.4 (a) FOS vs depth of anchor (b) FOS vs depth of anchor

Fig.4.4 (a) explains that in sand, the factor of safety decreases consistently with increasing anchor depth whereas Fig.4.4 (b) shows that in stiff clay, the factor of safety increases with depth about 4 to 5m and then slightly decreases.

5. Conclusions

The displacement, anchor force, bending moment, and factor of safety (FOS) vary significantly with depth across different soil types. FOS decreases with increase in depth of anchor for sand and layered soil. FOS increases upto 4m and then decreases for stiff clay and weathered rock.

The optimum anchor depth is about 4 m for stiff clay and weathered rock with maximum FOS and minimum bending moment.

Depth of anchor beyond 5m may cause higher displacements, increased bending moments, or reduced FOS, especially in sand and layered soils.

6.References

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