IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Analysis Of Cantilever Sheet Pile Embeded In Cohesive Soil

1Manoj Kumar Paul, 2Abhipriya Halder, 3Sibapriya Mukherjee3

1Student - MTech (HTE) , 2HOD - Narula Institute of Technology, 3Prof - Narula Institute of Technology

1NIT,

2NIT,

3NIT

ABSTRACT

The stability of sheet pile structures is a critical consideration in geotechnical engineering, particularly when employed in cohesive soils. This study presents a comprehensive comparative analysis of sheet pile stability in cohesive soil under varying retaining wall lengths. The objective is to assess the influence of retaining wall length on the overall stability of sheet piles.

The research methodology involves numerical simulations and analytical modelling using advanced geotechnical software and established engineering principles. A range of retaining wall lengths is considered to systematically evaluate their impact on the stability of sheet piles within cohesive soil profiles. Factors such as lateral earth pressure distribution, shear strength parameters, and deformation characteristics are incorporated into the analysis to provide a holistic understanding of the system behaviour.

This research is of practical significance for geotechnical engineers, designers, and practitioners involved in the planning and execution of projects requiring sheet pile structures in cohesive soil environments. The outcomes of this study can inform engineering practices, providing a basis for improved design guidelines and facilitating the development of more reliable and efficient solutions for retaining structures in similar geotechnical contexts.

Keywords: Sheet Pile, Retaining Height, *PLAXIS* 2D, Clay

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE PRESENT STUDY

Sheet piles are a crucial component of retaining wall structures used in civil engineering and construction projects to provide lateral support against soil or water pressure. Typically made of steel, these interlocking sheets are driven vertically into the ground, forming a continuous barrier that prevents collapse or erosion. The history of sheet piles dates back to the early 20th century, evolving from timber designs to the prevalent use of steel due to its strength and durability. Various shapes and configurations have been developed to suit different soil conditions, making sheet piles versatile for both temporary and permanent applications.

Sheet piles find extensive use in a variety of applications, such as waterfront structures (seawalls, bulkheads, quay walls), deep excavation projects, foundation construction, and environmental applications like shoreline protection and land reclamation. They play a crucial role in infrastructure development, providing earth retention for underground structures. The adaptability and durability of sheet piles make them indispensable in addressing challenges posed by soil conditions, stabilizing slopes, and preventing water ingress in construction sites.

The historical evolution of sheet piles reflects advancements in technology and material science. Their significance extends to environmental applications, where they contribute to shoreline protection and land reclamation, controlling erosion and stabilizing coastal infrastructure. As technology continues to advance, the design and application of sheet piles are expected to evolve, maintaining their significance in geotechnical engineering.

1.2 THE PRESENT STUDY

The construction of retaining structures in geotechnical engineering is pivotal, and sheet piles play a key role in providing effective earth retention solutions. This thesis focuses on an in-depth analysis of sheet piles within cohesive soil environments, utilizing the Limit Equilibrium Method (LEM) and the Finite Element Method (FEM). The study explores the interaction between sheet piles and cohesive soils at varying depths, aiming to enhance our understanding of their stability and performance.

In the present study, an attempt has been made to find out embedment depth as well as maximum bending moment of cantilever sheet pile in cohesive soil with varying cohesion (C in kN/m^2) as well as varying wall height. The study has been carried out by the LEM method and the numerical method as well as using *PLAXIS* 2D software (Connect Edition). The results of both of these methods are compared and valuable conclusions have been drawn. Different wall heights such as 4m, 4.5m, 5m, 5.5m, 6m, 6.5m, and 7m are considered for analysis while varying the undrained cohesion value of soil with values 25 kN/m^2, 30 kN/m^2 and 35 kN/m^2.

1.3 ORGANISATION OF THE THESIS

The thesis has been organized into eight chapters as follows:

1: **Introduction** reveals the background of the study and depicts the present research with the organization of the thesis

2: A **Literature Review** on the relevant topic has been made to present some relevant and available past research works in this chapter.

3: This chapter deals with the **Objective and Scope** of the work.

4: A brief **Methodology** of the present research has been illustrated in this chapter.

5: In this chapter, the **Limit Equilibrium Method** of the calculation adopted for the study has been presented.

6: In this chapter, the **Finite Element Method** of the calculation adopted for the study has been presented.

7: This chapter presents **Results and Discussion** in connection with the present research.

8: This chapter deals with the **Summary, Conclusion, and Scope of further Research**.

es: Names of different researchers mentioned in this dissertation have been arranged in alphabetical order under **REFERENCES**.

CHAPTER-2

LITERATURE REVIEW

2.1 OVERVIEW

In this chapter, a review of available literature relevant to this research is to be furnished, and results of previous research work done in the concerned areas have been discussed and summarized.

2.2 LITERATURE REVIEW

An attempt has been made to carry out a brief literature review in the nearest field of study. The research work has been discussed in **chronological order**.

G. J. W. King (1995) Here, proposed a revised method for analyzing and designing cantilever retaining walls in homogeneous cohesionless soil has been proposed, offering a noteworthy advancement over current design approaches. Unlike existing methods that relied on assumed linear pressure distributions and artificial simplifications, this new method eliminated such constraints. While dependent on an empirical parameter (£'), centrifuge model tests demonstrated that this parameter was well-constrained, with a recommended value of 0.35. The method explored the impact of soil density and surface roughness on the variation of the factor of safety with excavation height for a fixed wall height. Additionally, it provided insights into the bending moment distribution at various excavation heights. The inclusion of simple equations and design curves enhanced the ease of geometric design and bending moment calculations, with comparative analyses against conventional design methods. Overall, this proposed method promised a more robust and practical approach to cantilever retaining wall analysis and design.

B. Panthi (1999) Here, the variation in the depth of embedment in cantilever sheet piles was investigated, considering both geometrical and soil parameters. The findings culminated in the derivation of a direct equation (13) and the development of insightful design curves. These tools were efficiently employed for rapid calculations of the depth of embedment. However, it was crucial to note that if equation (14) or design curves with f = 1 were utilized, a suitable factor of safety on depth had to be applied. The analysis hinged on the assumption of the sheet pile's complete rigidity and a linear distribution of earth pressure. Furthermore, the potential for refining results through the integration of Day's ϵ value, aligning closely with finite element analysis and experimental outcomes, presented an avenue for further enhancement.

C. Cherubini (2001) Here, the conclusion underscored the inherent uncertainties in geotechnical engineering, emphasizing that neither factors of safety nor probabilities of failure could be considered highly accurate measures of safety. It highlighted the rarity of situations where factors of safety or probabilities of failure could be computed with precision, noting that accuracy better than 15% for factors of safety and a factor of two for probabilities of failure was seldom achievable. Despite these challenges, the conclusion suggested that even approximate values of probabilities of failure offered valuable insights into the uncertainties inherent in geotechnical engineering analyses.

The paper emphasized the importance of recognizing the limitations in calculating probabilities of failure and settlement exceeding computed values. Nevertheless, it argued that these approximations provided valuable insights, especially when assessing the consequences of uncertainties. The example presented by Moriwaki and Barneich illustrated the usefulness of even approximate values in understanding the implications of different uncertainties.

The conclusion promoted the idea that probabilities of failure should be seen as a complement to factors of safety rather than a substitute. The exercise of judgment in calculating probabilities of failure was deemed beneficial, shedding additional light on the reliability of the analysis process. Ultimately, the paper advocated for a holistic approach, asserting that having both an approximate value of the factor of safety and an approximate value of the probability of failure was superior to knowing either one alone..

Madabhushi & Chandrasekaran (2005) Here, the authors proposed a novel method for determining the pivot point of cantilever sheet pile walls. Unlike traditional approaches that relied on iterative methods or experimental data, the new method was based on the minimization of the moment ratio, offering a direct solution without the need for iterative procedures. The key insight lay in recognizing that the moment equilibrium of the sheet pile wall was crucial in pinpointing the pivot point.

The applicability of this approach spanned both cohesive and cohesionless backfills, making it a versatile solution. The introduced concept of shear strength demand proved valuable in assessing the stability of existing sheet pile walls and considering improvements through various ground improvement methods.

The validity of the proposed method was rigorously tested against centrifuge data and laboratory scale test results. Remarkably, the location of the pivot point determined through the moment ratio minimization approach aligned well with experimentally derived pivot points and matched results obtained through existing iterative procedures. The authors further demonstrated the effectiveness of the shear strength demand in estimating the geometry of sheet pile walls prone to instability, confirming its reliability through centrifuge test data.

Additionally, the shear strength demand was utilized to predict the shear strain mobilized in the passive zones on either side of the sheet pile wall. This representative shear strain was linked to wall rotations and deflections, providing a comprehensive understanding of wall behavior under various conditions. The calculated wall deflections aligned satisfactorily with experimentally observed values, particularly noting a substantial increase in deflections when the shear strength demand reached the full shear strength of the backfill material.

Overall, this paper introduced an innovative and efficient method for determining pivot points in cantilever sheet pile walls, offering a direct and reliable solution with broad applicability and validation through comprehensive testing.

Babu & Basha (2008) The review concluded that factors of safety and probabilities of failure should not be regarded as highly accurate measures of safety due to the inherent uncertainties in the field. Precision in calculating factors of safety or probabilities of failure was rare, with an accuracy better than 615% for factors of safety and a factor of two for probabilities of failure being a challenge. The paper emphasized that even though exact values might be elusive, estimating probabilities of failure provided valuable insights into the uncertainties prevalent in geotechnical engineering analyses. The review highlighted the importance of exercising judgment in calculating probabilities of failure, acknowledging that the process itself shed light on the reliability of the analysis. The conclusion emphasized that probabilities of failure should be seen as complementary, not a substitute, to factors of safety. It asserted that having both approximate values enhanced the understanding of safety, thereby underscoring the significance of considering both aspects in geotechnical engineering assessments.

Rymsza and Sahajda (2008) Monitored the deformations, horizontal displacement, and settlement of the roadbed for a restrained sheet-pile wall designed as an earth retention system for a railway embankment using an inclinometer and described the results using graphical representations generated by FEM software. The paper showed plots of lateral deformations at different sections of the embankment. The authors concluded that the lateral deformations of some walls were greater than others as the depth of embedment was less, which in turn, reduced the length of the passive earth pressure zone. According to them, the slight deviations from the values obtained from the site and computational results might have been due to the heterogeneous nature of the soil, whereas the soil considered in the analysis was homogeneous. Other reasons might have been errors due to inaccuracy in geodetic measurements.

Olubanwo and Ebo (2015) reviewed the theories and modeling methods of the interaction between soil and embedded sheet-piles. They stated that the non-linear behavior of soil interaction was complex and was neglected by conventional theories, often leading to inaccurate pressure distribution and over-conservativeness in design. According to them, many of these drawbacks could be overcome using Finite Element Analysis by proper modeling and ensuring that the assigned properties were as close to the material non-linearities as possible. They also found that no firm guidelines existed in the relevant design standards of sheet piles for determining their acceptable deflection.

They modeled cantilever and anchored sheet piles using the ANSYS FEM code and adjusted the model for nonlinear behavior. They plotted curves for deformation against the height of sheet-pile walls in homogeneous, and heterogeneous soils with carbon fiber and steel reinforcements. They made the same plots by varying the values of cohesion and internal friction. They concluded that small movements of the sheet pile were difficult to detect in the conventional equilibrium design approach. Homogeneous soil was found to have higher translational and rotational deformations compared to heterogeneous soil, indicating that the conventional design would overestimate the deformation in homogeneous soil. They also observed that the deformation of anchor piles was similar in both homogeneous and heterogeneous soils, and carbon fiber-reinforced walls showed more irregular deformation than steel-reinforced walls..

Chheng and Likitlersuang (2017) modeled an excavation site located in Bangkok using 3D Finite Element software (PLAXIS 3D). They divided the activities into four construction sequences, analyzed the horizontal wall deformation at each stage, and generated graphs plotting wall movement against the depth of the sheet pile wall and surface settlement against the distance from the wall. According to them, the 3D FEM agreed well with the instrumented data collected on-site. This, in turn, confirmed that the modeling could reflect the real behavior of sheet pile walls for deep excavation.

Javankhoshdel and Yacoub (2020) observed that simulating a soil-structure system using just a structural element with a soil model was insufficient, as it failed to induce the slip condition developed between the sheet pile and the soil. The soil-structure system model was carried out in 2D and 3D FEM packages, with a liner element chosen for the sheet-pile walls. The interactive behavior at the interface was modeled with material-dependent coefficients for joint elements. The relationship of total displacement, bending moment, and axial force with increasing liner depth and varying interface slippage coefficients was plotted. Displacements obtained from both the 2D and 3D software were compared.

As per the analysis, with the decrease in the interface coefficient, slippage increased, resulting in greater displacement. The FEM analysis failed to converge for small values of interface coefficients, creating a gap between the liner and soil and causing a loss of strength. A limitation of the analysis was that the material used for the interface element was linear and failed to accurately generate results if the material was non-linear.

Ichsan Rauf (2021) The study aimed to analyze the deflection behavior of the sheet pile through experimental testing and numerical analysis using the finite element method. PLAXIS software was used for numerical analysis. Soft clay was the soil under consideration for the study. The results of modeling the horizontal movement of the sheet pile with PLAXIS showed that the sheet pile failure tended to be similar to the results obtained in the laboratory model. However, the simulation results indicated that the sheet pile wall collapsed at a peak load of 71 kN/m² with a maximum deflection of 22 mm. A comparison of simulation results with PLAXIS revealed smaller values for both loading and deflection compared to the lab test results.

Xiaoyu Song and others (2022) Here, an attempt was made to quantify the bearing capacity of permanent steel sheet pile walls by evaluating both skin friction and end bearing components. Field tests were conducted to determine the bearing capacity of the sheet pile. Numerical methods using PLAXIS 3D software were employed to estimate vertical load-bearing capacity, lateral displacement, embedment depth, and maximum bending moment of the sheet pile. Driven pile capacity was estimated using CPT data according to the method suggested by the University of Florida. It was found that the ultimate bearing capacity of sheet pile walls exhibited a nonlinear relationship with the height of the retained soil/embedment ratio. For all three values of relative density, increasing depth had very little effect on the predicted ultimate vertical bearing capacity. Based on the simulation, predictions could be made regarding the relationship between the ultimate axial capacity and the embedment ratio in the soil. It was apparent that there was a significant increase in the ultimate capacity with increasing relative density regardless of embedment depth. It was found that for values smaller than d = 21.0 ft, a reduction in embedment depth resulted in a noticeable loss of bearing capacity for all types of soils considered. To accurately reflect the vertical resistance of the pile, the absolute value of pile embedment d had to be used. On the other hand, the retained soil height h could reduce the bearing capacity by increasing the active pressure on the pile.

2.3 MOTIVATION OF THE PRESENT RESEARCH

The above literature review reveals the extent of work, so far, has been conducted in cohesive soil pertaining to the sheet pile. The effect of cohesion and embedment depth on stability analysis of cantilever sheet piles in purely cohesive soil is not well addressed in the available literature review. With this in view, the present study has been taken up with the objectives and scope described in the next chapter.

CHAPTER-3

OBJECTIVE AND SCOPE

3.1 OVERVIEW

The objective and scope of this chapter are presented in the following sections.

3.2 OBJECTIVES

The objectives are as follows: -

- To analyze the cantilever sheet pile in cohesive soil with varying cohesion values and to determine the embedment depth, bending moment & lateral deformation.
- To formulate the bending moment of sheet pile of varying wall height with varying cohesion of pure clay soil by LEM and FEM (using *PLAXIS* 2D).

3.3 SCOPE OF THE STUDY

The scope of the study is outlined below

- To calculate the embedment depth of sheet pile in pure cohesive soil for varying retained soil heights (3.0m, 3.5m, 4.0m, 4.5m, 5.0m, 5.5m, 6.0m, 6.5m & 7.0m). The soil parameters are as follows: bulk density = 18 kN/m³, cohesion (Cu) = 25 kN/m³, 30 kN/m³, 35 kN/m³, and the groundwater table is well below the tip of the sheet pile.
- The methods used – LEM and FEM
- To compile the results of sheet pile calculations for different retaining heights.
- To predict embedment depth and maximum bending moment of cantilever sheet pile.

CHAPTER-4

METHODOLOGY

4.1 OVERVIEW

This chapter aims to determine the embedment depth of sheet piles with varying wall height and also find the maximum bending moment that occurs by employing manual calculation following LEM and *PLAXIS* 2D software (Connect Edition).

4.2 METHODOLOGY

The methodology for analyzing sheet pile stability in cohesive soil involves a comprehensive approach utilizing both the Limit Equilibrium Method (LEM) through manual calculations and the Finite Element Method (FEM) using *PLAXIS* 2D software (Connect Edition). The study aims to assess the performance and stability of sheet piles in cohesive soil conditions.

4.3 LIMIT EQUILIBRIUM METHOD (LEM)

The Limit Equilibrium Method (LEM) is a fundamental approach employed in geotechnical engineering to analyse the stability of structures, particularly sheet piles, in cohesive soil. In this context, cohesive soil refers to soil with particles that stick together due to the presence of clay minerals. LEM assesses the equilibrium conditions at potential failure surfaces to determine the factor of safety against sliding or overturning. When applied to sheet piles in cohesive soil, LEM considers factors such as soil shear strength, water pressure, and structural characteristics. By evaluating these parameters, engineers can ascertain the stability of sheet pile structures and optimize their design for reliable performance in cohesive soil conditions.

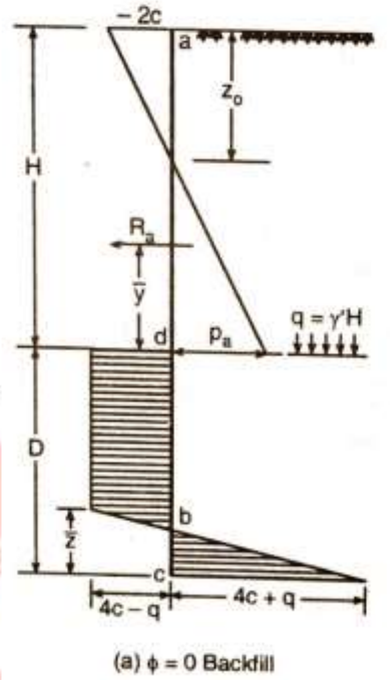


Figure 4.1: shows Limit Equilibrium Method for Cohesive Soil

4.4 FINITE ELEMENT METHOD (FEM) USING *PLAXIS* 2D SOFTWARE

The Finite Element Method (FEM) is a powerful numerical technique employed in geotechnical engineering, specifically in the analysis of sheet pile structures within cohesive soils. *PLAXIS* Software is a prominent tool for such simulations, providing a robust platform for FEM applications. In the context of sheet piles, *PLAXIS* allows engineers to model complex soil-structure interactions, considering factors like soil cohesion,

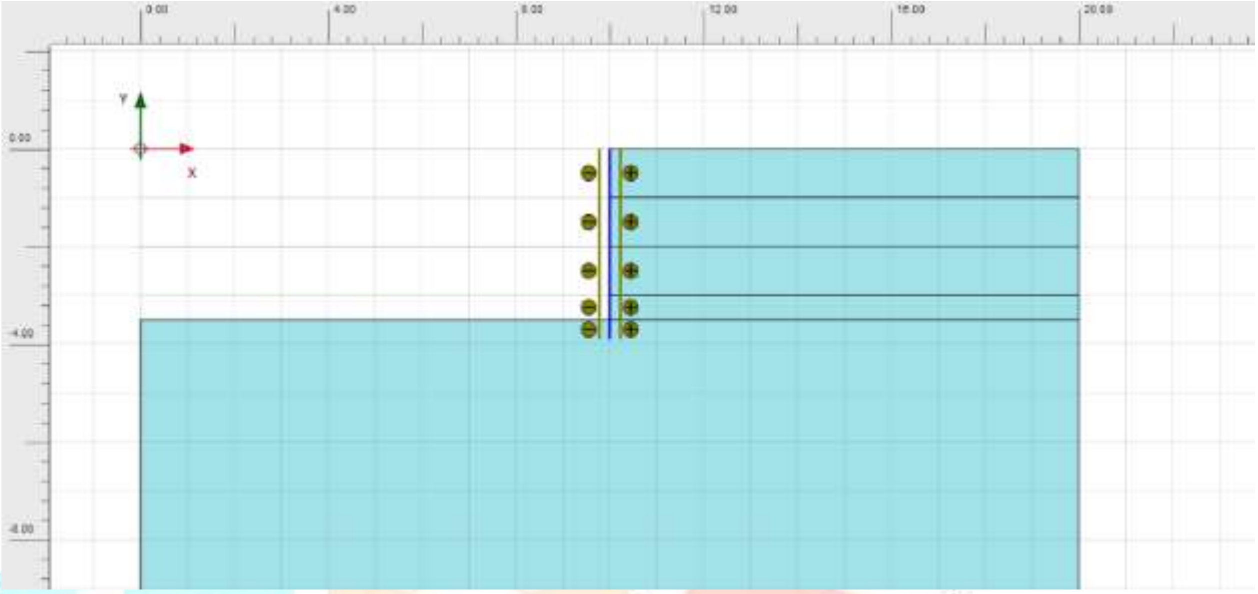


Figure 4.2: shows Finite Element Method (FEM) using Plaxis 2D Software

layering, and loading conditions. Through meticulous meshing and boundary conditions, *PLAXIS* aids in predicting deformation, stress distribution, and overall stability of sheet pile walls in cohesive soil. This facilitates informed decision-making in the design and optimization of geotechnical structures, ensuring their reliability and safety.

To design a cantilever sheet pile wall using *PLAXIS* 2D software, the following steps are followed:

- **Defining Geometry and Soil Layers:**
  - Geometry: Set up the dimensions of the sheet pile wall (length, depth, thickness).
  - Soil Layers: Define the soil layers behind and in front of the sheet pile wall. Specify properties such as soil type, unit weight, cohesion, and internal friction angle.

- **In model set up:**
  - Create a new project and select the appropriate units (metric or imperial).
  - Define the finite element mesh for your model. *PLAXIS* 2D uses triangular or quadrilateral elements for meshing.

- **Sheet Pile Wall Definition:**
  - Specify the properties of the sheet pile wall, including material properties (e.g., modulus of elasticity, Poisson's ratio).
- **Boundary Conditions:**
  - Apply boundary conditions to the model. For a cantilever sheet pile wall, fix the bottom of the sheet pile wall against movement in the horizontal direction (typically represented as roller supports) and allow movement in the vertical direction.
- **Loading Conditions:**
  - Apply appropriate loading conditions such as surcharge loads, water pressures, and any additional loads that act on the sheet pile wall.
- **Analysis:**
  - Run the analysis to calculate the deformation and stresses within the sheet pile wall and surrounding soil.
  - Review the results to ensure stability and check factors of safety against failure modes (e.g., sliding, overturning, excessive deformation).
- **Post-Processing:**
  - Analyze the results to understand the behavior of the sheet pile wall and soil interaction under different loading conditions.
  - Plot deformations, stresses, and other relevant parameters to assess the performance of the structure.
- **Optimization and Design Verification:**
  - Based on the analysis results, optimize the design parameters if necessary (e.g., sheet pile spacing, embedment depth).
  - Verify the design against applicable design codes and standards to ensure safety and stability.

CHAPTER-5

LIMIT EQUILIBRIUM METHOD

5.1 OVERVIEW

In this chapter, the Limit Equilibrium Method (LEM) is employed to manually analyze the stability of sheet piles through Excel calculations, focusing on determining the embedment length and maximum bending moment for various retaining wall heights and cohesive soil properties. By applying fundamental principles of soil mechanics and structural analysis, the study aims to evaluate how different soil cohesion levels influence the stability and design parameters of sheet piles. The analysis will involve calculating the factor of safety, assessing the soil-structure interaction, and deriving the critical embedment length required for stability, as well as the maximum bending moments experienced by the sheet piles under different conditions. This approach not only reinforces theoretical concepts but also provides practical insights into the design and performance of sheet pile systems in real-world engineering scenarios.

5.2 CALCULATION OF CANTILEVER SHEET PILE WALL IN COHENSIVE SOIL.

Fig. 5.1 shows the pressure distribution for the pressure distribution for cantilever sheet pile wall in purely cohesive soil ($\varphi = 0$). The active and passive pressure intensities for purely cohesive soil are given by

$p_a = \sigma K_a - 2c\sqrt{K_a} = \sigma - 2c$ **......(1)**

(Since $K_a = K_p = 1$ when $\varphi = 0$; and $\sigma = \gamma z$) and

$P_p = \sigma K_p + 2c\sqrt{K_p} = \sigma + 2c$ **......(2)**

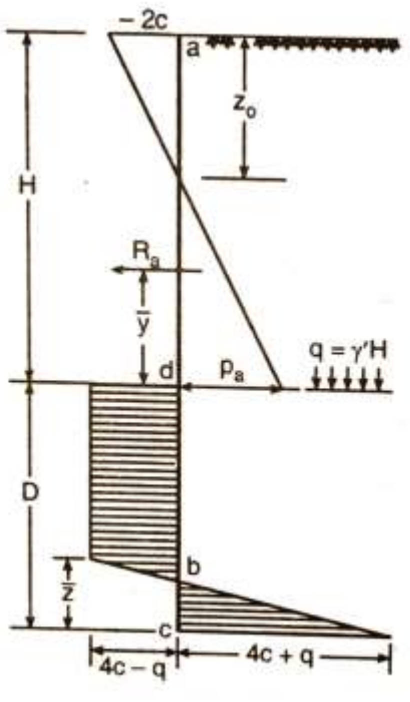
Thus, active pressure intensity at point **a** is equal to – 2c, and that at the dredge line is given by

$P_p = \gamma' H - 2c = q - 2c$ **......(3)**

where,

q = effective pressure at dredge line = $\sigma = \gamma' H$

The passive pressure diagram is shown hatched in Fig. 5.1.



(a) φ = 0 Backfill

Figure 5.1 : shows Cantilever Sheet Pile Wall in Cohensive Soil

At point d, on the left of the sheet piling at the dredge line, the overburden pressure $\sigma = 0$. Hence, net pressure at d is

$(p_p - p_a)_d = (0 + 2c) - (q - 2c) = 4c - q$ ......(4)

Also, at point c the net pressure is given by

$(p_p - p_a)_c = (q + \gamma D + 2c) - (\gamma D - 2c) = 4c + q$ ......(5)

← →

In order to find the height of $\overline{z}$ above the base c, equate the sum of horizontal forces to zero ($\Sigma H = 0$).

∴ $$R_a + \frac{\overline{z}}{2}(4c + q + 4c - q) - D(4c - q) = 0 \qquad ......(6)$$

(Where, Ra = resultant of active pressure above dredge line active at $\overline{y}$ above the dredge line.)

Solving for $\overline{z}$ $$\overline{z} = \frac{D\,(4c - q) - R_a}{4c} \qquad ......(7)$$

In order to get another equation of $\overline{z}$ and D, sum the moment of all forces about the base and equate it to zero.

$$R_a(\overline{y} + D) - \frac{D^2}{2}(4c - q) + \frac{\overline{z}}{3}\cdot\frac{\overline{z}}{2}(4c - q + 4c + q) = 0 \qquad ......(8)$$

Substituting $\overline{z}$ and simplifying, we get

$$D^2(4c - q) - 2DR_a - \frac{R_a(12\,c\,\overline{y} + R_a)}{2c + q} \qquad ......(9)$$

By solving the eq. 9 we get the value of D (Embedment Depth)

Thus, D is Taken as about 40% of the Factor of Safety.

To find the maximum Bending Moment, let us calculate the height (z') of the Point where the Bending Moment will act below the Dredge Line.

$$z' = {P_1}/{\rho_2} \qquad ......(10)$$

Now, the maximum Bending Moment at z' height below the Dredge Line.

$$BM = P_1(z' + \overline{y}) - \frac{(\rho_2 \times z'^2)}{2} \qquad ......(11)$$

5.3 DATA INPUT

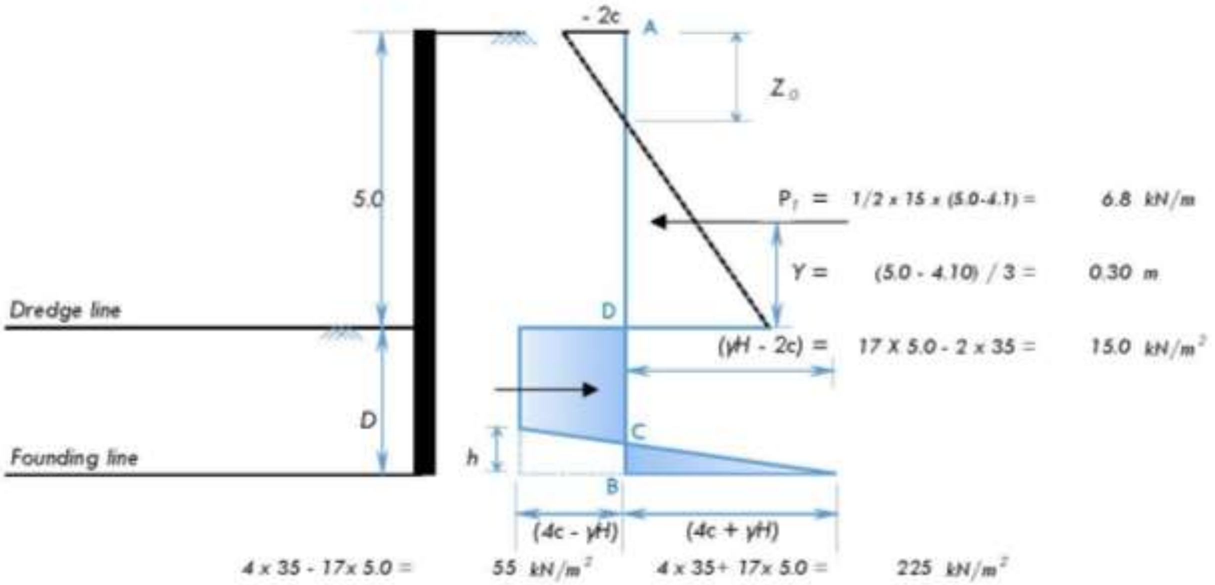
When Retaining height = 5.0 m :-

Design Criteria :

Soil Retaining Height, H = 5.0 m ← Input Retaining Height

Cohesion of Soil, C = 35 kN/m^2 ← Input Cohesion of Soil, C

Bulk Density of Soil, γ = 17 kN/m^3 ← Input Bulk Density of Soil, γ



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 35 / 17 = **4.10** m

To find **h**, sum of all Horizontal forces equals to zero, (**ΣH = 0**)

=> 6.75 + 1/2 x (55.00 + 225.00) x h = 55.00 x D

=> h = (55.00 D - 6.75) / 140.00

=> h = 0.1362

To find **D** , **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (55.00 + 225.00) x h x h/3 = 55.00 x D x D/2

=> 6.75 x (0.30 + D) + 1/2 x 280 x h^2/3 = 27.5 D^2

=> 2.03 + 6.75 x D + 46.67 x ((55 x D - 6.75) / 140)^2 = 27.5 x D^2

=> 2.03 + 6.75 x D + 0.0024 x (55 x D - 6.75)^2 = 27.5 x D^2

=> $-20.298\ D^2 + 4.9821\ D + 2.1335 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -20.3

b = 5.0

c = 2.1

$x = D = (-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.2 or 0.5

D = 0.5 m

Taking D by 40% for FOS = 2, D = 0.47 x 1.4 = **0.66** m

Max. Bending Moment act at the height, z' below Dredge line = P_1 / p_2 = 6.75 / 55 = 0.10 m

Max. Bending Moment = 6.75 x (0.1 + 0.3) - (55 x 0.1^2)/2 = **2.4** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
0.66	**2.4**	**4.1**	**0.14**

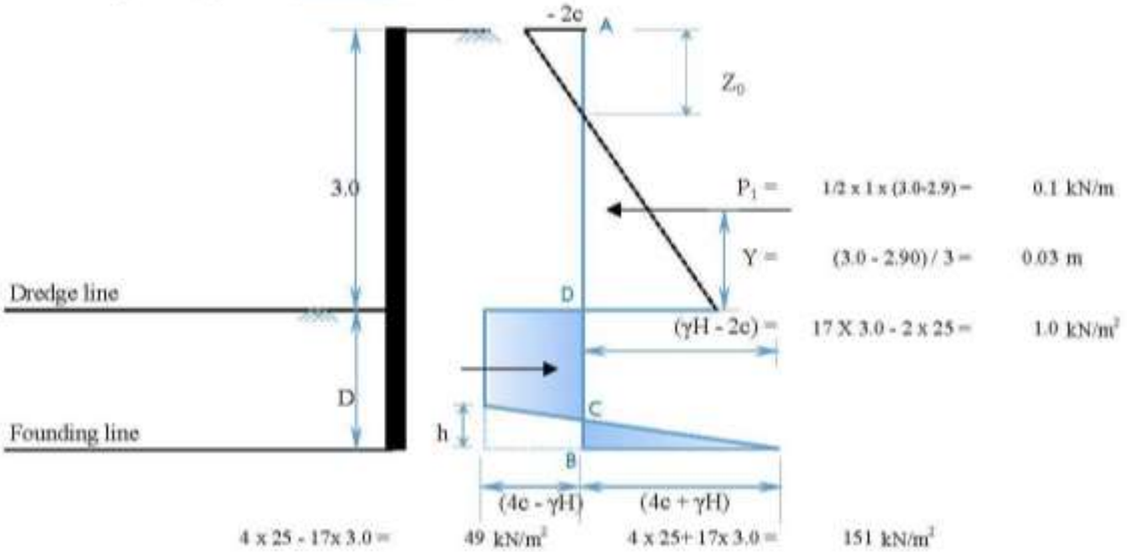
5.4 CALCULATION WITH DIFFERENT RETAINING HEIGHTS OF SHEET PILE.

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 25 kN/m²**

When Retaining height = 3.0 m :-

Design Criteria :

Soil Retaining Height, H =	**3.0** m
Cohesion of Soil, C =	**25** kN/m²
Bulk Density of Soil, γ =	**17** kN/m³



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 25 / 17 = **2.90** m

To find **h**, sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 0.05 + 1/2 x (49.00 + 151.00) x h = 49.00 x D

=> h = (49.00 D - 0.05) / 100.00

=> h = 0.00471

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (49.00 + 151.00) x h x h/3 = 49.00 x D x D/2

=> 0.05 x (0.03 + D) + 1/2 x 200 x h^2/3 = 24.5 D^2

=> 0.00 + 0.05 x D + 33.33 x ((49 x D - 0.05) / 100)^2 = 24.5 x D^2

=> 0.00 + 0.05 x D + 0.0033 x (49 x D - 0.05)^2 = 24.5 x D^2

=> $-16.497\ D^2 + 0.03367\ D + 0.00151 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -16.5

b = 0.0

c = 0.0

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = 0.0 or 0.0

D = 0.0 m

Taking D by 40% for FOS = 2, D = 0.01 x 1.4 = **0.02** m

Max. Bending Moment act at the height, z below Dredge line = P_1 / ρ_2 = 0.05 / 49 = 0.00 m

Max. Bending Moment = 0.05 x (0 + 0.03) - (49 x 0^2)/2 = **0.0** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
0.02	**0.0**	**2.9**	**0.00**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 25 kN/m²**

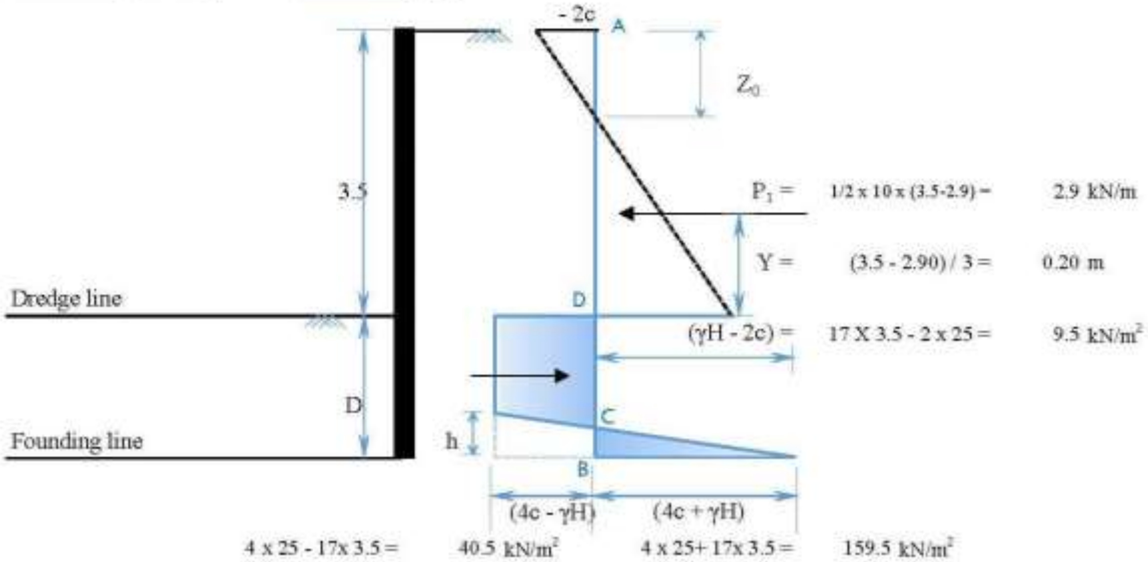
When Retaining height = 3.5 m :-

Design Criteria :

Soil Retaining Height, H = **3.5** m

Cohesion of Soil, C = **25** kN/m²

Bulk Density of Soil, γ = **17** kN/m³



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 25 / 17 = **2.90** m

To find **h**, sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 2.85 + 1/2 x (40.50 + 159.50) x h = 40.50 x D

=> h = (40.50 D - 2.85) / 100.00

=> h = 0.08624

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (40.50 + 159.50) x h x h/3 = 40.50 x D x D/2

=> 2.85 x (0.20 + D) + 1/2 x 200 x h^2/3 = 20.25 D^2

=> 0.57 + 2.85 x D + 33.33 x ((40.5 x D - 2.85) / 100)^2 = 20.25 x D^2

=> 0.57 + 2.85 x D + 0.0033 x (40.5 x D - 2.85)^2 = 20.25 x D^2

=> $-14.783\ D^2 + 2.0805\ D + 0.59708 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -14.8

b = 2.1

c = 0.6

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.1 or 0.3

D = 0.3 m

Taking D by 40% for FOS = 2, D = 0.28 x 1.4 = **0.40** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 2.85 / 40.5 = 0.10 m

Max. Bending Moment = 2.85 x (0.1 + 0.2) - (40.5 x 0.1^2)/2 = **0.7** kNm

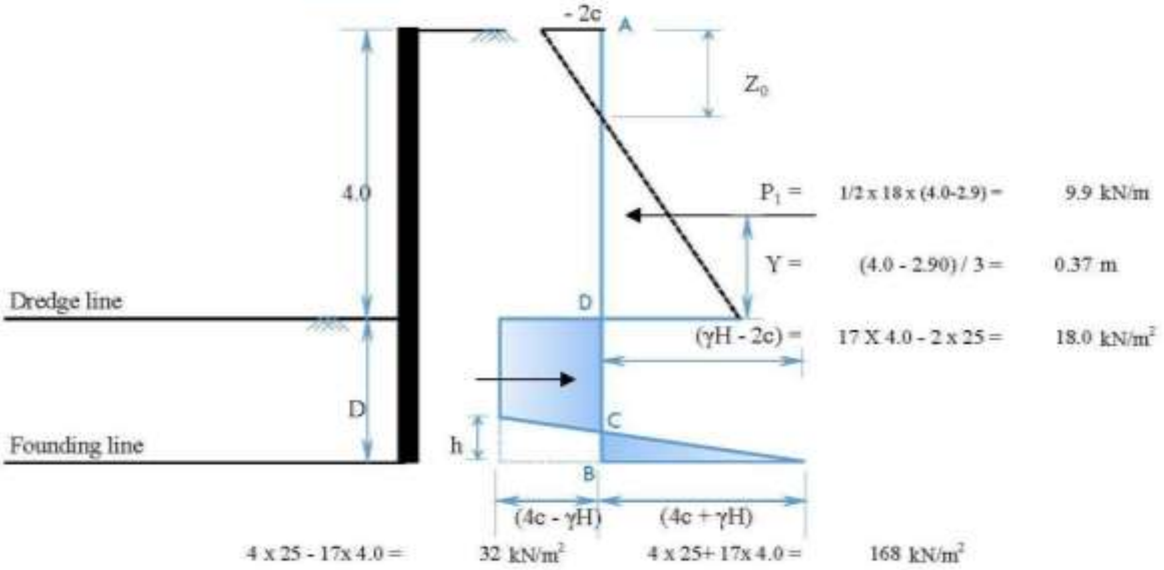
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
0.40	**0.7**	**2.9**	**0.09**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 25 kN/m²**

When Retaining height = 4.0 m :-

Design Criteria :

Soil Retaining Height, H =	**4.0**	m
Cohesion of Soil, C =	**25**	kN/m^2
Bulk Density of Soil, γ =	**17**	kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 25 / 17 = **2.90** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 9.90 + 1/2 x (32.00 + 168.00) x h = 32.00 x D

=> h = (32.00 D - 9.90) / 100.00

=> h = 0.20557

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (32.00 + 168.00) x h x h/3 = 32.00 x D x D/2

=> 9.9 x (0.37 + D) + 1/2 x 200 x h^2/3 = 16 D^2

=> 3.66 + 9.9 x D + 33.33 x ((32 x D - 9.9) / 100)^2 = 16 x D^2

=> 3.66 + 9.9 x D + 0.0033 x (32 x D - 9.9)^2 = 16 x D^2

=> $-12.587\ D^2$ + 7.788 D + 3.9897 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -12.6

b = 7.8

c = 4.0

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.3 or 1.0

D = 1.0 m

Taking D by 40% for FOS = 2, D = 0.95 x 1.4 = **1.33** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 9.9 / 32 = 0.30 m

Max. Bending Moment = 9.9 x (0.3 + 0.37) - (32 x 0.3^2)/2 = **5.2** kNm

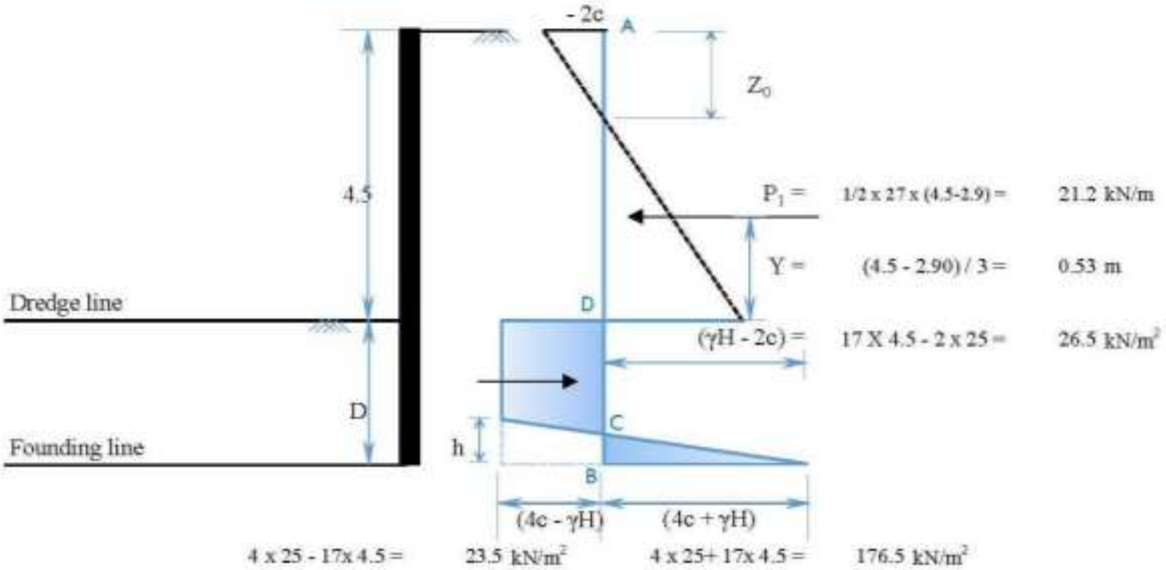
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
1.33	**5.2**	**2.9**	**0.21**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 25 kN/m²**

When Retaining height = 4.5 m :-

Design Criteria :

Soil Retaining Height, H =	**4.5** m
Cohesion of Soil, C =	**25** kN/m²
Bulk Density of Soil, γ =	**17** kN/m³



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 25 / 17 = **2.90** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 21.20 + 1/2 x (23.50 + 176.50) x h = 23.50 x D

=> h = (23.50 D - 21.20) / 100.00

=> h = 0.34046

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (23.50 + 176.50) x h x h/3 = 23.50 x D x D/2

=> 21.2 x (0.53 + D) + 1/2 x 200 x h^2/3 = 11.75 D^2

=> 11.24 + 21.2 x D + 33.33 x ((23.5 x D - 21.2) / 100)^2 = 11.75 x D^2

=> 11.24 + 21.2 x D + 0.0033 x (23.5 x D - 21.2)^2 = 11.75 x D^2

=> $-9.9092\ D^2 + 17.8787\ D + 12.7341 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -9.9

b = 17.9

c = 12.7

$x = D = (-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.5 or 2.4

D = 2.4 m

Taking D by 40% for FOS = 2, D = 2.35 x 1.4 = **3.29** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 21.2 / 23.5 = 0.90 m

Max. Bending Moment = 21.2 x (0.9 + 0.53) - (23.5 x 0.9^2)/2 = **20.8** kNm

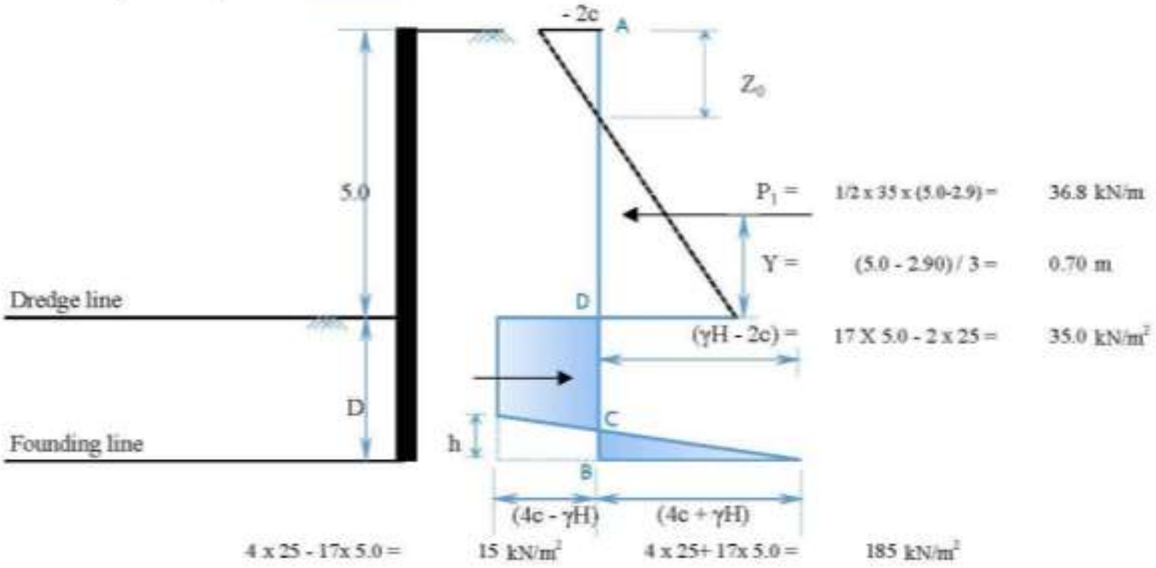
Summary			
Em Depth	**BM**	Z_0	**h**
m	kNm	m	m
3.29	**20.8**	**2.9**	**0.34**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 25 kN/m²**

When Retaining height = 5.0 m :-

Design Criteria :

Soil Retaining Height, H =	**5.0** m
Cohesion of Soil, C =	**25** kN/m^2
Bulk Density of Soil, γ =	**17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma$ = 2 x 25 / 17 = **2.90** m

To find **h**, sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 36.75 + 1/2 x (15.00 + 185.00) x h = 15.00 x D

=> h = (15.00 D - 36.75) / 100.00

=> h = 0.48561

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (15.00 + 185.00) x h x h/3 = 15.00 x D x D/2

=> 36.75 x (0.70 + D) + 1/2 x 200 x h^2/3 = 7.5 D^2

=> 25.73 + 36.75 x D + 33.33 x ((15 x D - 36.75) / 100)^2 = 7.5 x D^2

=> 25.73 + 36.75 x D + 0.0033 x (15 x D - 36.75)^2 = 7.5 x D^2

=> $-6.75\ D^2$ + 33.075 D + 30.2269 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -6.8

b = 33.1

c = 30.2

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = -0.8 or 5.7

D = 5.7 m

Taking D by 40% for FOS = 2, D = 5.69 x 1.4 = **7.96** m

Max. Bending Moment act at the height, z below Dredge line = P_1 / ρ_2 = 36.75 / 15 = 2.50 m

Max. Bending Moment = 36.75 x (2.5 + 0.7) - (15 x 2.5^2)/2 = **70.7** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
7.96	**70.7**	**2.9**	**0.49**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m^3 & C = 30 kN/m^2**

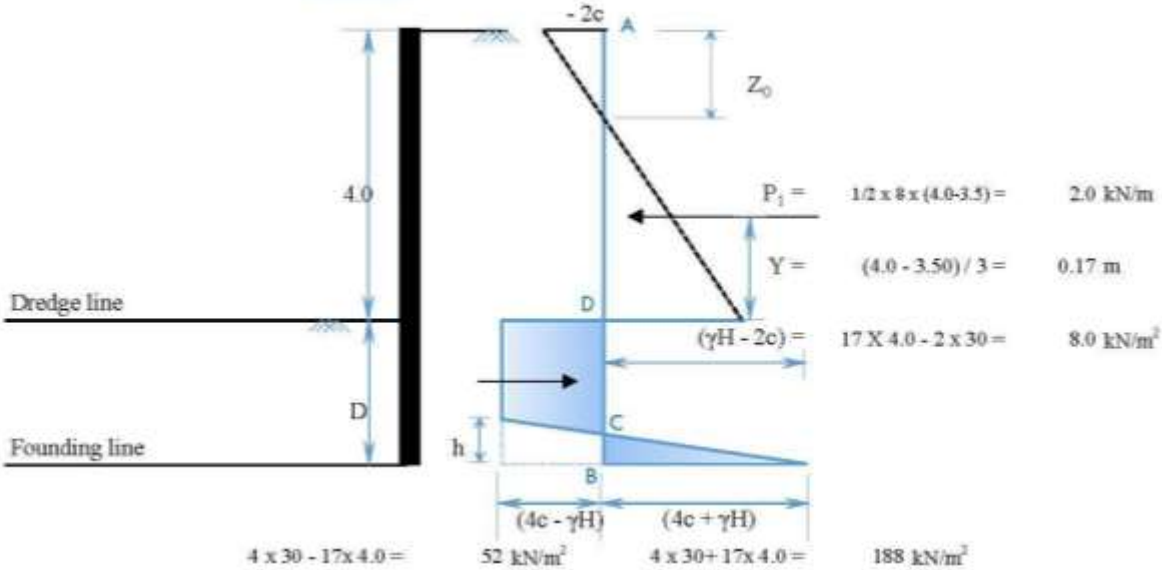
When Retaining height = 4.0 m :-

Design Criteria :

Soil Retaining Height, H = **4.0** m

Cohesion of Soil, C = **30** kN/m^2

Bulk Density of Soil, γ = **17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 30 / 17 = **3.50** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 2.00 + 1/2 x (52.00 + 188.00) x h = 52.00 x D

=> h = (52.00 D - 2.00) / 120.00

=> h = 0.062

To find **D, ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (52.00 + 188.00) x h x h/3 = 52.00 x D x D/2

=> 2 x (0.17 + D) + 1/2 x 240 x h^2/3 = 26 D^2

=> 0.34 + 2 x D + 40.00 x ((52 x D - 2) / 120)^2 = 26 x D^2

=> 0.34 + 2 x D + 0.0028 x (52 x D - 2)^2 = 26 x D^2

=> $-18.489\ D^2 + 1.42222\ D + 0.35111 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -18.5

b = 1.4

c = 0.4

$x = D = (-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.1 or 0.2

D = 0.2 m

Taking D by 40% for FOS = 2, D = 0.18 x 1.4 = **0.25** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 2 / 52 = 0.00 m

Max. Bending Moment = 2 x (0 + 0.17) - (52 x 0^2)/2 = **0.3** kNm

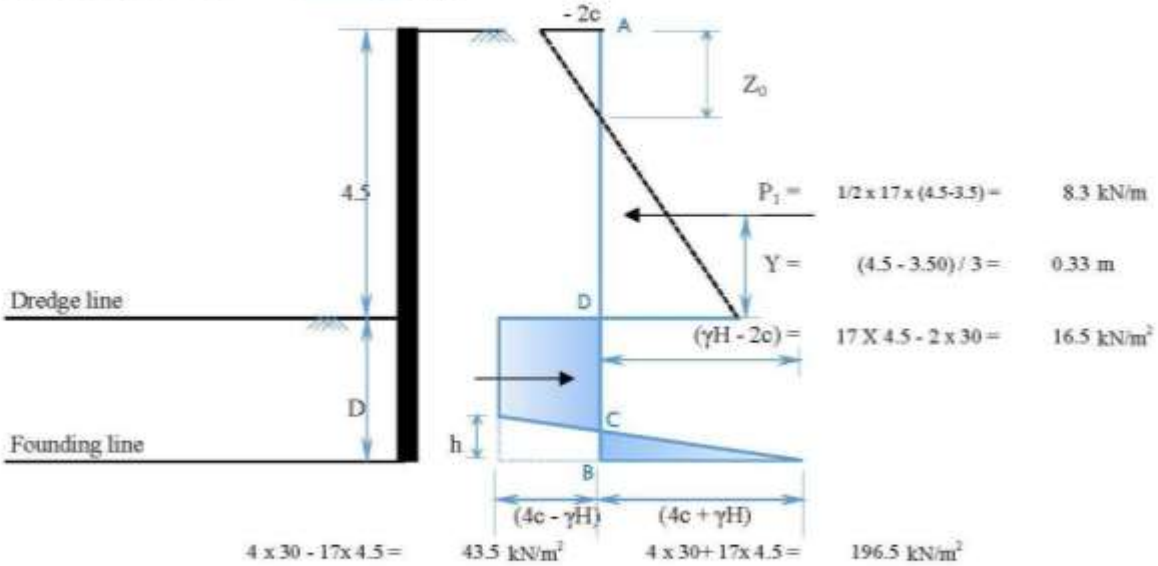
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
0.25	**0.3**	**3.5**	**0.06**

- **Sheet Pile Calculation with Soil Properties; $\gamma = 17\ kN/m^3$ & $C = 30\ kN/m^2$**

When Retaining height = 4.5 m :-

Design Criteria :

Soil Retaining Height, H =	**4.5**	m
Cohesion of Soil, C =	**30**	kN/m^2
Bulk Density of Soil, γ =	**17**	kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma$ = 2 x 30 / 17 = **3.50** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 8.25 + 1/2 x (43.50 + 196.50) x h = 43.50 x D

=> h = (43.50 D - 8.25) / 120.00

=> h = 0.1671

To find **D, ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (43.50 + 196.50) x h x h/3 = 43.50 x D x D/2

=> 8.25 x (0.33 + D) + 1/2 x 240 x h^2/3 = 21.75 D^2

=> 2.72 + 8.25 x D + 40.00 x ((43.5 x D - 8.25) / 120)^2 = 21.75 x D^2

=> 2.72 + 8.25 x D + 0.0028 x (43.5 x D - 8.25)^2 = 21.75 x D^2

=> $-16.494\ D^2 + 6.25625\ D + 2.91156 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -16.5

b = 6.3

c = 2.9

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = -0.3 or 0.7

D = 0.7 m

Taking D by 40% for FOS = 2, D = 0.65 x 1.4 = **0.91** m

Max. Bending Moment act at the height, z' below Dredge line = P_1 / ρ_2 = 8.25 / 43.5 = 0.20 m

Max. Bending Moment = 8.25 x (0.2 + 0.33) - (43.5 x 0.2^2)/2 = **3.5** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
0.91	**3.5**	**3.5**	**0.17**

- <u>**Sheet Pile Calculation with Soil Properties; $\gamma = 17\ kN/m^3$ & $C = 30\ kN/m^2$**</u>

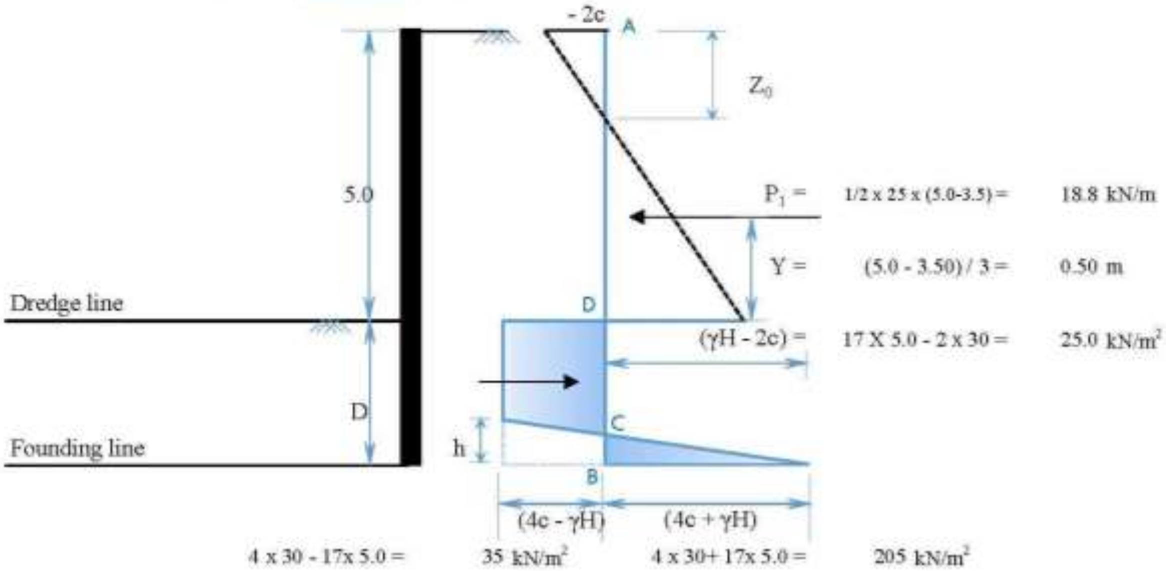
When Retaining height = 5.0 m :-

Design Criteria :

Soil Retaining Height, H = **5.0** m

Cohesion of Soil, C = **30** kN/m^2

Bulk Density of Soil, γ = **17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma$ = 2 x 30 / 17 = **3.50** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 18.75 + 1/2 x (35.00 + 205.00) x h = 35.00 x D

=> h = (35.00 D - 18.75) / 120.00

=> h = 0.29475

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (35.00 + 205.00) x h x h/3 = 35.00 x D x D/2

=> 18.75 x (0.50 + D) + 1/2 x 240 x h^2/3 = 17.5 D^2

=> 9.38 + 18.75 x D + 40.00 x ((35 x D - 18.75) / 120)^2 = 17.5 x D^2

=> 9.38 + 18.75 x D + 0.0028 x (35 x D - 18.75)^2 = 17.5 x D^2

=> $-14.097\ D^2 + 15.1042\ D + 10.3516 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -14.1

b = 15.1

c = 10.4

$x = D = (-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = -0.5 or 1.5

D = 1.5 m

Taking D by 40% for FOS = 2, D = 1.55 x 1.4 = **2.17** m

Max. Bending Moment act at the height, z' below Dredge line = P_1 / ρ_2 = 18.75 / 35 = 0.50 m

Max. Bending Moment = 18.75 x (0.5 + 0.5) - (35 x 0.5^2)/2 = **14.4** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
2.17	**14.4**	**3.5**	**0.29**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m^3 & C = 30 kN/m^2**

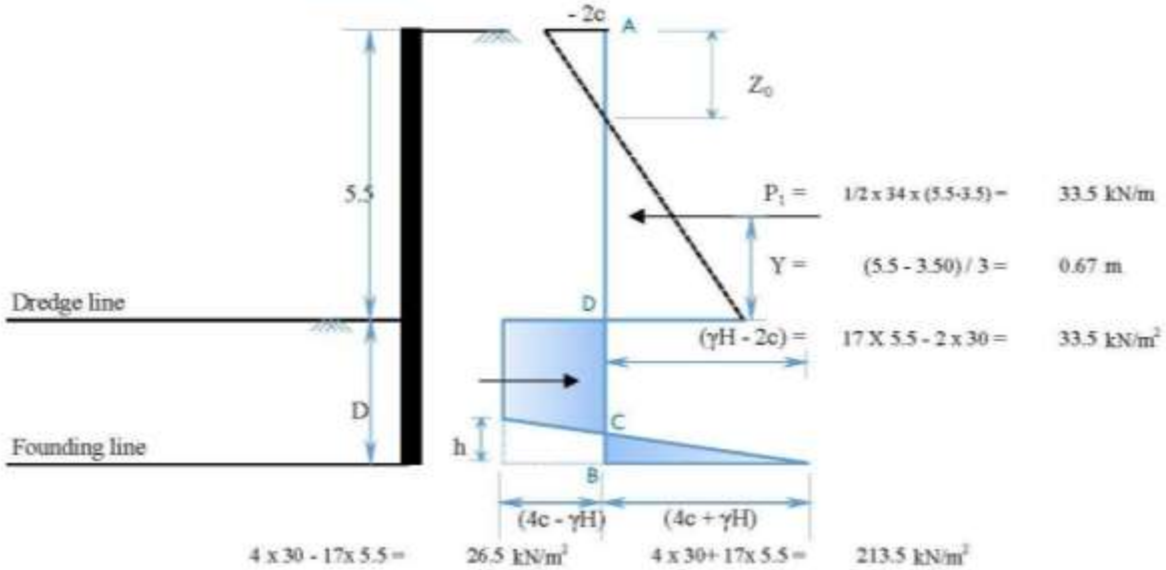
When Retaining height = 5.5 m :-

Design Criteria :

Soil Retaining Height, H = **5.5** m

Cohesion of Soil, C = **30** kN/m^2

Bulk Density of Soil, γ = **17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 30 / 17 = **3.50** m

To find **h**, sum of all Horizontal forces equals to zero, **($\Sigma H = 0$)**

=> 33.50 + 1/2 x (26.50 + 213.50) x h = 26.50 x D

=> h = (26.50 D - 33.50) / 120.00

=> h = 0.43389

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (26.50 + 213.50) x h x h/3 = 26.50 x D x D/2

=> 33.5 x (0.67 + D) + 1/2 x 240 x h^2/3 = 13.25 D^2

=> 22.45 + 33.5 x D + 40.00 x ((26.5 x D - 33.5) / 120)^2 = 13.25 x D^2

=> 22.45 + 33.5 x D + 0.0028 x (26.5 x D - 33.5)^2 = 13.25 x D^2

=> $-11.299\ D^2 + 28.5681\ D + 25.5624 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -11.3

b = 28.6

c = 25.6

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.7 or 3.2

D = 3.2 m

Taking D by 40% for FOS = 2, D = 3.23 x 1.4 = **4.52** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 33.5 / 26.5 = 1.30 m

Max. Bending Moment = 33.5 x (1.3 + 0.67) - (26.5 x 1.3^2)/2 = **43.6** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
4.52	**43.6**	**3.5**	**0.43**

- **Sheet Pile Calculation with Soil Properties; $\gamma = 17\ kN/m^3$ & $C = 30\ kN/m^2$**

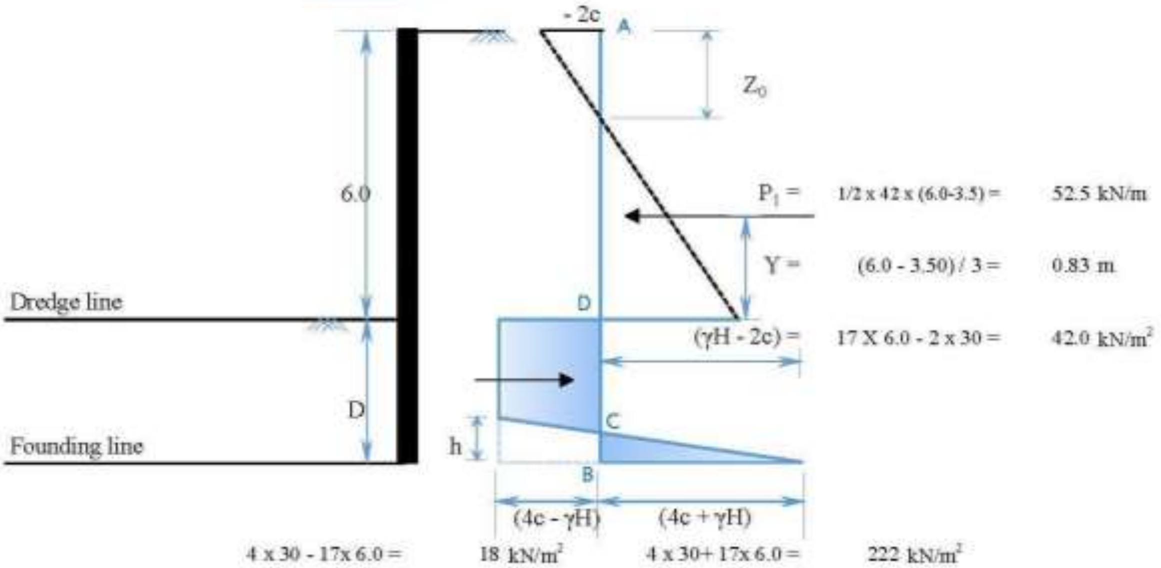
When Retaining height = 6.0 m :-

Design Criteria :

Soil Retaining Height, H = **6.0** m

Cohesion of Soil, C = **30** kN/m^2

Bulk Density of Soil, γ = **17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma$ = 2 x 30 / 17 = **3.50** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 52.50 + 1/2 x (18.00 + 222.00) x h = 18.00 x D

=> h = (18.00 D - 52.50) / 120.00

=> h = 0.57768

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (18.00 + 222.00) x h x h/3 = 18.00 x D x D/2

=> 52.5 x (0.83 + D) + 1/2 x 240 x h^2/3 = 9 D^2

=> 43.58 + 52.5 x D + 40.00 x ((18 x D - 52.5) / 120)^2 = 9 x D^2

=> 43.58 + 52.5 x D + 0.0028 x (18 x D - 52.5)^2 = 9 x D^2

=> -8.1 D^2 + 47.25 D + 51.2313 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -8.1

b = 47.3

c = 51.2

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = -0.9 or 6.8

D = 6.8 m

Taking D by 40% for FOS = 2, D = 6.77 x 1.4 = **9.48** m

Max. Bending Moment act at the height, z' below Dredge line = P_1 / ρ_2 = 52.5 / 18 = 2.90 m

Max. Bending Moment = 52.5 x (2.9 + 0.83) - (18 x 2.9^2)/2 = **120.1** kNm

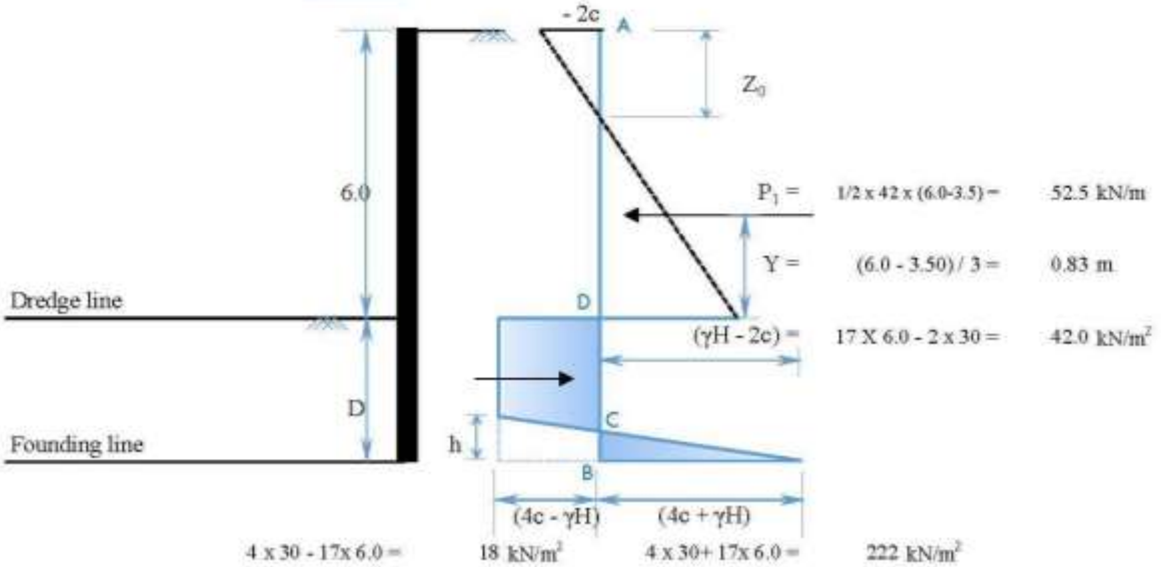
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
9.48	**120.1**	**3.5**	**0.58**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m^3 & C = 30 kN/m^2**

When Retaining height = 6.0 m :-

Design Criteria :

Soil Retaining Height, H =	**6.0** m
Cohesion of Soil, C =	**30** kN/m²
Bulk Density of Soil, γ =	**17** kN/m³



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 30 / 17 = **3.50** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 52.50 + 1/2 x (18.00 + 222.00) x h = 18.00 x D

=> h = (18.00 D - 52.50) / 120.00

=> h = 0.57768

To find **D, ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (18.00 + 222.00) x h x h/3 = 18.00 x D x D/2

=> 52.5 x (0.83 + D) + 1/2 x 240 x h^2/3 = 9 D^2

=> 43.58 + 52.5 x D + 40.00 x ((18 x D - 52.5) / 120)^2 = 9 x D^2

=> 43.58 + 52.5 x D + 0.0028 x (18 x D - 52.5)^2 = 9 x D^2

=> $-8.1\ D^2$ + 47.25 D + 51.2313 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -8.1

b = 47.3

c = 51.2

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.9 or 6.8

D = 6.8 m

Taking D by 40% for FOS = 2, D = 6.77 x 1.4 = **9.48** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 52.5 / 18 = 2.90 m

Max. Bending Moment = 52.5 x (2.9 + 0.83) - (18 x 2.9^2)/2 = **120.1** kNm

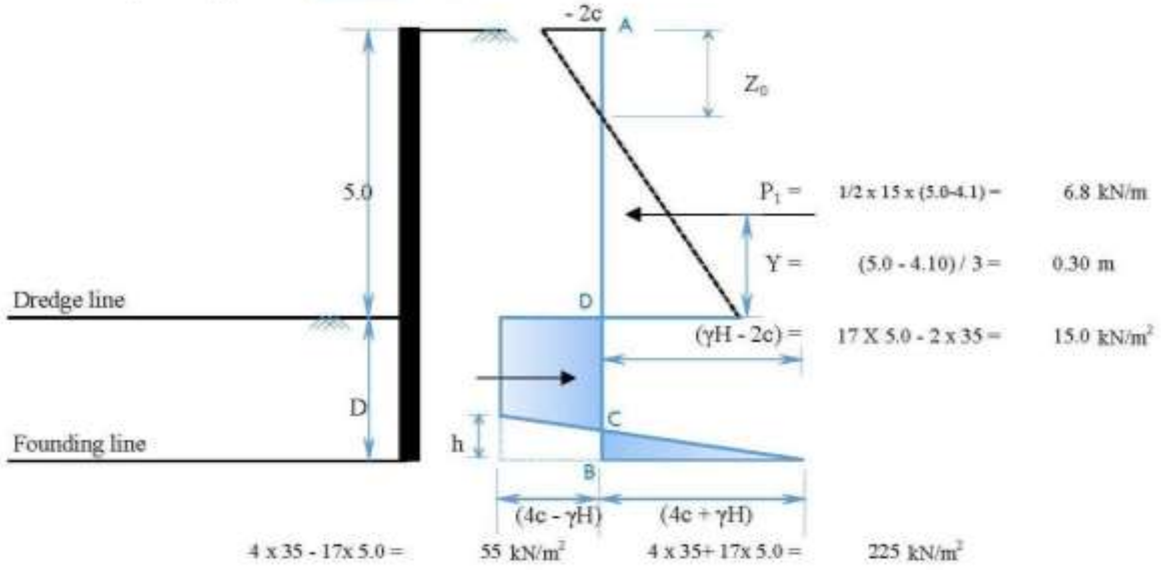
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
9.48	**120.1**	**3.5**	**0.58**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 35 kN/m²**

When Retaining height = 5.0 m :-

Design Criteria :

Soil Retaining Height, H =	**5.0**	m
Cohesion of Soil, C =	**35**	kN/m^2
Bulk Density of Soil, γ =	**17**	kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 35 / 17 = **4.10** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 6.75 + 1/2 x (55.00 + 225.00) x h = 55.00 x D

=> h = (55.00 D - 6.75) / 140.00

=> h = 0.13619

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (55.00 + 225.00) x h x h/3 = 55.00 x D x D/2

=> 6.75 x (0.30 + D) + 1/2 x 280 x h^2/3 = 27.5 D^2

=> 2.03 + 6.75 x D + 46.67 x ((55 x D - 6.75) / 140)^2 = 27.5 x D^2

=> 2.03 + 6.75 x D + 0.0024 x (55 x D - 6.75)^2 = 27.5 x D^2

=> $-20.298\ D^2$ + 4.98214 D + 2.13348 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -20.3

b = 5.0

c = 2.1

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.2 or 0.5

D = 0.5 m

Taking D by 40% for FOS = 2, D = 0.47 x 1.4 = **0.66** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 6.75 / 55 = 0.10 m

Max. Bending Moment = 6.75 x (0.1 + 0.3) - (55 x 0.1^2)/2 = **2.4** kNm

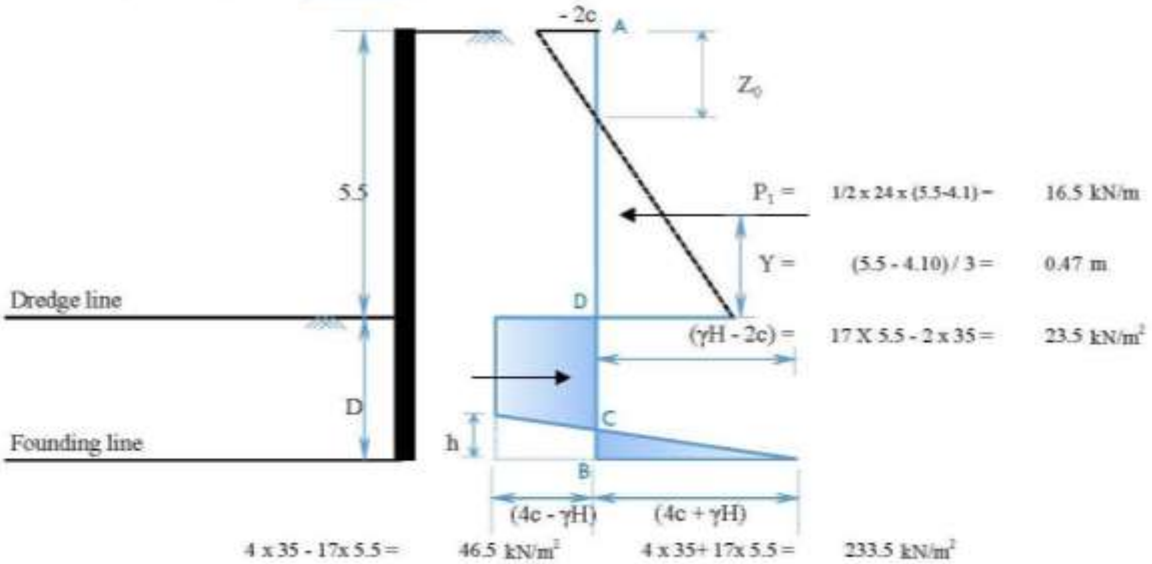
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
0.66	**2.4**	**4.1**	**0.14**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m^3 & C = 35 kN/m^2**

When Retaining height = 5.5 m :-

Design Criteria :

Soil Retaining Height, H =	**5.5** m
Cohesion of Soil, C =	**35** kN/m²
Bulk Density of Soil, γ =	**17** kN/m³



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 35 / 17 = **4.10** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 16.45 + 1/2 x (46.50 + 233.50) x h = 46.50 x D

=> h = (46.50 D - 16.45) / 140.00

=> h = 0.25466

To find **D**, **ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (46.50 + 233.50) x h x h/3 = 46.50 x D x D/2

=> 16.45 x (0.47 + D) + 1/2 x 280 x h^2/3 = 23.25 D^2

=> 7.73 + 16.45 x D + 46.67 x ((46.5 x D - 16.45) / 140)^2 = 23.25 x D^2

=> 7.73 + 16.45 x D + 0.0024 x (46.5 x D - 16.45)^2 = 23.25 x D^2

=> $-18.102\ D^2 + 12.8075\ D + 8.37579 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -18.1

b = 12.8

c = 8.4

$x = D = (-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.4 or 1.1

D = 1.1 m

Taking D by 40% for FOS = 2, D = 1.12 x 1.4 = **1.57** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 16.45 / 46.5 = 0.40 m

Max. Bending Moment = 16.45 x (0.4 + 0.47) - (46.5 x 0.4^2)/2 = **10.6** kNm

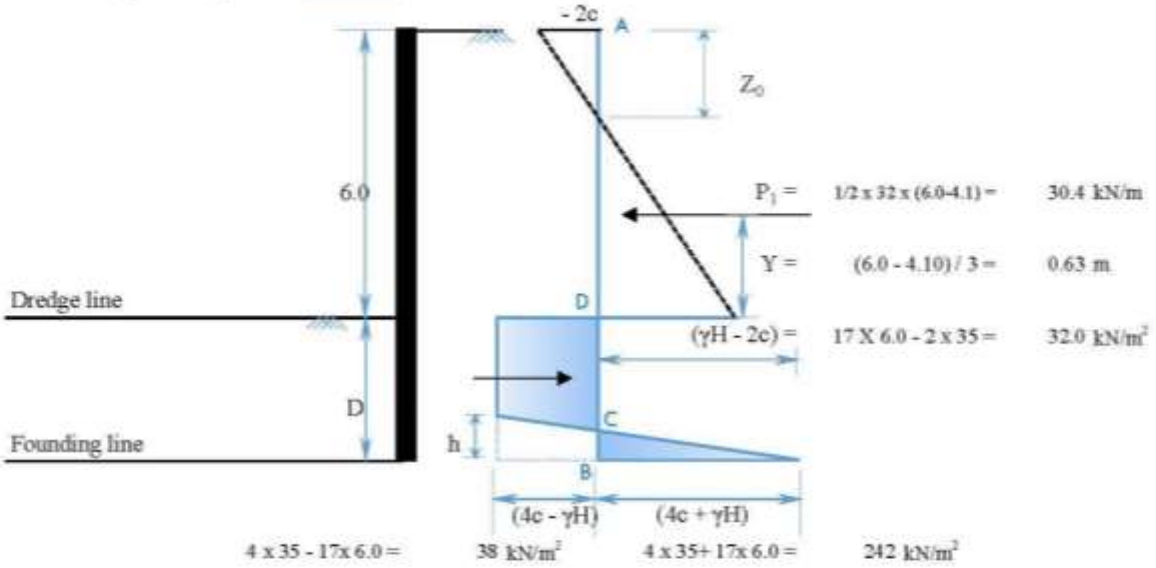
Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
1.57	**10.6**	**4.1**	**0.25**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m³ & C = 35 kN/m²**

When Retaining height = 6.0 m :-

Design Criteria :

Soil Retaining Height, H =	**6.0** m
Cohesion of Soil, C =	**35** kN/m^2
Bulk Density of Soil, γ =	**17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma$ = 2 x 35 / 17 = **4.10** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 30.40 + 1/2 x (38.00 + 242.00) x h = 38.00 x D

=> h = (38.00 D - 30.40) / 140.00

=> h = 0.38502

To find **D, ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (38.00 + 242.00) x h x h/3 = 38.00 x D x D/2

=> 30.4 x (0.63 + D) + 1/2 x 280 x h^2/3 = 19 D^2

=> 19.15 + 30.4 x D + 46.67 x ((38 x D - 30.4) / 140)^2 = 19 x D^2

=> 19.15 + 30.4 x D + 0.0024 x (38 x D - 30.4)^2 = 19 x D^2

=> -15.562 D^2 + 24.899 D + 21.3524 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -15.6

b = 24.9

c = 21.4

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = -0.6 or 2.2

D = 2.2 m

Taking D by 40% for FOS = 2, D = 2.22 x 1.4 = **3.11** m

Max. Bending Moment act at the height, z' below Dredge line = P_1 / ρ_2 = 30.4 / 38 = 0.80 m

Max. Bending Moment = 30.4 x (0.8 + 0.63) - (38 x 0.8^2)/2 = **31.3** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
3.11	**31.3**	**4.1**	**0.39**

- **Sheet Pile Calculation with Soil Properties; γ = 17 kN/m^3 & C = 35 kN/m^2**

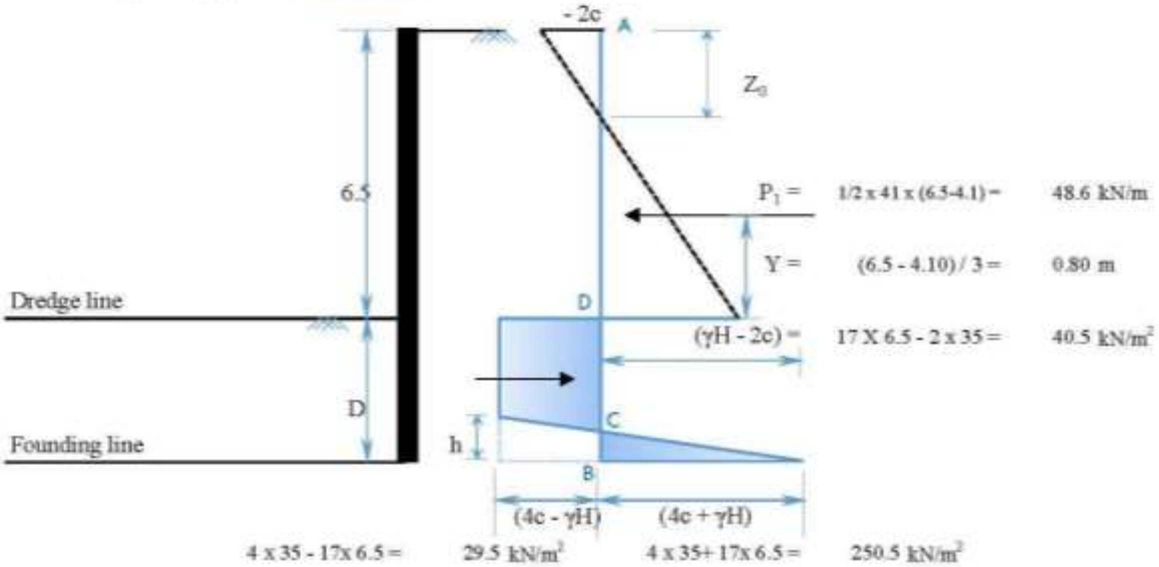
When Retaining height = 6.5 m :-

Design Criteria :

Soil Retaining Height, H = **6.5** m

Cohesion of Soil, C = **35** kN/m^2

Bulk Density of Soil, γ = **17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma =$ 2 x 35 / 17 = **4.10** m

To find **h,** sum of all Horizontal forces equals to zero, **($\Sigma H = 0$)**

=> 48.60 + 1/2 x (29.50 + 250.50) x h = 29.50 x D

=> h = (29.50 D - 48.60) / 140.00

=> h = 0.52571

To find **D, ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (29.50 + 250.50) x h x h/3 = 29.50 x D x D/2

=> 48.6 x (0.80 + D) + 1/2 x 280 x h^2/3 = 14.75 D^2

=> 38.88 + 48.6 x D + 46.67 x ((29.5 x D - 48.6) / 140)^2 = 14.75 x D^2

=> 38.88 + 48.6 x D + 0.0024 x (29.5 x D - 48.6)^2 = 14.75 x D^2

=> $-12.678\ D^2 + 41.7729\ D + 44.5037 = 0$

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -12.7

b = 41.8

c = 44.5

$x = D = (-b \pm \sqrt{(b^2 - 4ac)}) / 2a =$ -0.8 or 4.1

D = 4.1 m

Taking D by 40% for FOS = 2, D = 4.14 x 1.4 = **5.80** m

Max. Bending Moment act at the height, z' below Dredge line = $P_1 / \rho_2 =$ 48.6 / 29.5 = 1.60 m

Max. Bending Moment = 48.6 x (1.6 + 0.8) - (29.5 x 1.6^2)/2 = **78.9** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
5.80	**78.9**	**4.1**	**0.53**

- **Sheet Pile Calculation with Soil Properties; $\gamma = 17\ kN/m^3$ & $C = 35\ kN/m^2$**

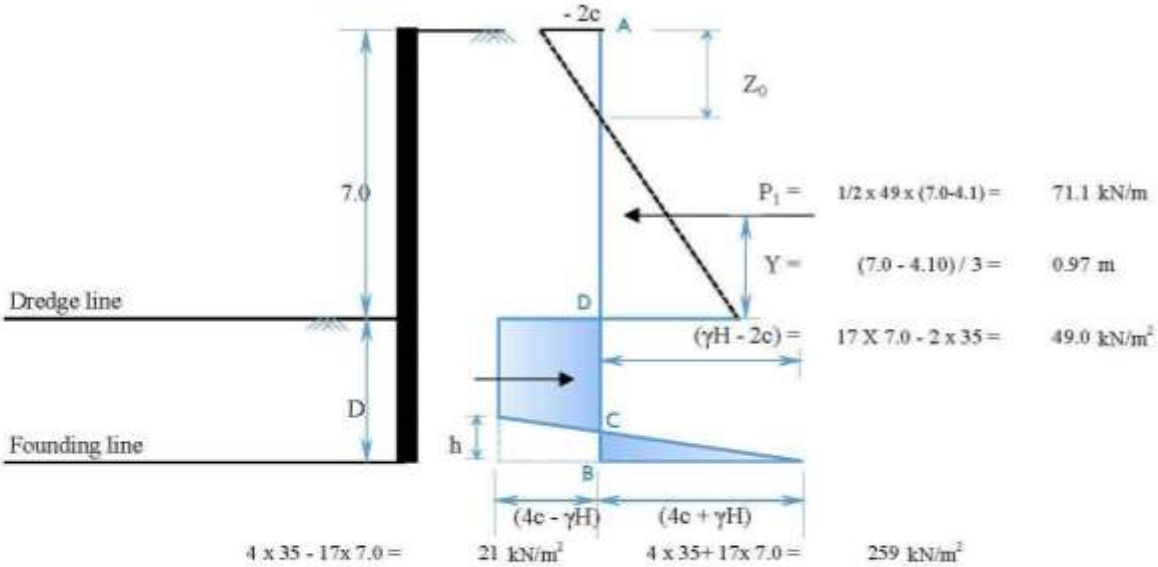
When Retaining height = 7.0 m :-

Design Criteria :

Soil Retaining Height, H = **7.0** m

Cohesion of Soil, C = **35** kN/m^2

Bulk Density of Soil, γ = **17** kN/m^3



Height of point of zero pressure, $Z_0 = 2c/\gamma$ = 2 x 35 / 17 = **4.10** m

To find **h,** sum of all Horizontal forces equals to zero, **(ΣH = 0)**

=> 71.05 + 1/2 x (21.00 + 259.00) x h = 21.00 x D

=> h = (21.00 D - 71.05) / 140.00

=> h = 0.67102

To find **D, ΣM @ base = 0**

=> P1 (y + D) + 1/2 x (21.00 + 259.00) x h x h/3 = 21.00 x D x D/2

=> 71.05 x (0.97 + D) + 1/2 x 280 x h^2/3 = 10.5 D^2

=> 68.92 + 71.05 x D + 46.67 x ((21 x D - 71.05) / 140)^2 = 10.5 x D^2

=> 68.92 + 71.05 x D + 0.0024 x (21 x D - 71.05)^2 = 10.5 x D^2

=> -9.45 D^2 + 63.945 D + 80.9378 = 0

=> for value D, let compare with equation, $ax^2 + bx + c = 0$

a = -9.5

b = 63.9

c = 80.9

x = D = $(-b \pm \sqrt{(b^2 - 4ac)}) / 2a$ = -1.1 or 7.9

D = 7.9 m

Taking D by 40% for FOS = 2, D = 7.86 x 1.4 = **11.00** m

Max. Bending Moment act at the height, z below Dredge line = P_1 / ρ_2 = 71.05 / 21 = 3.40 m

Max. Bending Moment = 71.05 x (3.4 + 0.97) - (21 x 3.4^2)/2 = **189.1** kNm

Summary			
Em Depth	**BM**	**Z_0**	**h**
m	kNm	m	m
11.00	**189.1**	**4.1**	**0.67**

5.5 RESULTS OF LIMIT EQUILIBRIUM METHOD

Table 5.1: Results of Limit Equilibrium Method

Wall Height (m)	Cohesion of Soil (Cu) (kN/m^2)	Critical Height (m)	Embedment Depth (m)	Bending Moment (kN-m)
3.0	25	2.9	0.02	0.0
3.5		2.9	0.40	0.7
4.0		2.9	1.33	5.2
4.5		2.9	3.29	20.8
5.0		2.9	7.96	70.7
4.0	30	3.5	0.25	0.3
4.5		3.5	0.91	3.5
5.0		3.5	2.17	14.4
5.5		3.5	4.52	43.6
6.0		3.5	9.48	120.1
5.0	35	4.1	0.66	2.4
5.5		4.1	1.57	10.6
6.0		4.1	3.11	31.3
6.5		4.1	5.80	78.9
7.0		4.1	11.00	189.1

From the above table it is observed that for retaining wall height of 3 to 5 meters with a soil cohesion of 25 kN/m^2, the embedment depth and bending moment increase significantly, reflecting greater structural requirements to maintain stability. When the cohesion is 30 kN/m^2 and heights range from 4 to 6 meters, a similar trend is observed. At the highest cohesion of 35 kN/m^2, with retaining heights from 5 to 7 meters, the bending moment exhibit a sharp rise,

CHAPTER - 6

NUMERICAL METHOD (FEM)

6.1 OVERVIEW

In this chapter, we employ *PLAXIS* 2D software (Connect Edition). for a comprehensive analysis using the Finite Element Method (FEM) to determine the maximum bending moments of sheet piles subjected to various retaining heights and cohesive soil properties. By inputting parameters such as soil cohesion, and sheet pile geometry & Material Properties into *PLAXIS* 2D, we simulate the interaction between the soil and sheet pile to obtain precise bending moment values. Additionally, we incorporate the embedment lengths derived from manual calculations using the Limit Equilibrium Method (LEM) to assess their impact on the structural performance of the sheet piles. This dual approach of FEM analysis in *PLAXIS* 2D, combined with LEM-derived embedment lengths, provides a robust framework for understanding the behavior of sheet piles under different geotechnical conditions and ensures accurate and reliable design outcomes.

6.2 ABOUT *PLAXIS* 2D SOFTWARE FOR ANALYSIS OF SHEET PILE

PLAXIS 2D is a specialized finite element software designed for the analysis of geotechnical engineering problems, including the behaviour of sheet piles. Utilizing a user-friendly graphical interface, *PLAXIS* 2D allows for detailed modelling of soil-structure interactions, taking into account complex soil behaviour and structural responses. The software's advanced computational capabilities enable it to simulate the performance of sheet piles under various loading conditions and soil properties, making it an invaluable tool for engineers.

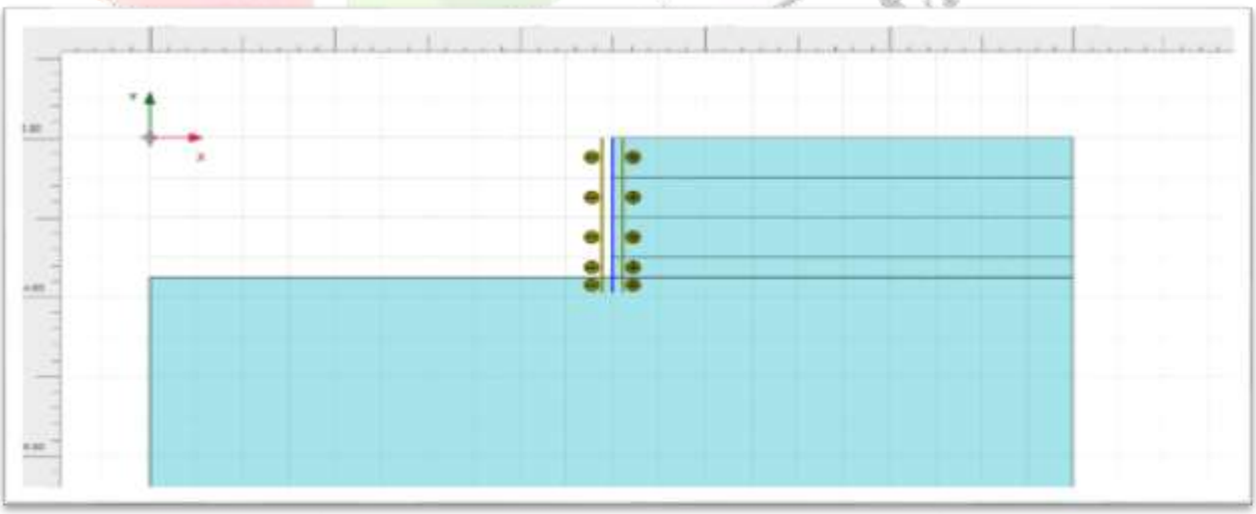


Figure 6.1: shows Sheet Pile Analysis in Plaxis 2D Software

For the analysis of sheet piles, *PLAXIS* 2D provides a range of features including the ability to define soil layers with different properties, model the construction sequence, and apply various types of loads and boundary conditions. The software can accurately calculate key parameters such as bending moments, shear forces, and displacements, helping engineers design safe and efficient sheet pile walls. The results obtained from

PLAXIS 2D are crucial for understanding the structural integrity and stability of sheet piles in retaining structures, ensuring that they can withstand the forces exerted by the retained soil and any additional loads. By integrating FEM analysis in *PLAXIS* 2D with manual methods like the Limit Equilibrium Method (LEM), engineers can achieve a comprehensive understanding of sheet pile behavior, leading to more reliable and optimized designs.

6.3 DATA INPUT

- **Soil Properties: (Constant Data) -**

General > Material Set:

Identification : Clay

Drainage Type: Undrained (B)

General > General Properties:

γ_{unsat} : 17 kN/m^3

(Bulk Density of Soil)

γ_{sat} : 17 kN/m^3

(Saturates Density of Soil)

(As the water level is very much below, $\gamma_{unsat} = \gamma_{sat}$)

Parameters > Stiffness:

E' : 150 x 10^3 kN/m^2

ν' : 0.4

Parameters > Strength:

$S_{u,ref}$: 25 kN/m^2

(Cohesion of Soil, C)

Groundwater > Model:

Data Set : Standard

Groundwater > Soil:

Type : Very Fine

Figure 6.2: shows Plaxis Input of Soil Properties

Figure 6.3: shows Plaxis Input of Soil Parameters

Groundwater > Flow Parameters:

Use Defaults : From Grain Size Distribution

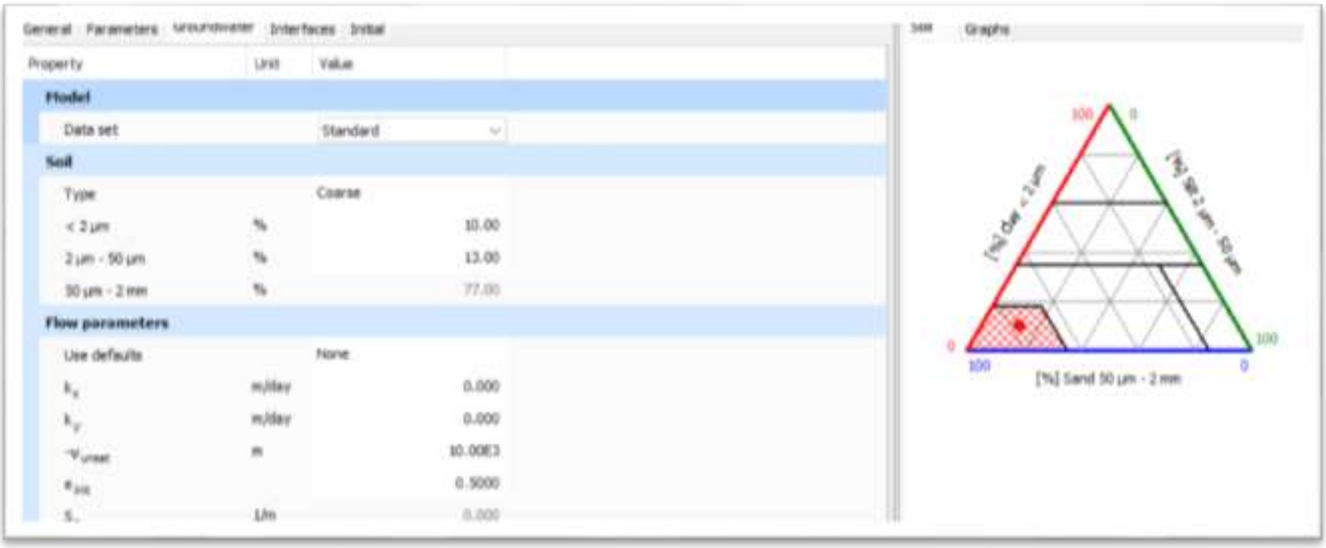


Figure 6.4: shows Plaxis Input of Soil Ground water

Interfaces > Strength:

Strength : Manual

R_{inter} : 0.67

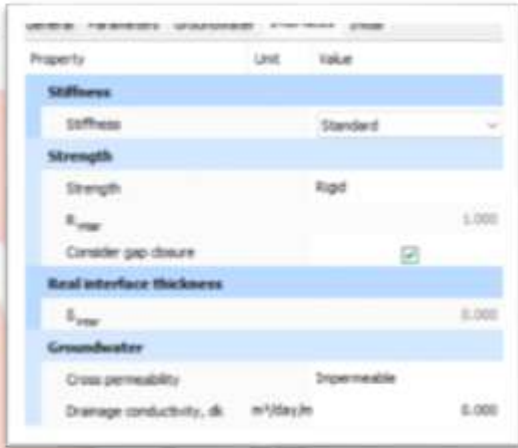


Figure 6.5: shows Plaxis Input of Soil

- **Plates Properties: (Constant Data) –**

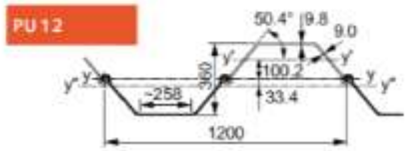
Taken Sheet Pile Section as

PU – 12 – 240

From *Arcelor Mittal Steel Foundation Solutions (General Catalogue 2019)*

Section	Width	Height	Thickness		Sectional area	Mass		Moment of inertia	Elastic section modulus	Static moment	Plastic section modulus	Class[1]						
	b mm	h mm	t mm	s mm	cm²/m	single pile kg/m	wall kg/m²	cm⁴/m	cm³/m	cm³/m	cm³/m	S 240 GP	S 270 GP	S 320 GP	S 355 GP	S 390 GP	S 430 GP	S 460 AP
PU® sections																		
PU 12	600	360	9.8	9.0	140	66.1	110	21600	1200	715	1457	-	-	-	2	2	2	3
PU 12S	600	360	10.0	10.0	151	71.0	118	22660	1260	755	1543	-	-	-	2	2	2	2

Figure 6.6: shows Section Properties of PU-12-240 Section



Section	S = Single pile D = Double pile T = Triple pile	Sectional area	Mass	Moment of inertia	Elastic section modulus	Radius of gyration	Coating area[1]
		cm²	kg/m	cm⁴	cm³	cm	m²/m
PU 12	Per S	84.2	66.1	4500	370	7.31	0.80
	Per D	168.4	132.2	25920	1440	12.41	1.59
	Per T	252.6	198.3	36060	1690	11.95	2.38
	Per m of wall	140.0	110.1	21600	1200	12.41	1.32

Figure 6.7: shows Section Dimension of PU-12-240 Section

General > Material Set:

Identification : PU – 12 – 240

Material Type : Elastic

General > Properties:

Check the Box of Isotropic

EA_1 : 294 $\times 10^4$ kN/m

EI : 45.36 $\times 10^3$ kN m^2/m

w : 1.101 kN/m/m

ν : 0.28

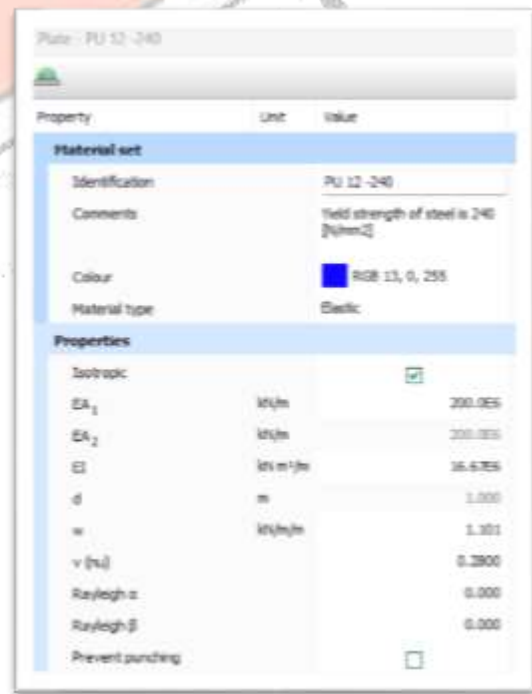


Figure 6.8: shows Plaxis Input of Plates Properties

6.4 LIST OF NUMERICAL CASES

Table 6.1: List of Numerical Cases.

Sl. No	Cu (kN/m²)	Wall Height (m)	Critical Height (m) Z = 2C/γ	Embedment Depth (m)
1	25	3.00	2.9	0.02
2		3.50		0.4
3		4.00		1.33
4		4.50		3.29
5		5.00		7.96
6	30	4.00	3.5	0.25
7		4.50		0.91
8		5.00		2.17
9		5.50		4.52
10		6.00		9.48
11	35	5.00	4.1	0.66
12		5.50		1.57
13		6.00		3.11
14		6.50		5.8
15		7.00		11

Above table shows the list of various cases which have been analysed in the PLAXIS 2D software. Input parameters such as wall height, cohesion of soil and embedment depth as found in manual calculation are fed into the software. The table further shows, three number different 'C' values are considered for analysis. For each C value case five number different wall heights are considered and analysed in the software. Therefore, total fifteen number cases are studied here.

6.5 RESULT OF *PLAXIS* 2D

- **Tabular Form**

Table 6.2: Result from PLAXIS 2D

Wall Height (m)	Cohesion of Soil (kN/m2)	Critical Height (m)	Embedment Depth (m)	Bending Moment (kN-m)
3.0	25	2.9	0.02	--
3.5		2.9	0.40	1.1
4.0		2.9	1.33	7.9
4.5		2.9	3.29	26.4
5.0		2.9	7.96	--
4.0	30	3.5	0.25	--
4.5		3.5	0.91	3.5
5.0		3.5	2.17	19.4
5.5		3.5	4.52	44.7
6.0		3.5	9.48	--
5.0	35	4.1	0.66	--
5.5		4.1	1.57	12.5
6.0		4.1	3.11	42.1
6.5		4.1	5.80	66.1
7.0		4.1	11.00	--

Table 6.2 presents results from PLAXIS 2D simulations for different wall heights (ranging from 3.0 m to 6.5 m), varying cohesion values of the soil (25 kN/m², 30 kN/m², and 35 kN/m²), and corresponding critical heights, embedment depths, and bending moments of sheet piles. Each row corresponds to a specific combination of wall height and soil cohesion, detailing the critical height where failure occurs, the embedment depth required for stability, and the maximum bending moment experienced by the sheet pile. Notably, some bending moments are not calculated ("--"), likely indicating conditions where stability is not achieved within the defined parameters. The table provides a comprehensive view of how different soil conditions and wall heights impact the design and stability considerations of sheet pile structures in cohesive soils, essential for engineering analysis and design decisions.

6.6 MAXIMUM BENDING MOMENT IN PLAXIS 2D

- **Retaining Height, h = 4.0 m & Cohesion of Soil, C = 25 kN/m2**

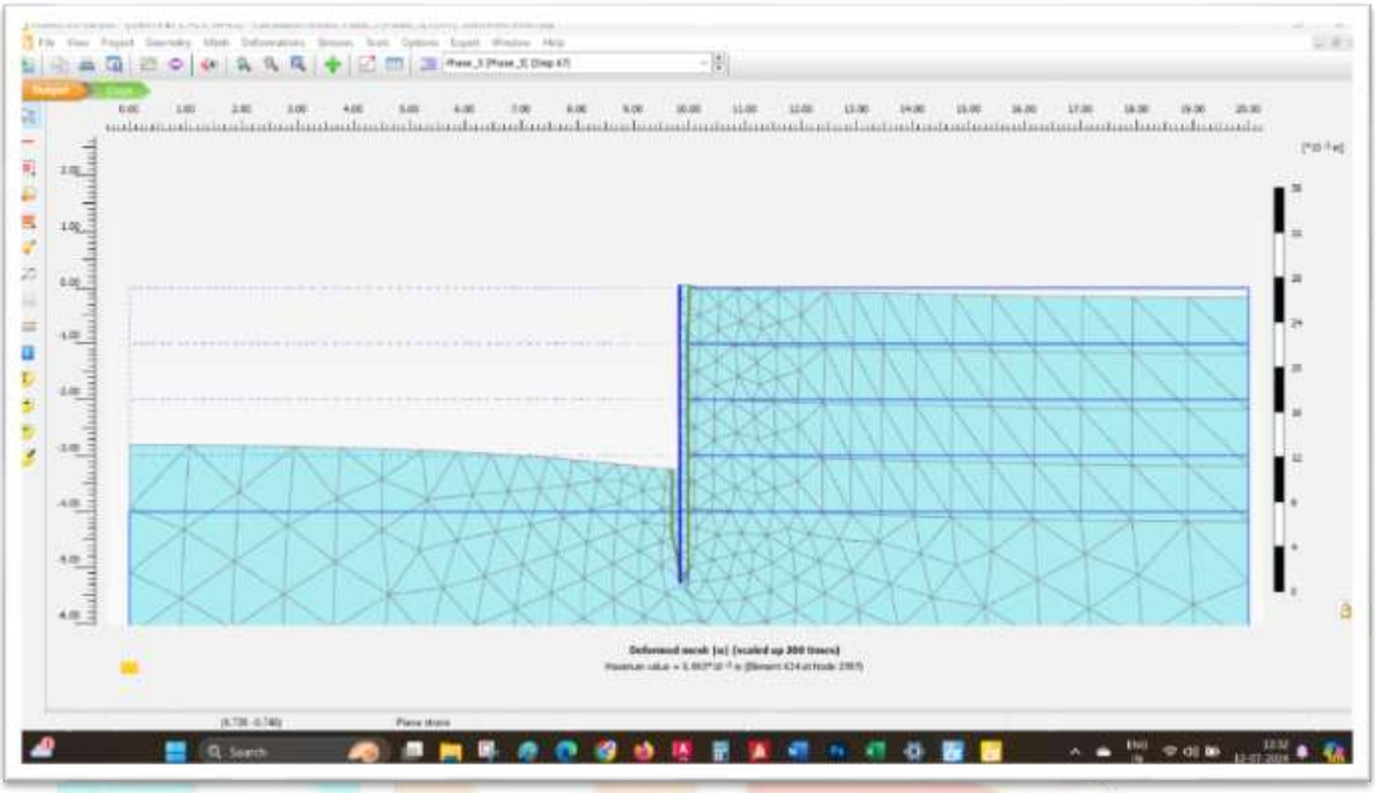


Figure 6.9: shows Mesh Deformation of Sheet Pile (H = 4.0 m & C = 25 kN/m²)

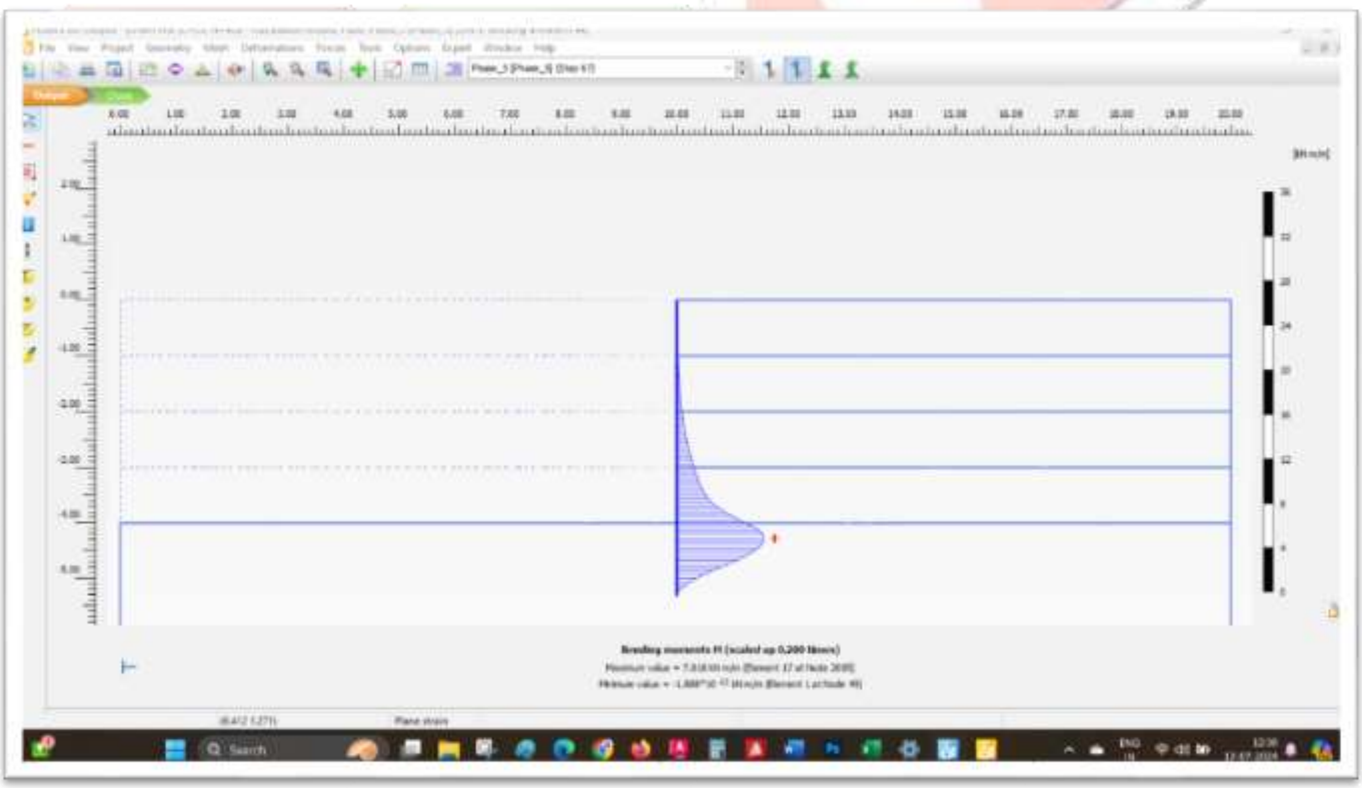


Figure 6.10: shows Bending Moment of Sheet Pile (H = 4.0 m & C = 25 kN/m²)

- **Retaining Height, h = 4.5 m & Cohesion of Soil, C = 25 kN/m2**

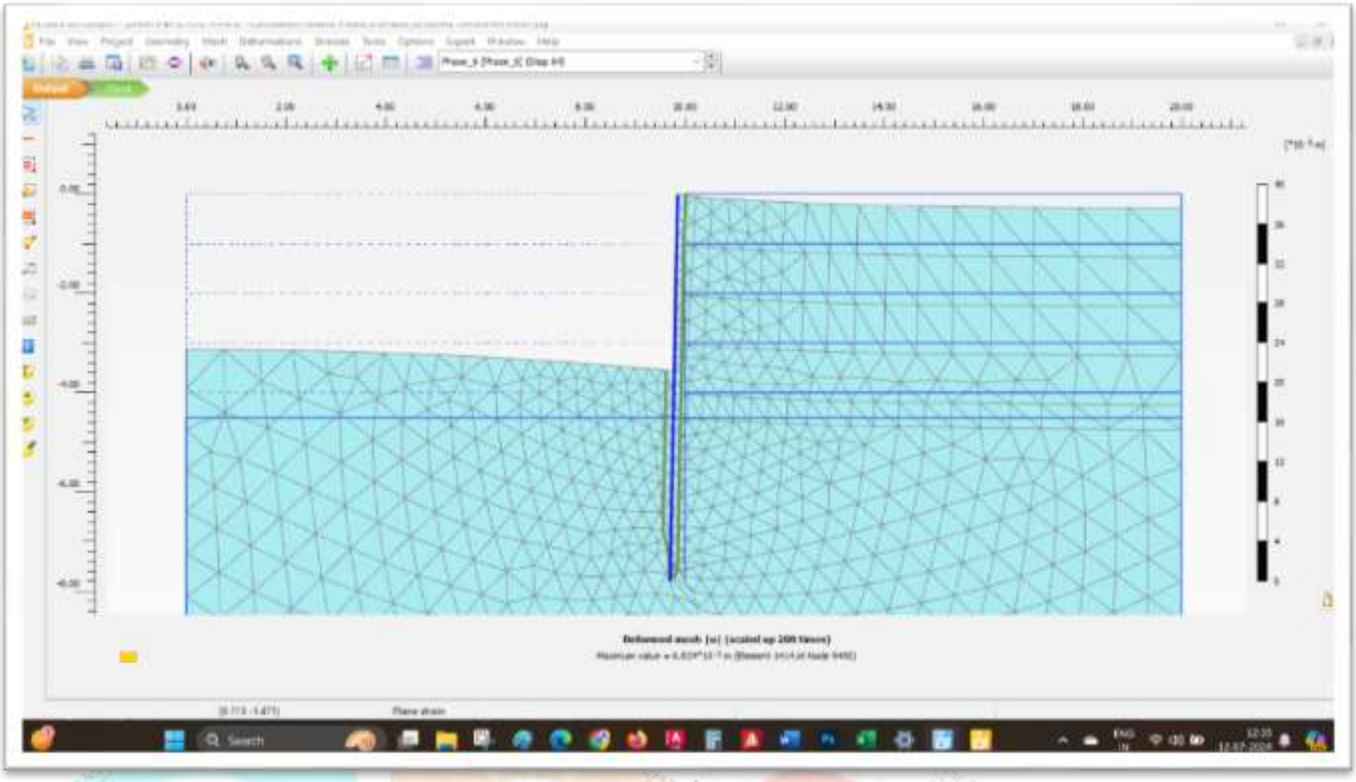


Figure 6.11: shows Mesh Deformation of Sheet Pile (H = 4.5 m & C = 25 kN/m²)

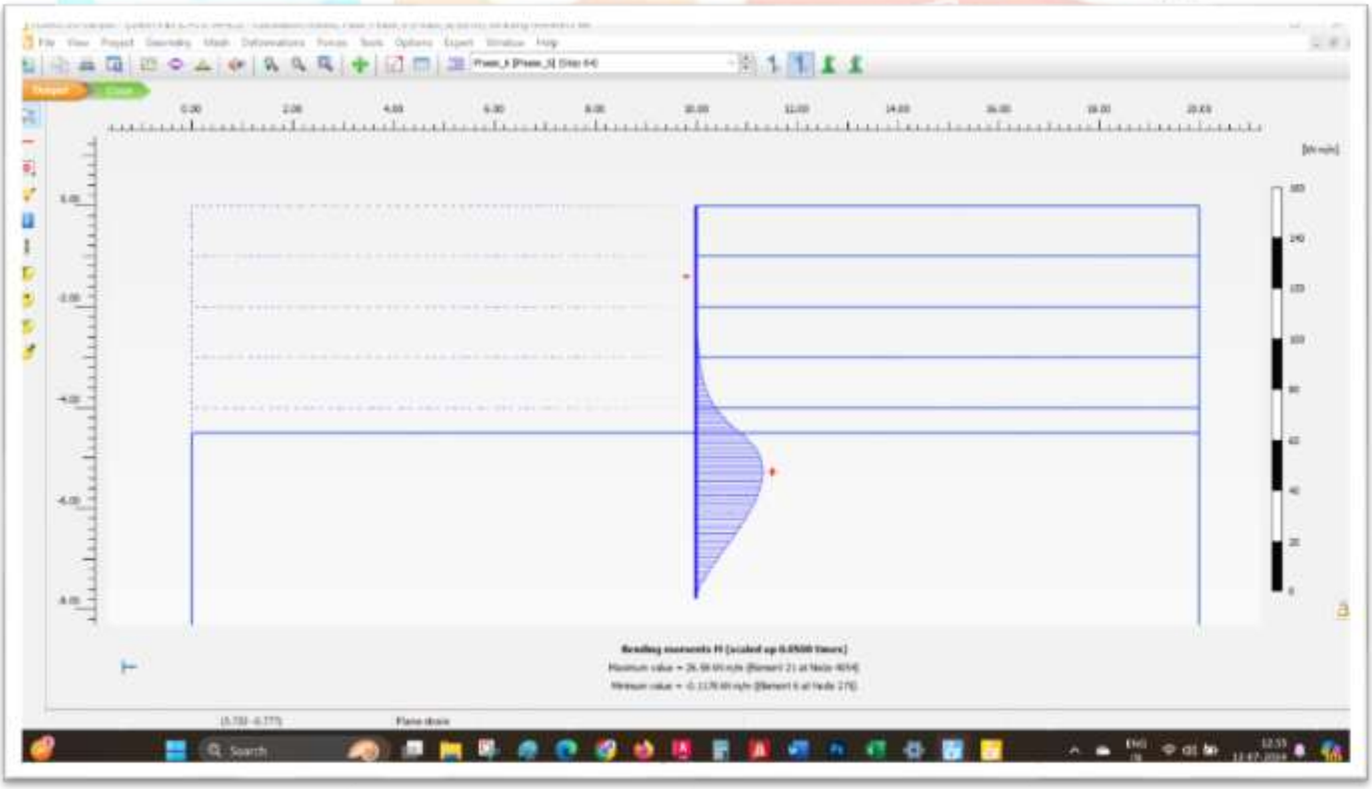


Figure 6.12: shows Bending Moment of Sheet Pile (H = 4.5 m & C = 25 kN/m²)

- **Retaining Height, h = 4.5 m & Cohesion of Soil, C = 30 kN/m²**

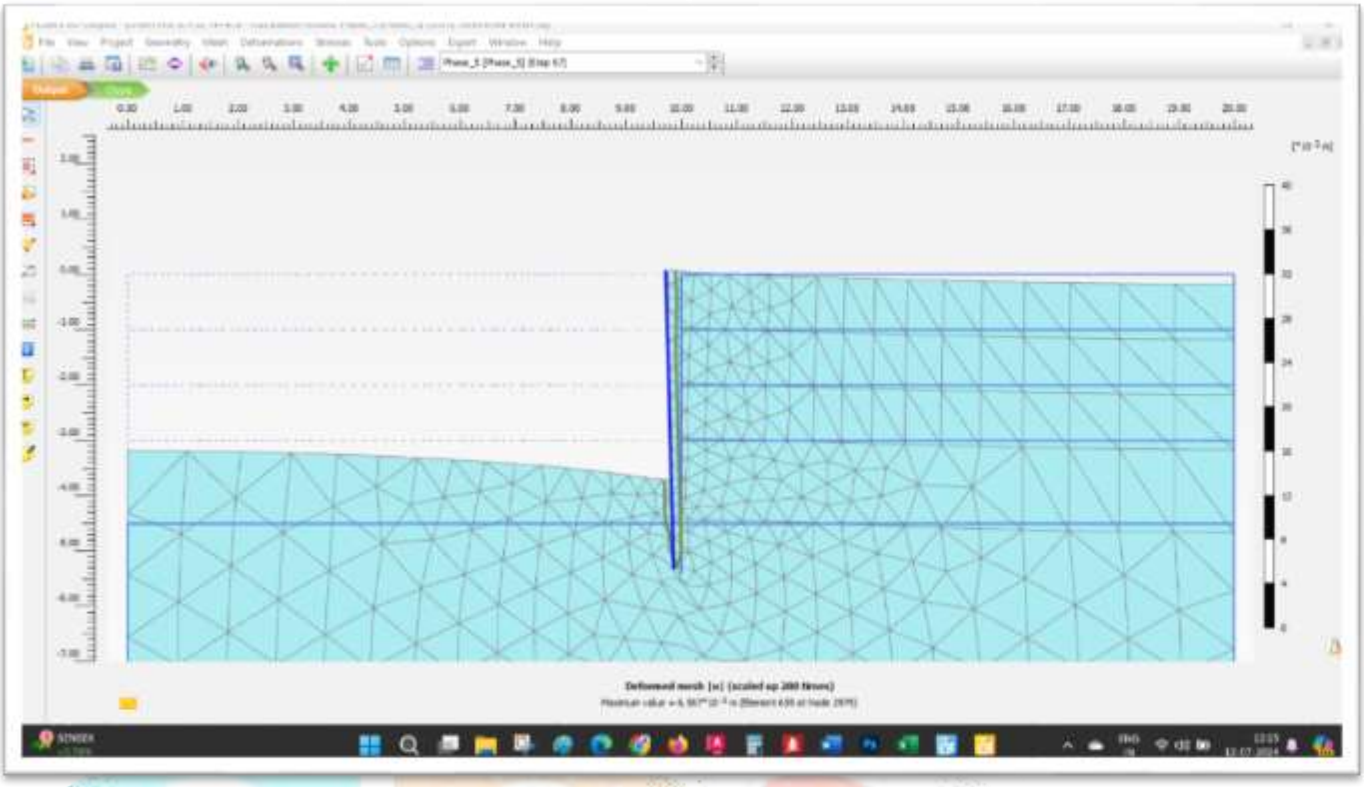


Figure 6.13: shows Mesh Deformation of Sheet Pile (H = 4.5 m & C = 30 kN/m²)

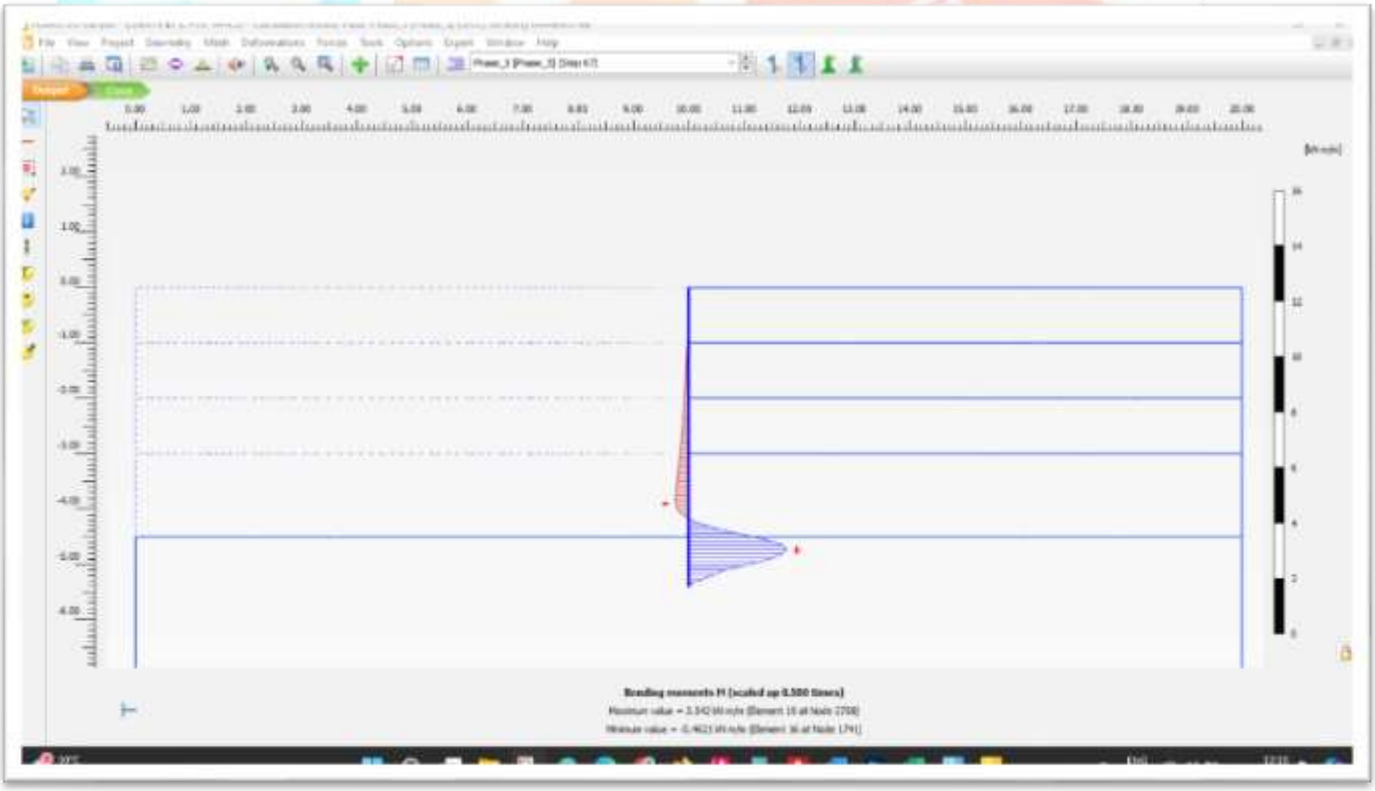


Figure 6.14: shows Bending Moment of Sheet Pile (H = 4.5 m & C = 30 kN/m²)

- **Retaining Height, h = 5.0 m & Cohesion of Soil, C = 30 kN/m^2**

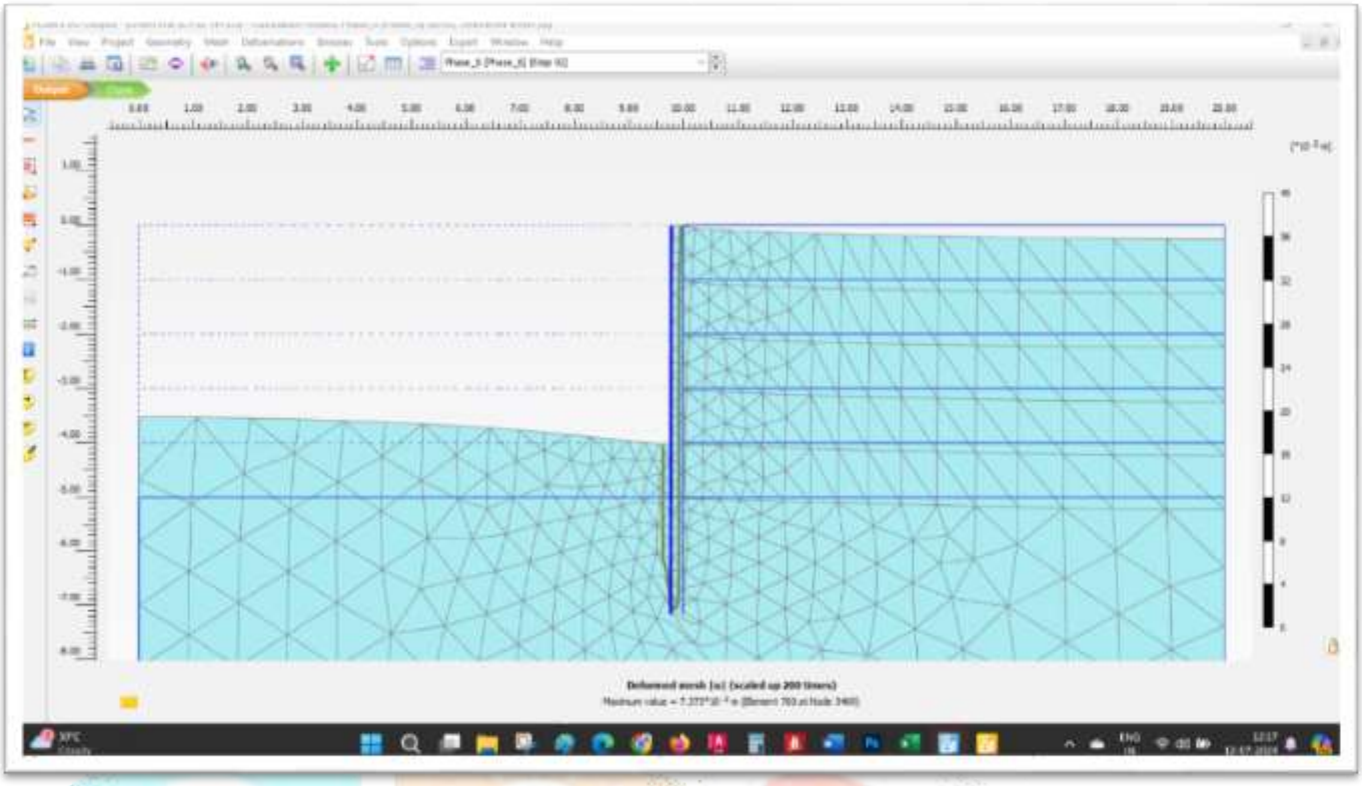


Figure 6.15: shows Mesh Deformation of Sheet Pile (H = 5.0 m & C = 30 kN/m^2)

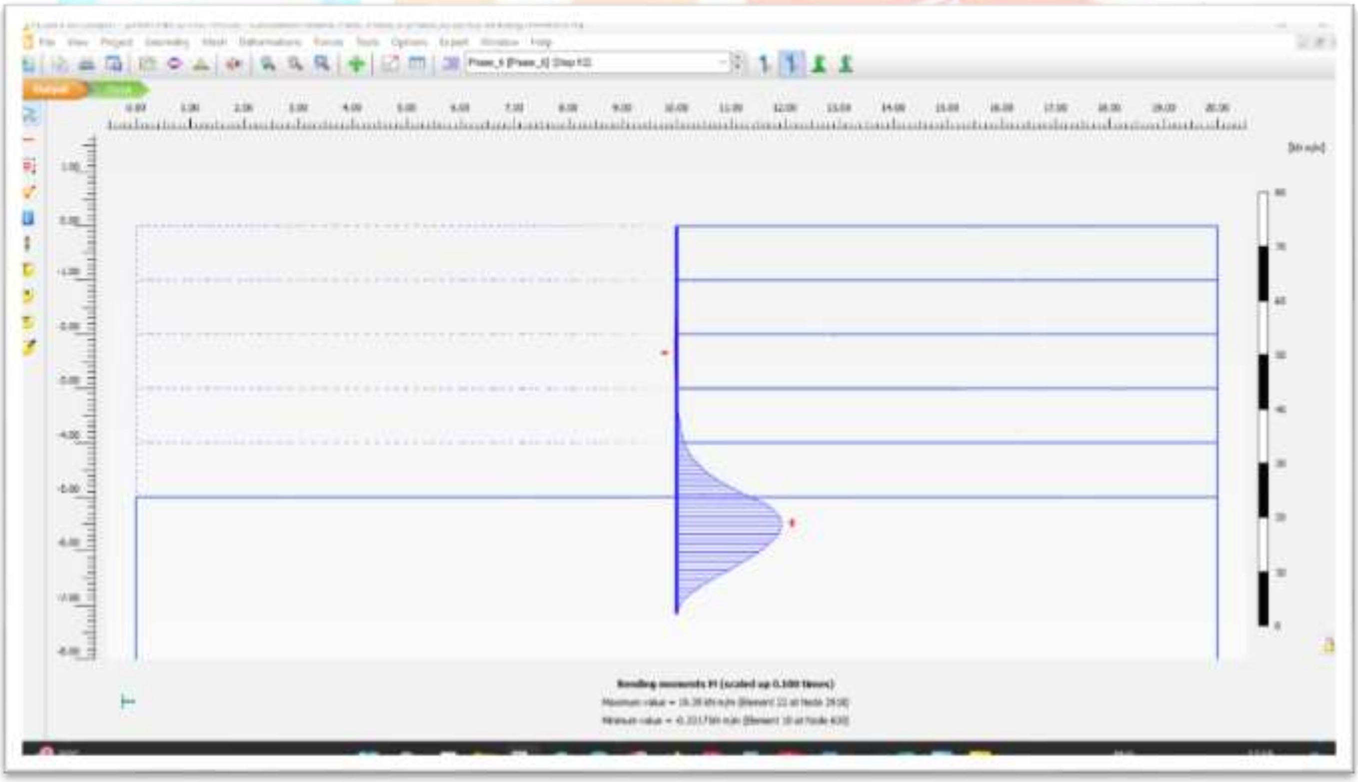


Figure 6.16: shows Bending Moment of Sheet Pile (H = 5.0 m & C = 30 kN/m^2)

- **Retaining Height, h = 5.5 m & Cohesion of Soil, C = 30 kN/m2**

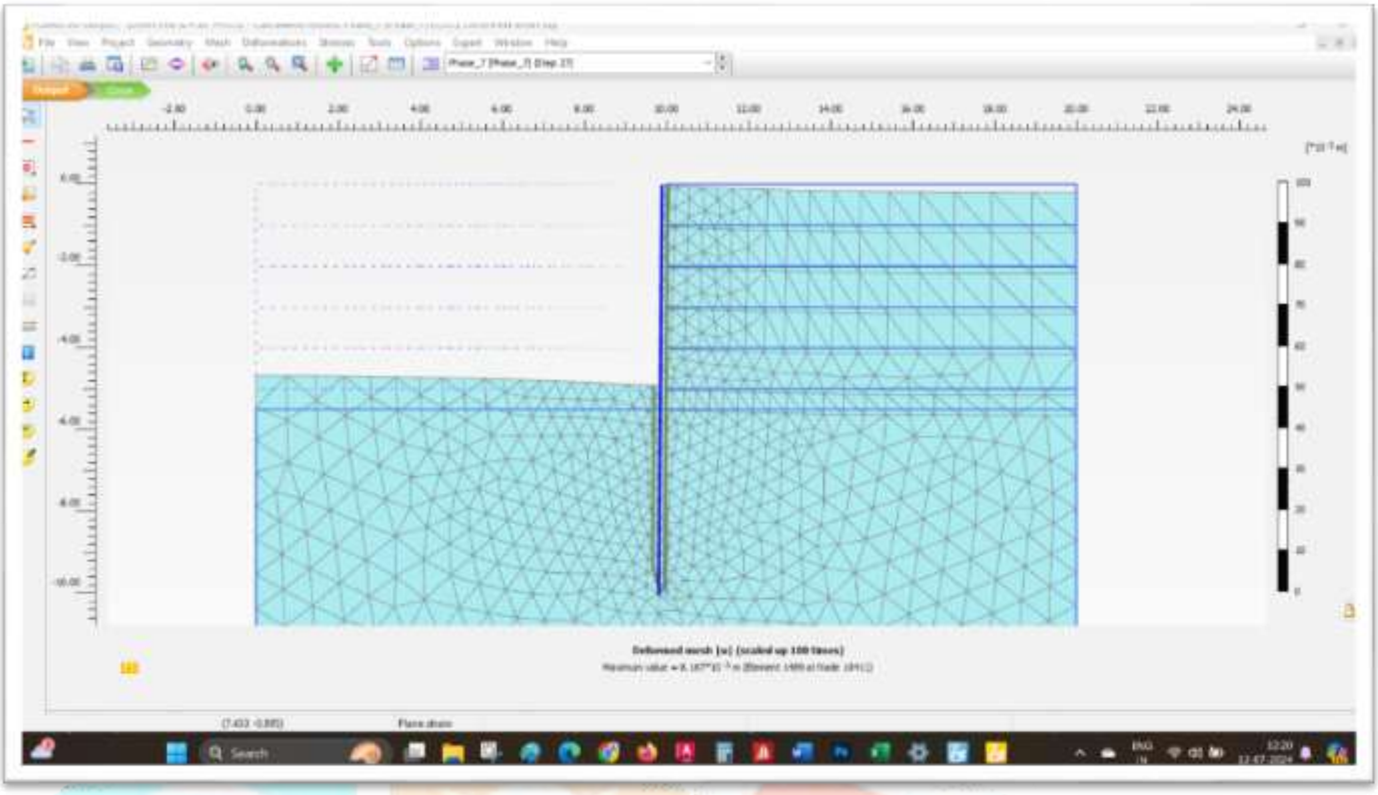


Figure 6.17: shows Mesh Deformation of Sheet Pile (H = 5.5 m & C = 30 kN/m²)

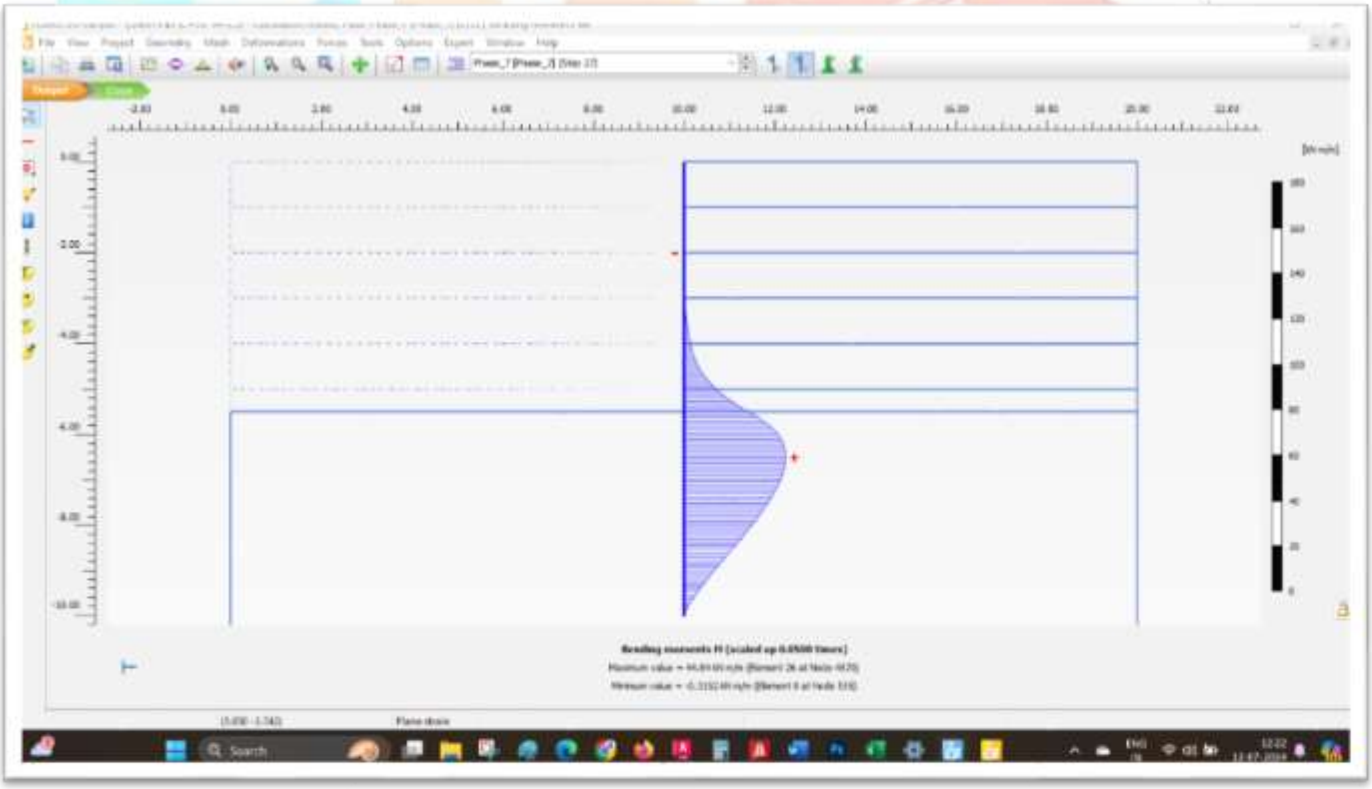


Figure 6.18: shows Bending Moment of Sheet Pile (H = 5.5 m & C = 30 kN/m²)

- **Retaining Height, h = 5.5 m & Cohesion of Soil, C = 35 kN/m2**

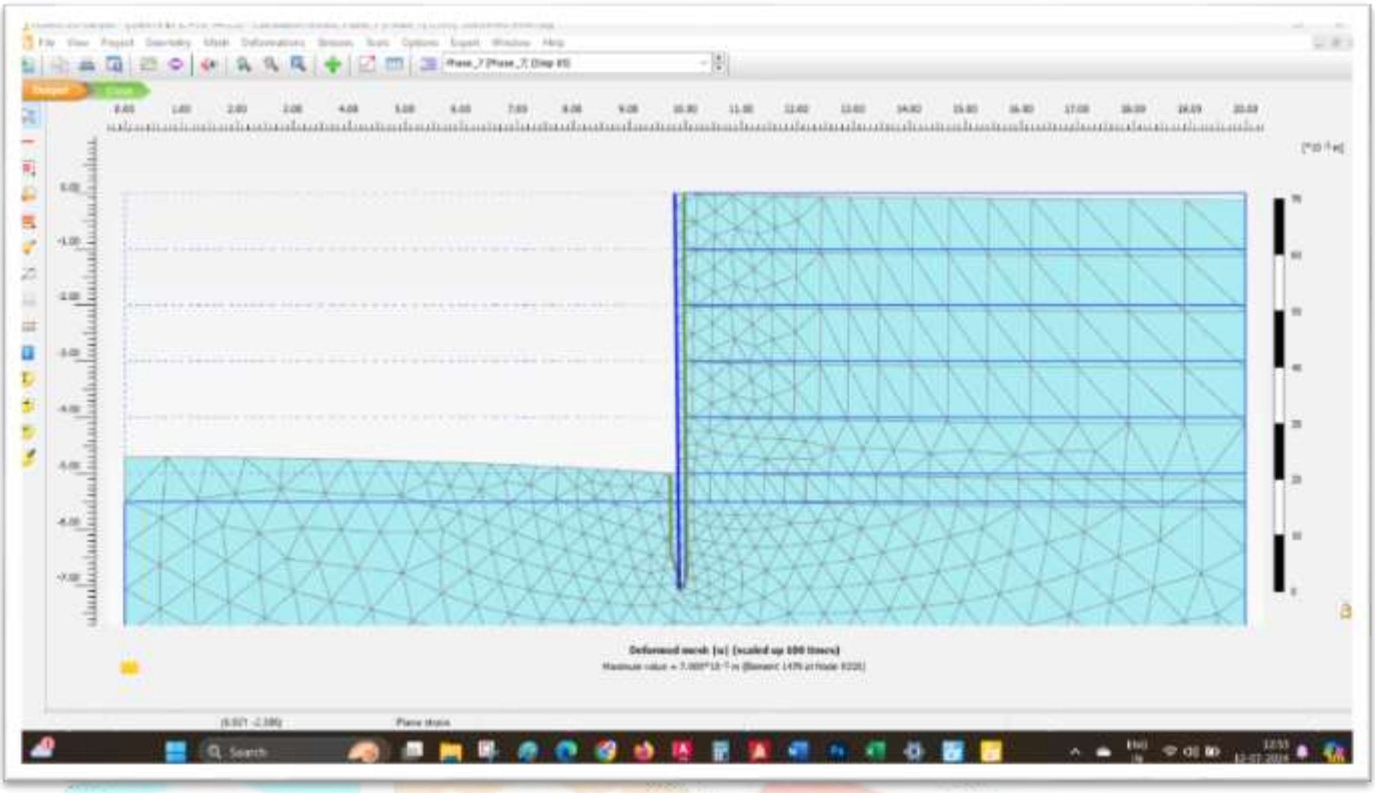


Figure 6.19: shows Mesh Deformation of Sheet Pile (H = 5.5 m & C = 35 kN/m²)

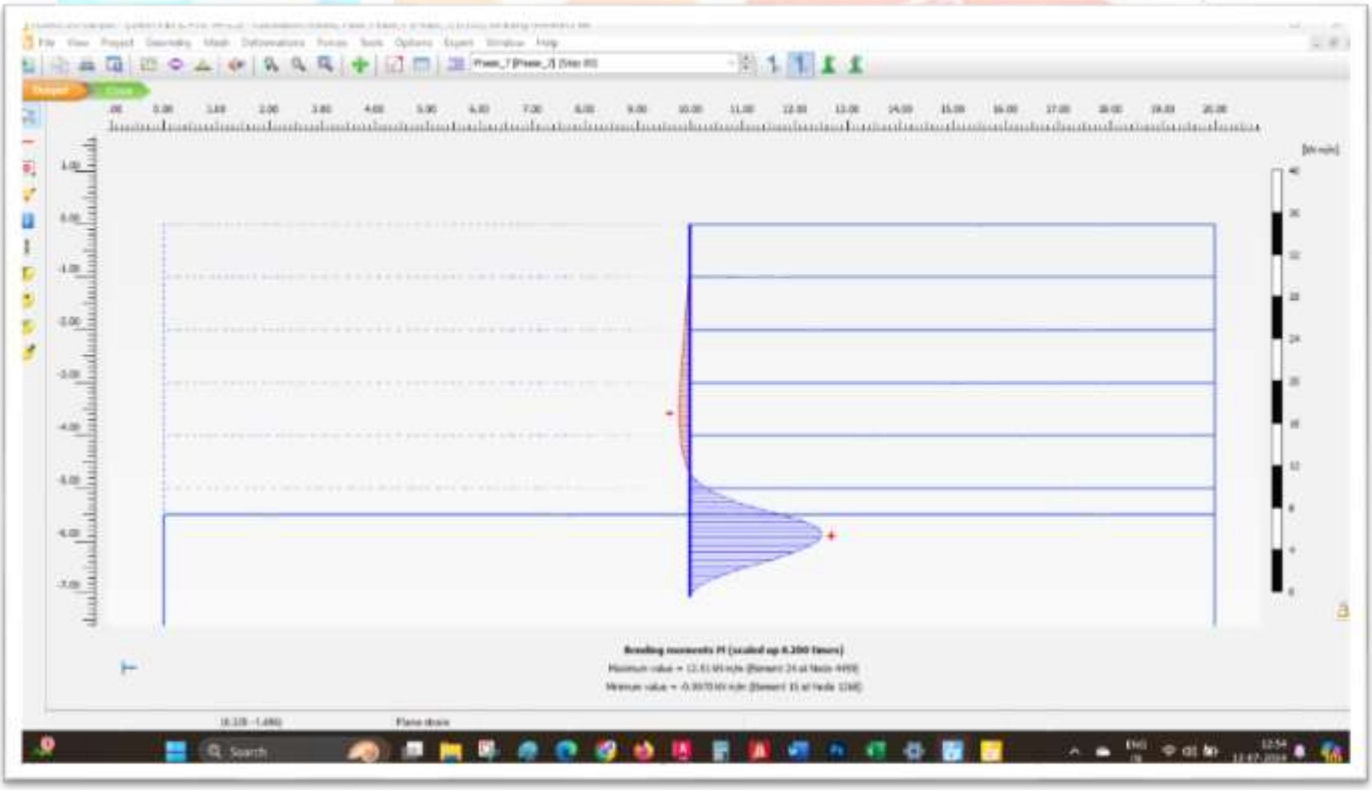


Figure 6.20: shows Bending Moment of Sheet Pile (H = 5.5 m & C = 35 kN/m²)

- **Retaining Height, h = 6.0 m & Cohesion of Soil, C = 35 kN/m2**

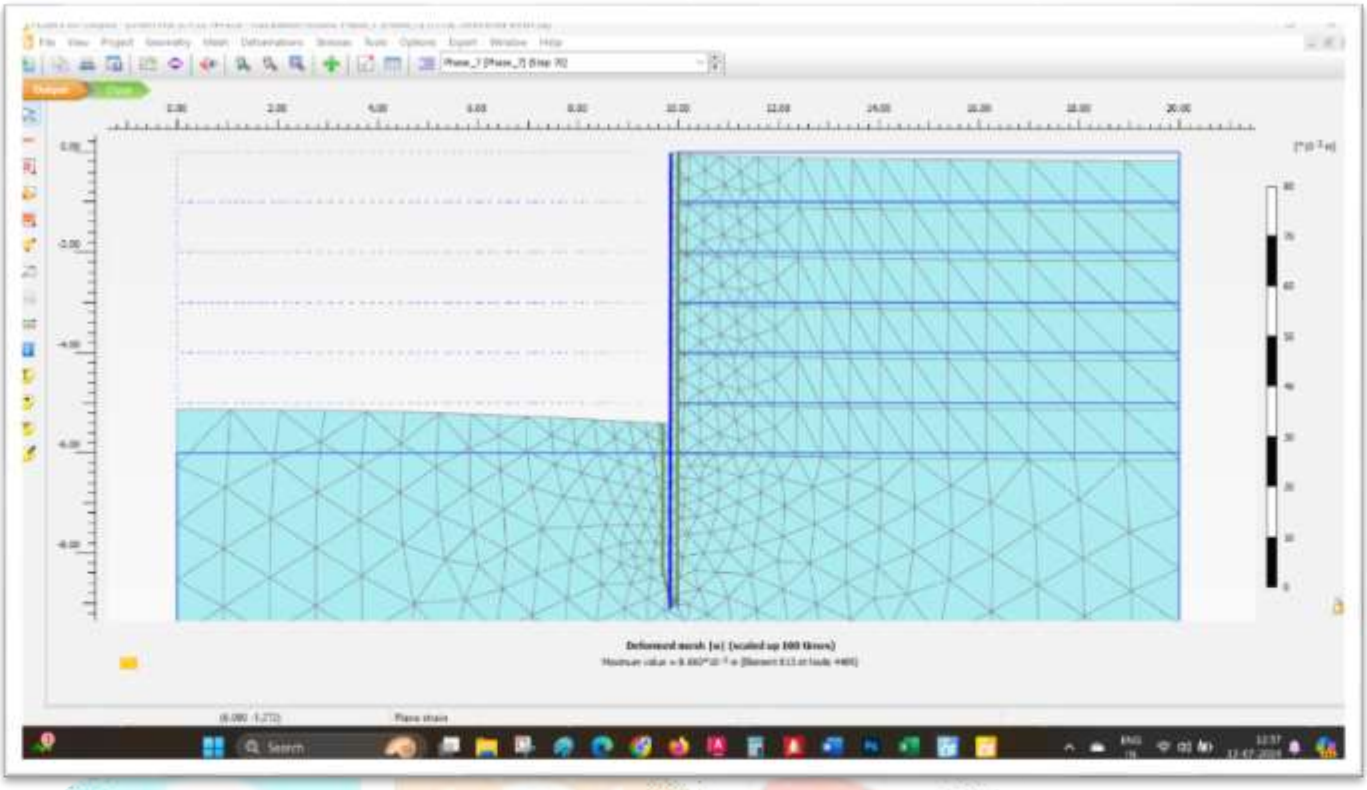


Figure 6.21: shows Mesh Deformation of Sheet Pile (H = 6.0 m & C = 35 kN/m^2)

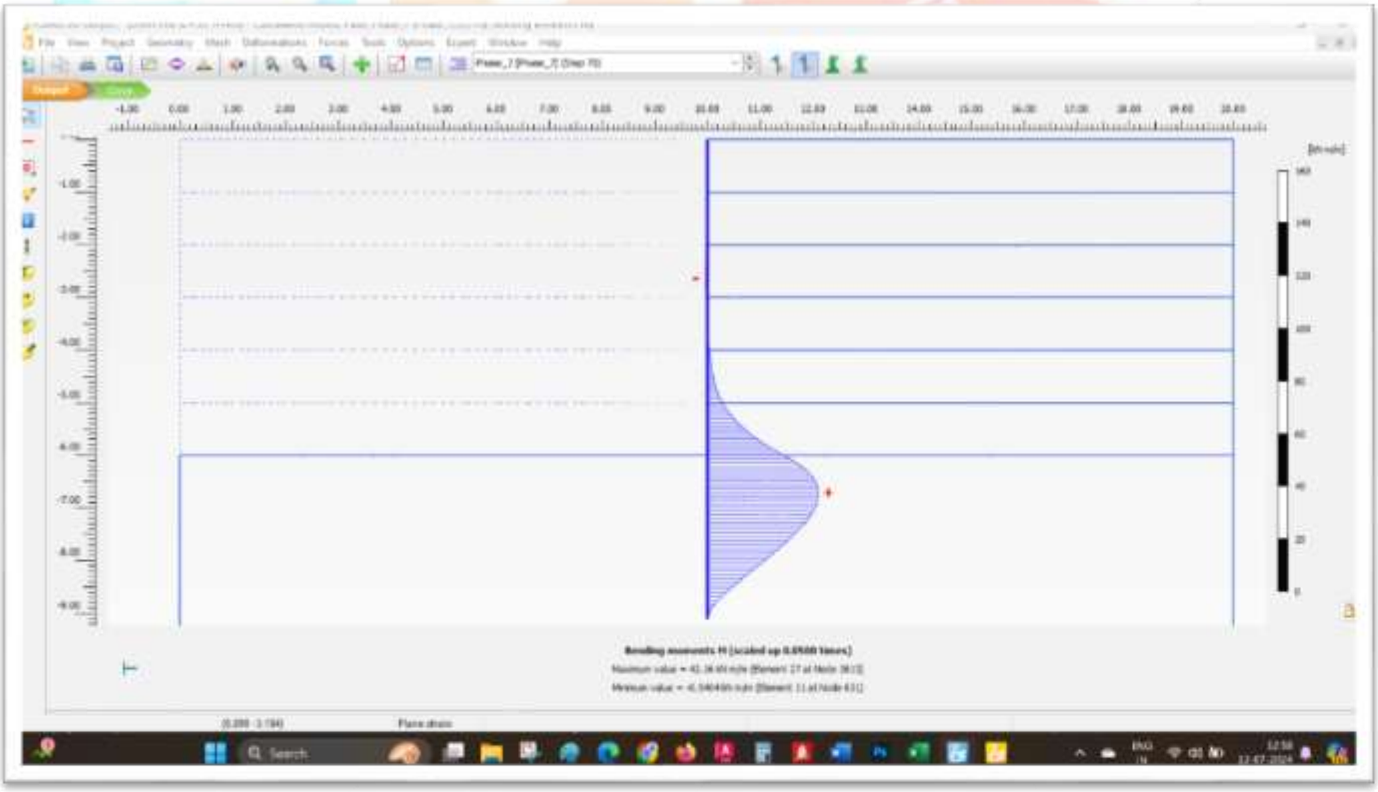


Figure 6.22: shows Bending Moment of Sheet Pile (H = 6.0 m & C = 35 kN/m^2)

- **Retaining Height, h = 6.5 m & Cohesion of Soil, C = 35 kN/m2**

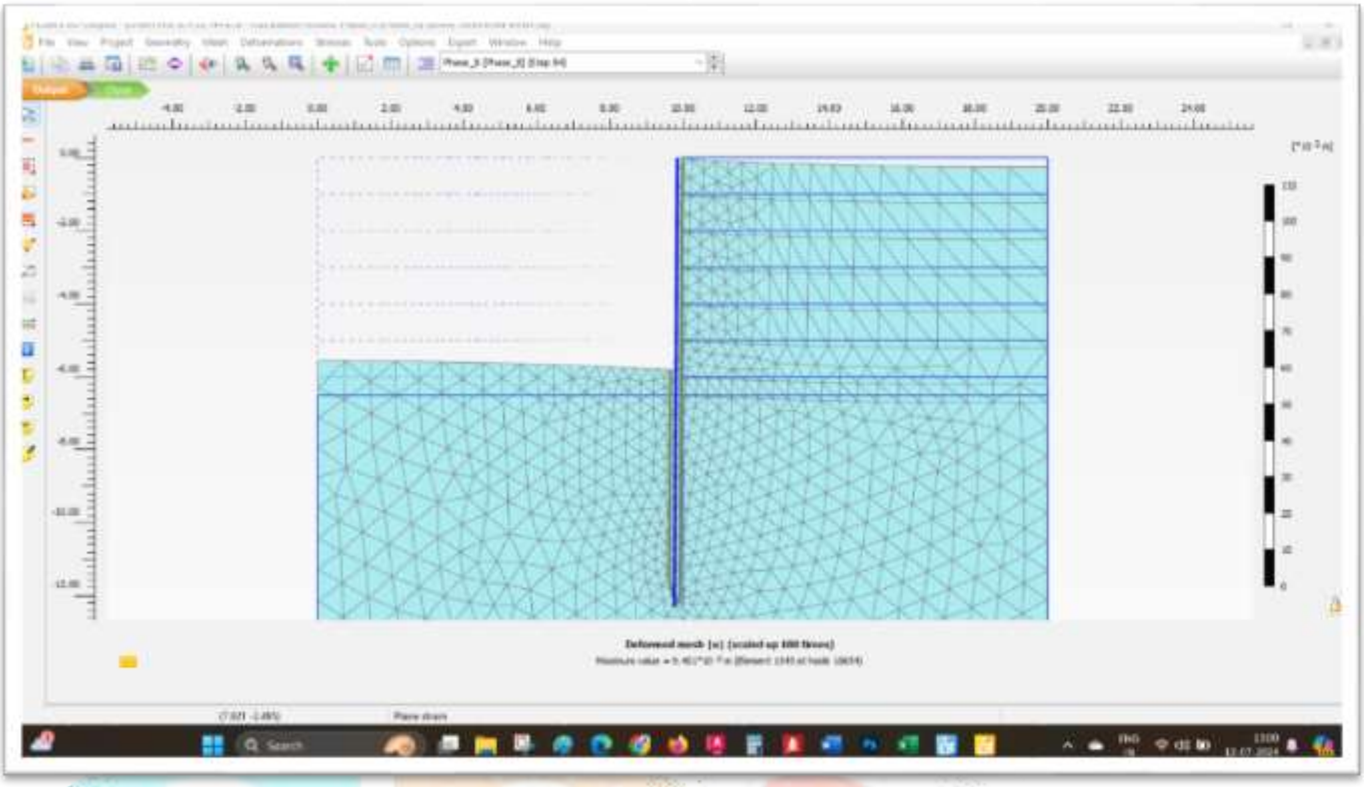


Figure 6.23: shows Mesh Deformation of Sheet Pile (H = 6.5 m & C = 35 kN/m²)

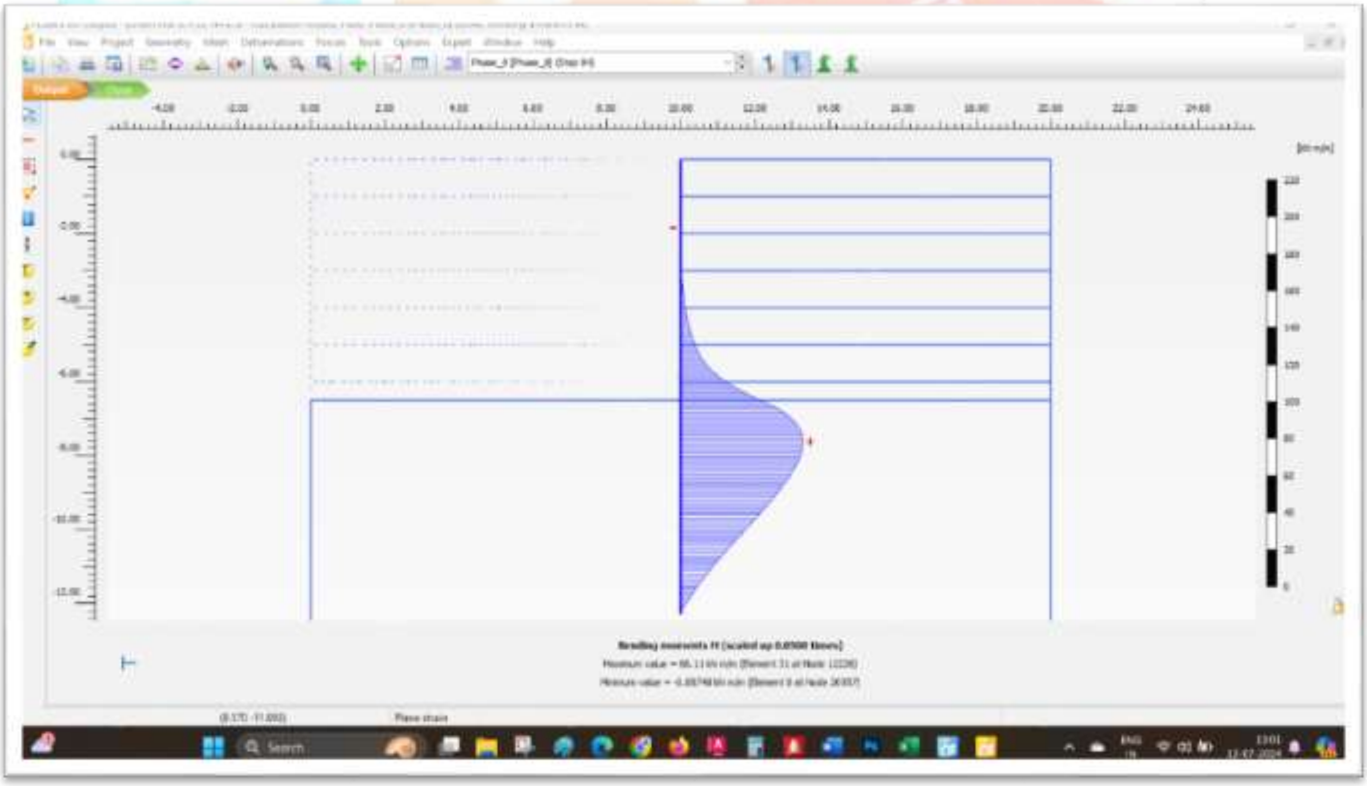


Figure 6.24: showa Bending Moment of Sheet Pile (H = 6.5 m & C = 35 kN/m²)

CHAPTER - 7

RESULTS AND DISCUSSION

7.1 OVERVIEW

The results and discussion section are presented below

7.2 EFFECT OF COHESION (Cu) ON EMBEDMENT DEPTH AND WALL HEIGHT

The present study reveals that if the cohesion value of soil is more, higher height of soil could be supported by cantilever sheet pile and vice versa. The embedment depth of the sheet pile depends on the cohesion value of soil and the height of soil height above the dredge level supported by the cantilever sheet pile. If the cohesion value of soil increases embedment depth of sheet pile decreases. In other word, for soft soil having lower cohesion value, there required higher embedment depth of the sheet pile.

7.3 EFFECT OF COHESION (Cu) ON BENDING MOMENT

7.3.1 RESULTS OF LEM ANALYSIS

Analysis by LEM has the following outcome

Table 7.2: Results of Limit Equilibrium Method

Wall Height (m)	Cohesion of Soil (Cu) (kN/m^2)	Critical Height (m)	Embedment Depth (m)	Bending Moment (kN-m)
3.0	25	2.9	0.02	0.0
3.5		2.9	0.40	0.7
4.0		2.9	1.33	5.2
4.5		2.9	3.29	20.8
5.0		2.9	7.96	70.7
4.0	30	3.5	0.25	0.3
4.5		3.5	0.91	3.5
5.0		3.5	2.17	14.4
5.5		3.5	4.52	43.6
6.0		3.5	9.48	120.1
5.0	35	4.1	0.66	2.4
5.5		4.1	1.57	10.6
6.0		4.1	3.11	31.3
6.5		4.1	5.80	78.9
7.0		4.1	11.00	189.1

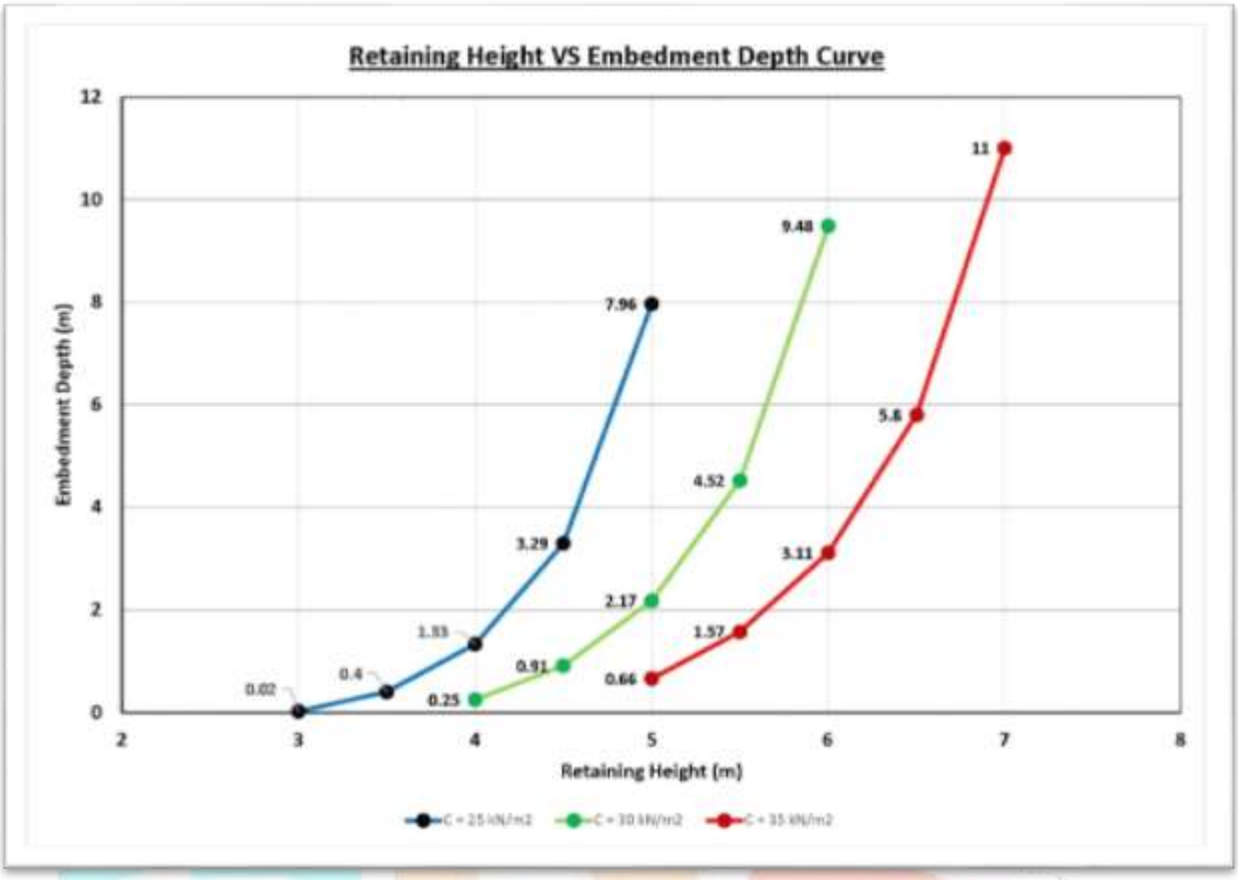


Figure 7.1: presents Retaining Height vs Embedment Depth Curve

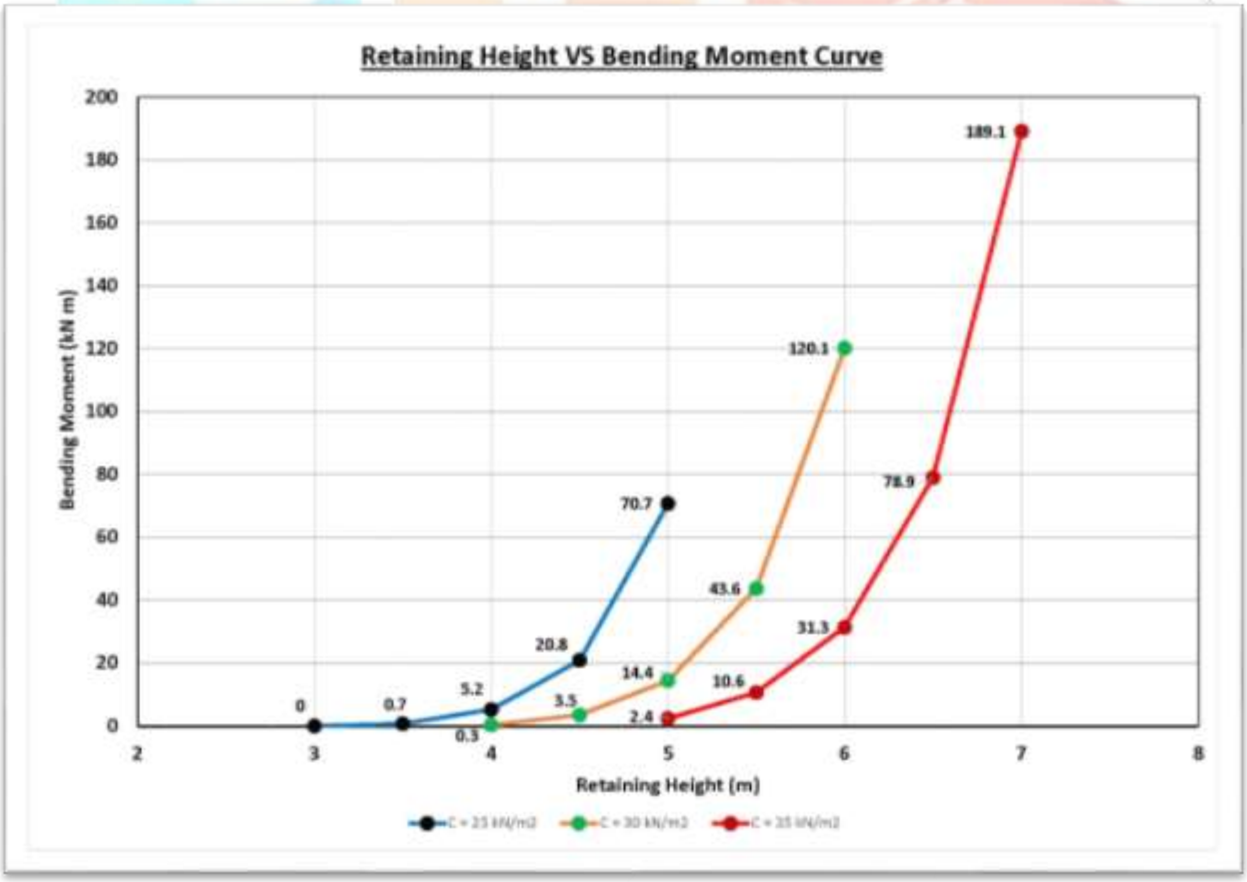


Figure 7.2: presents Retaining Height vs Maximum Bending Moment Curve

The graphs as mentioned above, visually illustrate the relationships between retaining height, embedment depth, and maximum bending moment of the sheet piles.

In the first graph, "Retaining Height vs Embedment Depth," the embedment depth increases exponentially as the retaining height rises, indicating that taller retaining walls require significantly deeper embedment to ensure stability.

In the second graph, "Retaining Height vs Maximum Bending Moment," the bending moment also increases sharply with the retaining height. This trend suggests that taller retaining structures experience much higher bending forces, necessitating careful design and reinforcement to withstand these loads.

These visual representations confirm the analysis that as the height of the retaining wall increases, both the embedment depth and bending moment grow substantially, especially for soils with higher cohesion. This information is crucial for engineers to design safe and effective retaining structures.

7.3.2 RESULTS OF NUMERICAL ANALYSIS

Numerical analysis of the sheet pile in PLAXIS 2D software revels the following result

Table 7.2: Result from PLAXIS 2D

Wall Height (m)	Cohesion of Soil (kN/m2)	Critical Height (m)	Embedment Depth (m)	Bending Moment (kN-m)	Lateral Displacement (mm)
3.0	25	2.9	0.02	--	--
3.5		2.9	0.40	1.1	-2.0
4.0		2.9	1.33	7.9	-0.8
4.5		2.9	3.29	26.4	-1.5
5.0		2.9	7.96	--	--
4.0	30	3.5	0.25	--	--
4.5		3.5	0.91	3.5	-1.4
5.0		3.5	2.17	19.4	-1.2
5.5		3.5	4.52	44.7	-1.9
6.0		3.5	9.48	--	--
5.0	35	4.1	0.66	--	--
5.5		4.1	1.57	12.5	-1.8
6.0		4.1	3.11	42.1	-1.6
6.5		4.1	5.80	66.1	-2.3

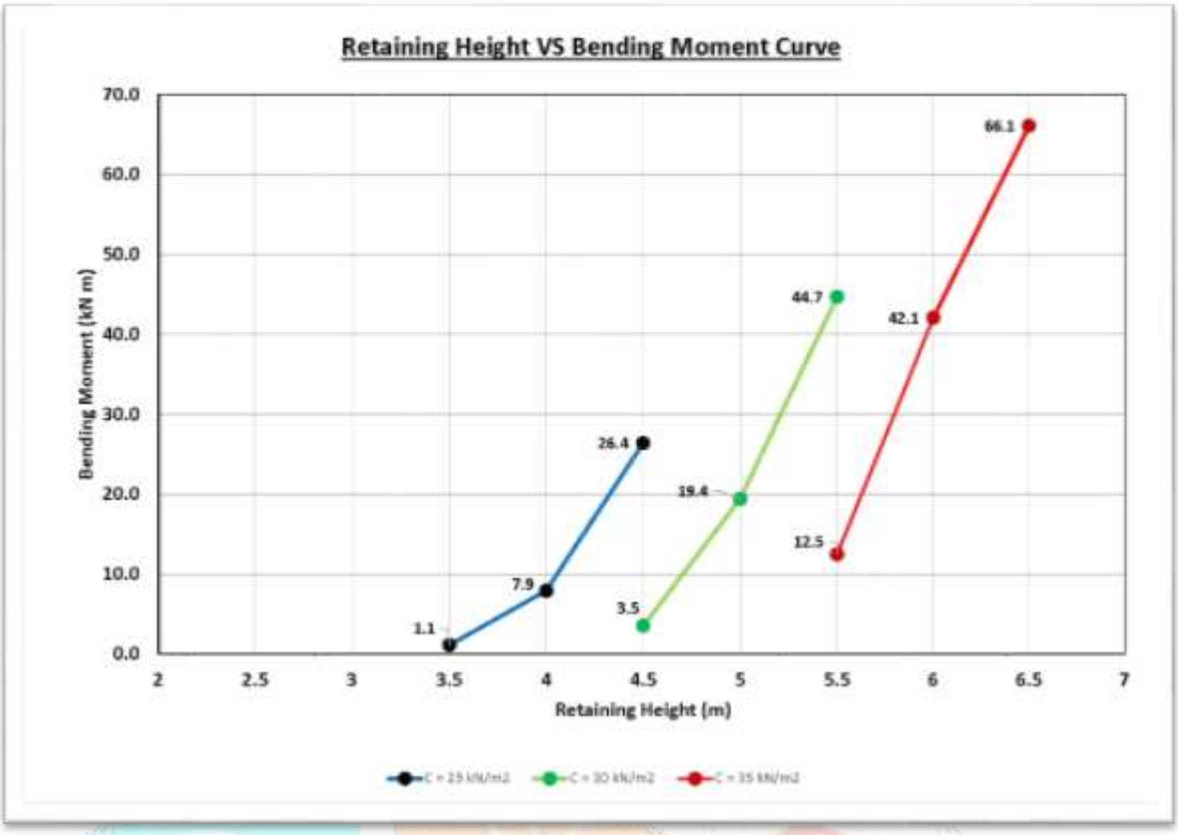


Figure 7.3: presents Retaining Height VS Bending Moment Curve

The graph illustrates the relationship between wall height and bending moment based on the results obtained from PLAXIS 2D. As the wall height increases, the bending moment also increases, reflecting a nonlinear trend. Initially, for lower wall heights (up to 4.0 meters), the increase in bending moment is relatively gradual. However, as the wall height continues to rise beyond 4.0 meters, the bending moment increases more sharply. This indicates that taller walls experience significantly higher bending moments, highlighting the necessity for robust structural design and analysis for taller retaining structures to ensure stability and safety.

7.4 COMPARATIVE RESULT TABLE OF BOTH LEM AND FEM

Table 7.3: Comparative Table of both LEM & FEM

Height of Wall (m)	C value (kN/m^2)	Critical Height (m)	Bending Moment (kNm)		Remarks
			Limit Equilibrium Method (LEM)	Finite Element Method (FEM)	
3.0		2.9	0.1	--	*PLAXIS* Gives No Result
3.5		2.9	0.7	1.1	--
4.0	25	2.9	5.2	7.9	--
4.5		2.9	20.8	26.4	--
5.0		2.9	70.7	--	*PLAXIS* Gives No Result
4.0		3.5	0.3	--	*PLAXIS* Gives No Result
4.5		3.5	3.5	3.5	--
5.0	30	3.5	14.4	19.4	--
5.5		3.5	43.6	44.7	--
6.0		3.5	120.1	--	*PLAXIS* Gives No Result
5.0	35	4.1	2.4	--	*PLAXIS* Gives No Result

5.5		**4.1**	**10.6**	**12.5**	**--**
6.0		**4.1**	**31.3**	**42.1**	**--**
6.5		**4.1**	**78.9**	**66.1**	**--**
7.0		**4.1**	**189.1**	**--**	***PLAXIS* Gives No Result**

This table above on effect of Cohesion (Cu) on maximum bending moment explain that FEM analysis tends to give higher value of maximum bending moment as compared to the LEM analysis. For any particular cohesion value there is limitation on maximum cantilever height of the wall. For each such cohesion value cases, for the maximum height of wall as calculated in LEM analysis the FEM analysis do not agree and reveals no result.

CHAPTER - 8

SUMMARY, CONCLUSIONS AND SCOPE OF FURTHER RESEARCH

8.1 OVERVIEW

The summary, conclusion, and further scope of the study are depicted in this chapter.

8.2 SUMMARY

In this present study, an attempt has been made to address the effect of cohesion of purely cohesive soil on the stability check of sheet pile walls in terms of embedment depth and mending moment calculation. The complete analysis has been done in conventional Limit Equilibrium Method (LEM) and Numerical method by PLAXIS 2D software (connect edition) for varying wall heights starting from **3m to 7m.** The varying cohesion values of soil considered here for the analysis are **25 kN/m^2, 30 kN/m^2 and 35 kN/m^2**. The embedment depth calculated in LEM analysis is used in Numerical analysis for the calculation of the maximum bending moment. The results obtained in both of these analyses are compared in tabular as well as in graphical form.

8.3 CONCLUSIONS

The following conclusions are drawn based on the present study

1. The embedment depth of sheet pile increases with decreasing soil cohesion, and also increases with the height of the wall. Specifically, for constant soil cohesion, the embedment depth increases by approximately 250% to 300% for each 0.5m increment in wall height.

2. The maximum bending moment of a sheet pile increases with decreasing soil cohesion and also increases with increment in wall height.

3. FEM analysis by PLAXIS 2D software yields a higher value of the maximum bending moment in sheet piles under identical conditions of wall height and soil cohesion. For C = 25 kN/m^2 and wall height 4.5m PLAXIS yields 27% higher value, C = 30 kN/m^2 and wall height 5.5 m PLAXIS yields 35% higher value, and C = 35 kN/m^2 and wall height 6.0m PLAXIS yield 34.5% higher value.

8.4 LIMITATIONS

Following are the limitations of the present study :

1. Only pure cohesive soil of particular strength such as 25 kN/m^2, 30 kN/m^2 and 35 kN/m^2 are considered here.
2. The sheet pile considered here is cantilever sheet pile only.
3. The ground water level is below the tip of the sheet pile.
4. Surcharge load of any kind is not considered in the present study.

8.5 SCOPE OF FURTHER RESEARCH

Further research works may be directed in the following directions :

1. Similar study can be carried out considering sandy soil.
2. Anchored sheet pile may be considered for similar study.
3. This type of study can be undertaken for layered soil such as layered clay, layered sand and a combination of sand and clay.
4. The maximum bending moment obtained in LEM or FEM can be checked with field study.

➢ REFERENCES

- ***Bjerrum, L. (1957).*** *"Earth Pressures on Flexible Structures." Norwegian Geotechnical Institute, Publication No. 16.*
- ***Broms, B. B. (1964).*** *"Lateral Resistance of Piles in Cohesive Soils." Journal of the Soil Mechanics and Foundations Division, ASCE, 90(SM2), 27-63.*
- ***Brinkgreve, R. B. J., Engin, E., & Swolfs, W. M. (2018).*** *PLAXIS 2D 2018 Manual. PLAXIS*
- ***Budhu, M. (2011).*** *Soil Mechanics and Foundations (3rd ed.). John Wiley & Sons.*
- ***Bowles, J. E. (1996).*** *Foundation Analysis and Design (5th ed.). McGraw-Hill.*
- ***Coduto, D. P., Yeung, M.-C., & Kitch, W. A. (2016).*** *Geotechnical Engineering: Principles and Practices (2nd ed.).*
- ***Das, B. M. (2010).*** *Principles of Foundation Engineering (7th ed.). Cengage Learning.*
- ***Hull, T. S. (1989).*** *"Finite Element Analysis of Sheet Pile Walls." Journal of Geotechnical Engineering, ASCE, 115(8), 1085-1097.*
- ***Jumikis, A. R. (1984).*** *Soil Mechanics. Krieger Publishing Company.*
- ***Lambe, T. W., & Whitman, R. V. (1969).*** *Soil Mechanics. John Wiley & Sons.*
- ***Matlock, H. (1970).*** *"Correlations for Design of Laterally Loaded Piles in Soft Clay." Offshore Technology Conference, OTC 1204.*

- ***Mayerhof, G. G. (1953).*** *"The Ultimate Load Carrying Capacity of Piles in Cohesive Soils." Proceedings of the 3rd International Conference on Soil Mechanics and Foundation Engineering, 1, 68-72.*
- ***NAVFAC (1986).*** *Design Manual 7.2: Foundations and Earth Structures. Department of the Navy, Naval Facilities Engineering Command.*
- ***Poulos, H. G., & Davis, E. H. (1980).*** *Pile Foundation Analysis and Design. John Wiley & Sons.*
- ***Prakash, S. (1981).*** *Soil Dynamics and Earthquake Engineering. McGraw-Hill.*
- ***Randolph, M. F., & Wroth, C. P. (1978).*** *"Analysis of Deformation of Vertically Loaded Piles." Journal of the Geotechnical Engineering Division, ASCE, 104(GT12), 1465-1488.*
- ***Reese, L. C., & Van Impe, W. F. (2001).*** *Single Piles and Pile Groups Under Lateral Loading. CRC Press.*
- ***Rowe, P. W. (1957).*** *"Sheet Pile Walls in Soft Clay." Geotechnique, 7(2), 65-74.*
- ***Terzaghi, K., Peck, R. B., & Mesri, G. (1996).*** *Soil Mechanics in Engineering Practice (3rd ed.). John Wiley & Sons.*