Numerical Modelling of Braced Sheet Pile

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Abstract

Multiple basement construction and constructions of highrise structures are well known in modern era. The braced sheet pile was provided for deep excavation to avoid failures. For adequate safety of structure and adjoining soil, detailed analysis is required. Many previous researchers have focused their research in this area. In this study numerical modelling of braced sheet pile is done using Plaxis 2D FEM based software. The model was developed for three soil type viz. Silty sand, Soft clay and Sand. The depth of braced sheet pile was 30metres. The strut was placed at 4.5m, 9m, 13m, 17m and 18m. The analysis was carried out with different soil parameters e.g friction, young's modulus etc of soil for all the three cases. The behaviour of Sheet pile wall such as Shear forces, Axial forces, Bending moment, Total displacement etc. under different soil condition was calculated by commercially available Finite element based software Plaxis 2D and obtained results were compared with previous obtained result. It was observed that the obtained results were found in agreement with previous results.

Keywords

Introduction

Rapid growth of urbanization necessities multiple basement construction to fulfill infrastructure requirement. Proper planning is necessary to predict the serviceability of structure and adjacent soil, if the basement excavations are taken close to the property/ boundary. The sheet pile bracing system is the most well-known for deep excavation work. The heavy soil mass is supported by retaining walls in various fields of civil engineering such as hydraulics and irrigation structures, highways, railways, tunnels, mining etc. and evaluation of lateral earth pressure is key factor to design braced sheet pile wall. A sheet pile wall consists of a series of sheet piles driven side by side into the ground. This results in a continuous vertical wall for the purpose of retaining an earth bank. A sheet pile wall is a flexible wall having negligible weight and weight has no control over the wall stability. The stability is entirely due to the passive resistance developed between the wall and the soil. Sheet piles are pre-cast members comprising varieties ranging from simple wood planks and light gauge sheet metals to heavy sections made of reinforced concrete and structural steel members. Therefore detailed study of stability of sheet pile wall will resolve the above situation. Many previous researcher (Athanasopoulos G. A et al (2011) [1] , Brom*s* B. B. (1988) [2], Bhatkar T et al (2017) [3], Dao Thi Van Tram et al 2014 [4], Dina A. Emarah et al (2018) [5], Doubrovsky M. P et al (2015) [6], Koichi Isobe et al (2014) [7], McNulty T. A et al 1987 [8], Suched Likitlersuang et al (2013) [9], Whittle A. J (1994) et al[10], Yoo Chungsik et al (2001) [11], Zekkos D. P et al (2004) [12]) have investigated the behaviour of wall movement and ground surface settlement in case of deep excavation by means of empirical and numerical analysis. Many researchers develop numerical model to analyse the behaviour of sheet pile wall in different types of soils. Based on previous results, it was seen that safe range of deep cut for lateral movement in soft clay was 1.12-3.35% to maximum depth of excavation and settlement of 0.93% to maximum depth of excavation. Behaviour of sheet pile wall with single anchored and double anchored in sand was studied; stiffer sheet pile gave higher value of maximum bending moment. In the double anchored sheet pile wall the lower values of anchor forces and that of maximum bending moments were achieved at the higher density of the soil. The results obtained from analysis of braced sheet pile was varied with soil properties, level of ground water table and the properties of sheet pile wall and strut. Based on model study and the data obtained from analysis of sheet pile wall in soft clay observed lateral wall deflection is less as compared to maximum ground surface settlement. Max settlement on the ground was observed in between 15-25m away from the wall. if sheet pile deviates from verticality in any condition construction of sheet pile wall became difficult and also in some cases it became impossible to extract the individual sheet pile.

In this study numerical modelling was developed for braced sheet pile wall in different types of soil such as silty sand, soft clay and sand. The overall depth of braced sheet pile was 30m. The excavation has to be done up to 21.5m. The properties of soil were taken from previous case studies. This evaluation was done by varying the various parameters e.g. young's modulus, friction, cohesion and Poisson's ratio of soil. In this study struts were fixed at level -4.50m, -9.0m, -13.0m, -17.0m, -18.0m from ground level and the horizontal spacing was 6.00m. Excavation was done in various stages. The values of bending moment, shear force, axial force and total displacement were calculated considering various parameter for all three cases.

Soil Profile

Numerical model was developed by using plaxis 2D FEM based software. The overall depth of secant pile was 30m. The excavation has to be done up to 21.5m. The soil strata have sand deposit mostly reach in silt content. The ground water table lies 8m below ground surface. Fully embedded wall was used in model. The Young's Modulus of wall is 3.1622×10^7 kN/m^2 with moment of inertia of wall is 0.050894 m^4/m. The value of flexural stiffness for wall is 1.6094×10^6 kN.m^2/m.
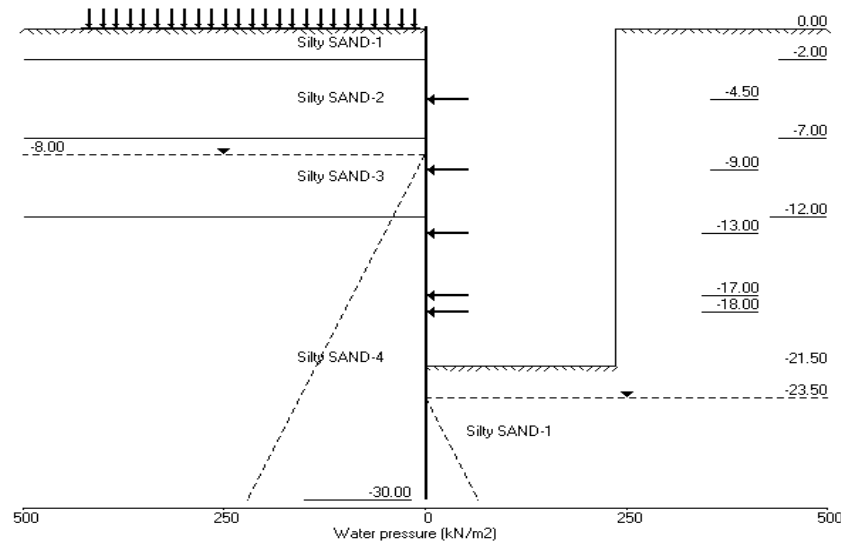

Fig. 1: Section of Proposed Secant Pile

Methodology

The material properties of soil and structural element are taken from previous case studies. The analysis of sheet pile wall is carried out by Finite Element Analysis based software Plaxis 2D.

1. Material and Structural Properties

Strut No.	Elevation (m)	Strut spacing (m^2)	Strut C/S area (m^2)	Youngs Modulus (kN/m^2)	Free Length (m)
1	-4.50	6.00	0.02696	2.00 E+08	6
2	-9.00	6.00	0.02696	2.00 E+08	6
3	-13.00	6.00	0.053992	2.00 E+08	6
4	-17.00	6.00	0.08000	2.00 E+08	6
5	-18.00	6.00	0.08000	2.00 E+08	6

Table 1: Details of Struts and its Location

SI. No.	Properties of Soil	Unit weight (KN/m^3)	Young's modulus (KN/m^2)	Poison's ratio	Cohesion (KN/m^2)	Friction angle (Degrees)
1.	Silty Sand 1	18	10000	0.3	1	30°
2.	Silty Sand 2	18	12300	0.3	1	30°
3.	Silty Sand 3	19	34500	0.3	1	34°
4.	Silty Sand 4	19	38300	0.3	1	36°

Table 2: Properties of Silty Sand

SI. No.	Properties of Soil	Unit weight (KN/m^3)	Young's modulus (KN/m^2)	Poison's ratio	Cohesion (KN/m^2)	Friction angle (Degrees)
1.	Soft clay-I 1	18.0	8846.154	0.15	13.85	30°
2.	Soft clay-I 2	18.5	12300	0.3	14	29°
3.	Soft clay-I 3	18.7	34500	0.3	15	32°
4.	Soft clay-I 4	19	38300	0.3	14.5	36°

Table 3: Properties of Soft Clay

SI. No.	Properties of Soil	Unit weight (KN/m^3)	Young's modulus (KN/m^2)	Poison's ratio	Cohesion (KN/m^2)	Friction angle (Degrees)
1.	Sand 1	17	10000	0.15	5.19	30°
2.	Sand 2	17.5	12300	0.3	5.19	32°
3.	Sand 3	17.7	34500	0.3	5.19	34°
4.	Sand 4	17.9	38300	0.3	5.19	36°

Table 4: Properties of Sand

SI. No.	Properties	Unit	Value
1.	Axial Stiffness	kN/m	2.46×10^8
2.	Flexural rigidity	kNm^2/m	1.6×10^6
3.	Poission's Ratio	------	0.15
4.	Weight per Area	Kn/m/m	6.28

Table 5: Properties of Plate

2. Stability Analysis by FEM Based Software Plaxis 2D

Plaxis 2D FEM based software used two types of analysis i.e. plastic and consolidation analysis. These analyses are used commercially. Plastic calculation is non linear and mainly used in loading and unloading problems. In plastic calculation consolidation and pore pressure dissipation is not taken in consideration since this is time independent phenomenon. For the analysis a 15-node elements mesh was taken and the texture of the mesh was set to fine so as to reduce the distance between two consecutive elements. By using lines, plates and interfaces the outlines of the model are made. The option of standard Fixities is chosen for the boundaries, which renders a fixed boundary situation for the entire geometry model.
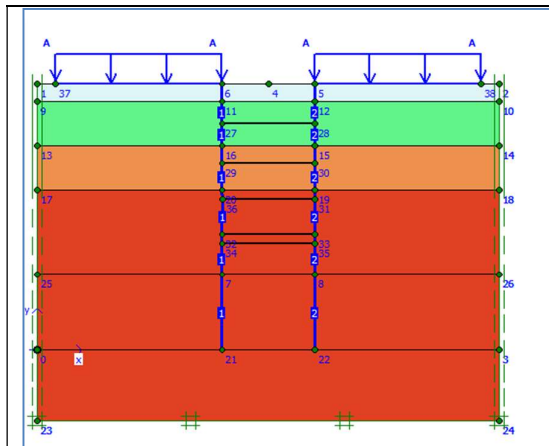
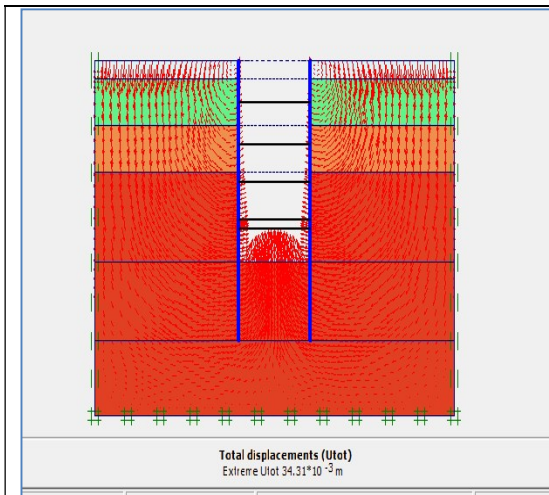**Fig. 2: Soil Profile With Surcharge Load**

Deformed Mesh
Extreme total displacement 67.25*10^{-3} m
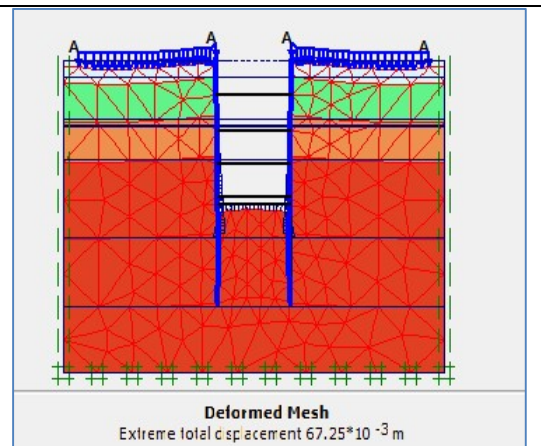
Fig. 3: Deformed Mesh

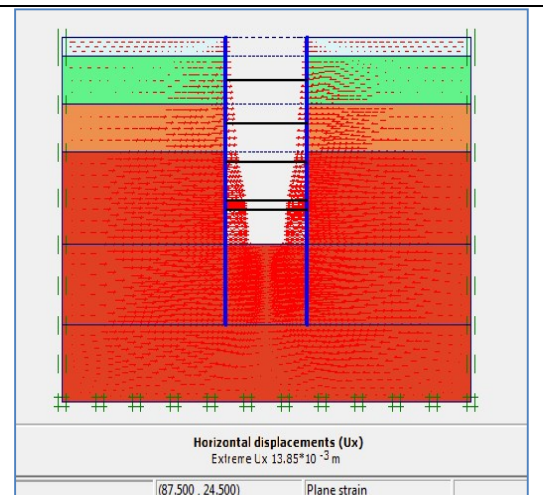**Fig. 4: Total Displacement of Sheet Pile Wall**

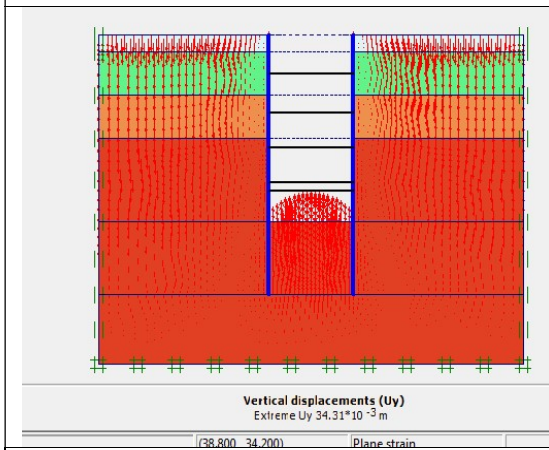**Fig. 5: Horizontal Displacement of Sheet Pile Wall**

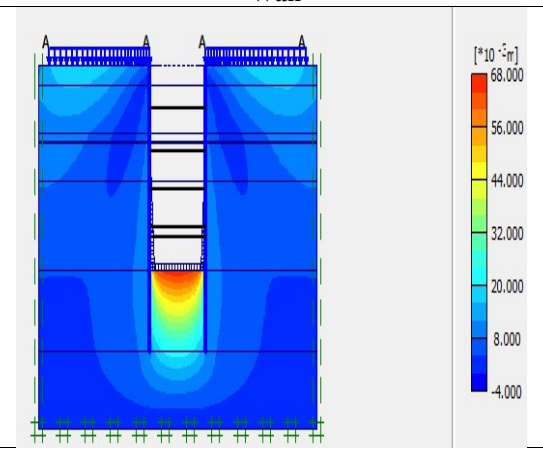**Fig. 6: Vertical Displacement of Sheet Pile Wall**

Fig. 7: Active Groundwater Head with Loads

Results and Discussion

The results are obtained from three soil types- Soft clay, Sand and Silty Sand using Plaxis 2D FEM based software. Displacements values at various points are also in safe range. The bending moment values and displacement values are also in safe range. The maximum value of axial force in soft clay is 629.93 KN/m, in silty sand is 503.26 KN/m and in sand is 506.17 KN/m. The maximum value of bending moment in soft clay is 512.12 KN-m/m, in silty sand is 225.28 KN-m/m and in sand is 302.09 KN-m/m. The maximum value of shear force in soft clay is 364.47 KN /m, in silty sand is 292.77 KN-m/m and in sand is 305.65 KN-m/m

Parameters	Soft Clay	Silty Sand	Sand
Axial Force(KN/m)	629.93	503.26	506.17
Bending Moment (KN-m/m)	512.12	225.28	302.09
Shear Force(KN/m)	364.47	292.77	305.65

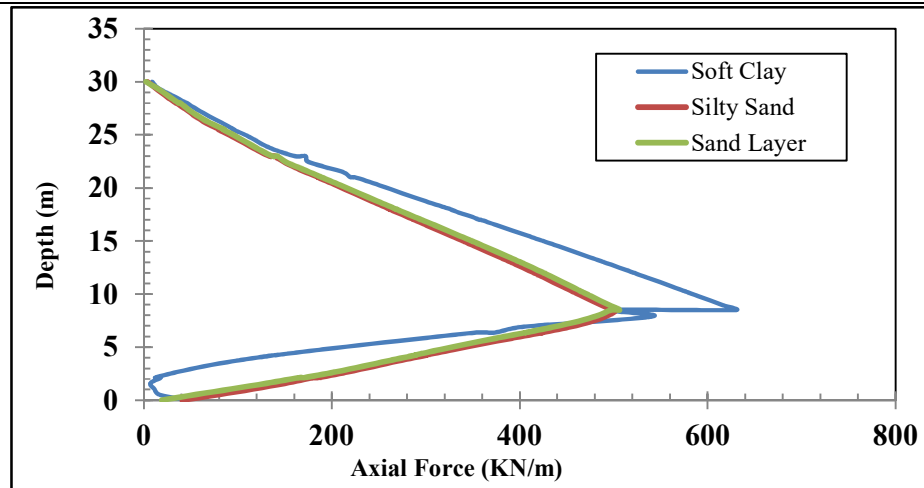**Table 6: Result of Plaxis 2D FEM Software**

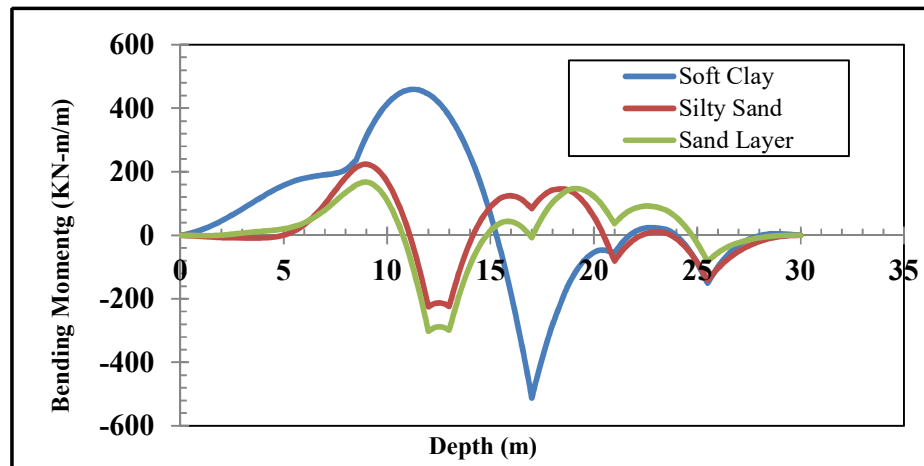**Fig. 8: Variation of Axial Force With Respect to Depth**

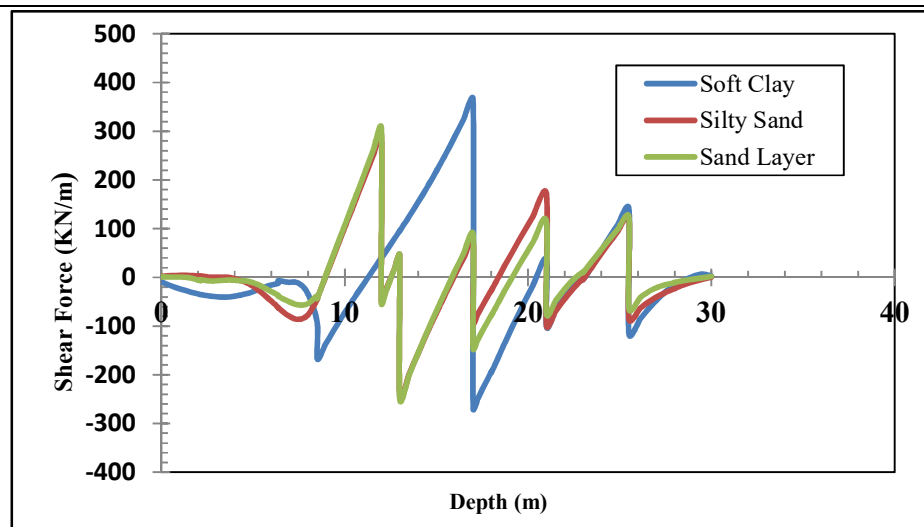**Fig. 9: Variation of Bending Moment With Respect to Depth**

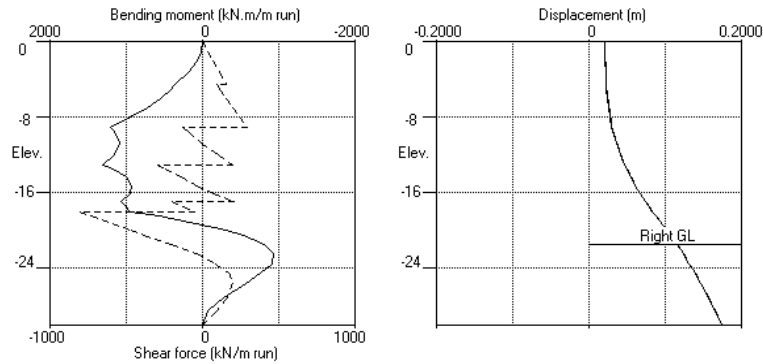**Fig. 10: Variation of Shear Force With Respect to Depth**

Fig. 11: Bending Moment, Shear Force and Displacement on Sheet Pile Wall

Comparison of Result of Plaxis 2D and Wallap Software of Silty Sand
The axial force calculated by Plaxis 2D is 498.632 KN/m. The value of Bending Moment calculated by Plaxis 2D is 224.034KN-m/m where as wallap software calculated 572.30 KN-m/m. The difference is due to Plaxis adopting low strain analysis method as wallap consider high strain analysis. The value of Shear Force calculated by Plaxis 2D is 292.77KN/m where as wallap software calculated 784.90 KN/m. The difference is due to wallap software augment the shear force value which is sum of axial force and shear force value of Plaxis2D. The value of Displacement calculated by Plaxis 2D is 0.167 m where as wallap software calculated 0.194 m.

Conclusion
From previous researcher pointed out that bending moment, shear force and axial force were more in soft clay compared to sand and silty sand. On comparing it was observed that obtained results were in line with previous results. The difference of obtained results from Wallap software and Plaxis 2D software for settlement, Axial force, shear force and bending moment are negligible. Such intensive modeling of the sheet pile wall and backfill with different soil, many observations can be made and many questions have been clarified and raised as a result. Shear force, bending moment and displacement by the PLAXIS gave smaller value as compare to wallap software.

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