FINITE ELEMENT ANALYSIS OF A DEEP EXCAVATION SUPPORTED USING A SECANT PILE WALL: A CASE STUDY

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Coulomb (1776) introduced the first method to calculate the lateral earth pressure acting on retaining walls. Rankine theory was introduced as a result of improving the previous work (Rankine, 1857). Many methods are currently used to evaluate the earth pressure distributions of the retaining wall and the prop forces of the support system used in deep excavations. The Apparent earth Pressure Diagram (APD) and Distributed Prop Load method (DPL) introduced by Terzaghi, K. & Peck (1967) and Twine and Roscoe (1999) are the most widely used empirical methods to calculate the earth pressure distributions and prop forces acting on multi-propped retaining walls.

Finite element modelling has become the most widely used feature with rapid technological advancement. Studies have found that soil stiffness is the parameter that has the dominant control over ground movement induced by deep excavation. Elastic modulus (E_{50}), unloading-reloading modulus (E_{ur}), and tangent modulus (E_0) are the most widely used soil stiffness parameters in design work.

This study suggests recommendations for selecting appropriate parameters and correct modelling procedures in the FEM of deep excavations using measured field data using two-dimensional analysis. Previous studies indicate that the elastic modulus (E_{50}) of the soil can be increased several times to obtain the unloading-reloading stiffness (E_{ur}) of the soil during deep excavation. The back analysis technique is commonly used in studies to calibrate the critical parameters to minimize the deviation between numerically computed results and field observation results. Back analysis was used to calibrate the elastic modulus of the soil by comparing the lateral wall deformation profile obtained from the FEM software with inclinometer readings acquired from the excavation site. Prop force and earth pressure distribution results obtained from FE analysis were compared with Peck and DPL methods considering sandy and clayey soil.

Prop forces from the numerical model were compared with those from different empirical methods commonly used to estimate prop forces on multi-propped retaining structures. The study highlights that the elastic modulus (E_{50}) values derived from the SPT N data can be multiplied by 2 to 4 times to obtain the unloading-reloading modulus (E_{ur}) value that would reasonably predict the wall movement in the FE analysis. As the depth of excavation increases, the lateral deformation was underestimated mainly due to the impact of the corner effects. Considering sandy soil, both Peck and DPL methods produced higher prop force values for the first prop level, while the second and third prop levels had lower values compared to the results of the numerical analysis. The lower earth pressure distribution obtained from the DPL and Peck methods compared to the earth pressure distribution of the FE analysis caused this result.

Keywords: Deep Excavation, Finite Element Analysis, Elastic Modulus, Back Analysis, Apparent Pressure Diagrams

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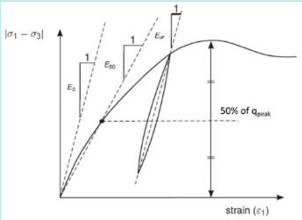
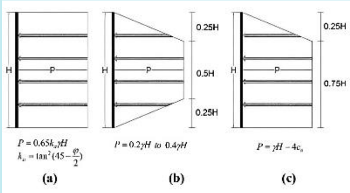
BACKGROUND



Triaxial compression test results



Notes: (a) Sands, (b) stiff-hard clays, (c) Soft to medium clay

Apparent earth pressure diagrams presented by Terzaghi & Peck (1967)

Class	Soil	Over retained height	DPL
AS	Same as AF for medium strength clay		
AF	Medium strength clay	Top 20%	$0.2\ \gamma H$
		Bottom 80%	$0.3\ \gamma H$
	Low strength clay with stable base	Top 20%	$0.5\ \gamma H$
		Bottom 80%	$0.65\ \gamma H$
	Low strength clay with enhanced base stability	Top 20%	$0.65\ \gamma H$
		Bottom 80%	$1.15\ \gamma H$
BS	High to very high strength clay	All	$0.5\ \gamma H$
BF	High to very high strength clay	All	$0.3\ \gamma H$
C	Granular soil, dry	All	$0.2\ (\gamma - \gamma_w) H$
	Granular soil, submerged	Above water	$0.2\ \gamma H$
		Below water	$0.2\ (\gamma - \gamma_w) H + \gamma_w (z - d_w)$

Triaxial compression test results

METHODOLOGY

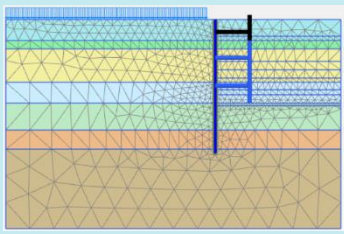
Literature Review → Develop the Model → Analysis → Recommendations

Analysis
- Effect of Elastic Modulus
- Effect of Mesh Distribution
- Comparison of Prop Forces
- Comparison of Earth Pressure Distribution

FINITE ELEMENT MODEL

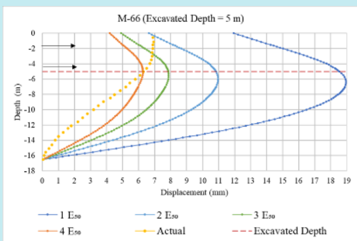
PLAXIS 2D
Plan Strain Idealization
Mohr Coulomb Model
Drainage Type – Drained
Strut and Waler Material Type – Elastic
Retaining Wall Behaviour – Elastic
$Ø = 0.45\ N_{70} + 20^0$
Elastic Modulus = 7 N (Yoshida & Yoshinaka, 1972)

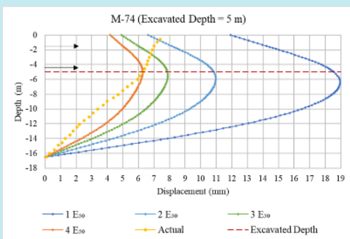
Soil		1 Clayey sand (SPT N = 6)	2 Clayey Sand (SPT N = 26)	3 Silty clayey sand (SPT N = 34)	4 Clayey sand (SPT N = 50)	5 Fine sand (SPT N = 15)	6 HWR (SPT N = 8)
Depth (m)		0.0 to -2.5	-2.5 to -3.5	-3.5 to -7.5	-7.5 to -10.0	-10.0 to -13.2	-13.2 to -15.5
Material Model		Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
γ_{unsat}	[kN/m³]	16.00	20.00	20.00	21.00	17.00	16.00
γ_{sat}	[kN/m³]	17.00	21.00	21.00	22.00	18.00	17.00
k_x	[m/s]	10^{-9}	10^{-6}	10^{-6}	10^{-6}	10^{-4}	10^{-6}
k_y	[m/s]	10^{-9}	10^{-6}	10^{-6}	10^{-6}	10^{-4}	10^{-6}
E_{ref}	[kN/m²]	12000	40000	50000	70000	22000	14000
ν	[-]	0.350	0.300	0.300	0.250	0.300	0.350
c_{ref}	[kN/m²]	3.00	8.00	8.00	10.00	0.00	3.00
φ	[°]	24.00	30.00	32.00	38.00	28.00	25.00
ψ	[°]	0.00	0.00	2.00	8.00	0.00	0.00
$R_{inter.}$	-	0.67	0.67	0.67	0.67	0.67	0.67



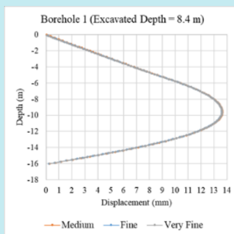
ANALYSIS

Effect of Elastic Modulus





Effect of Mesh Distribution



Prop Force Comparison

Stage	Strut Level	Strut Dimensions	Finite Element Analysis	Peck Method (Sand)	Peck Method (Clay)	DPL Method (Sand)	DPL Method (Clay)
		(mm)	(kN/m)	(kN)	(kN)	(kN)	(kN)
Stage 5	At - 1.5 m	200x200x49	101.77	118.15	119.73	88.16	220.4
Stage 6	At - 1.5 m	200x200x49	58.05	148.75	150.8	132.15	330.32
	At - 4.575	300x300x94	325.79	215.54	318.07	233.96	396.61
	At - 1.5 m	200x200x49	33.74	164.01	162.04	156.77	391.95
Stage 8	At - 4.575 m	300x300x94	360.89	205.55	330.38	241.63	412.58
	At - 7.9 m	300x300x94	308.84	268.73	430.22	260.96	384.21

Earth Pressure Distribution Comparison