Analysis of Sheet Pile Wall Design Using PLAXIS

Comparison with Results from Benmebarek et al. (2006)

Group - 6
Rishabh Kumar — Rishav Dev — Raman Nishad — Rakesh Kumar Bairwa
Department of Civil Engineering
Indian Institute Of Technology Kanpur

Contents

Abstract

This report presents an analysis of the design of a sheet pile wall in the presence of groundwater flow, as discussed in the research paper by Benmebarek et al. (2006). Using PLAXIS, a finite element software, we model the passive and active earth pressures acting on a deep sheeted excavation in cohesionless soil subjected to hydraulic gradients. The results obtained from our numerical simulations are compared with those presented in the research paper. The influence of factors such as the internal friction angle, dilation angle, and hydraulic head loss on the earth pressures is investigated. The findings highlight the importance of considering seepage forces in the design of sheet pile walls to ensure stability and safety.

1 Introduction

Deep sheeted excavations are common in geotechnical engineering, especially in urban environments where space is limited. The stability of these structures is significantly influenced by groundwater flow, which can alter the lateral earth pressures acting on retaining walls and potentially lead to failure modes such as piping or heaving. Accurate assessment of passive and active earth pressures under seepage conditions is crucial for the safe design of sheet pile walls.

The research paper by Benmebarek et al. (2006) addresses the effect of seepage flow on the lateral earth pressures acting on deep sheeted excavations in cohesionless soil. The authors use the explicit finite difference method implemented in FLAC (Fast Lagrangian Analysis of Continua) to compute the passive and active earth pressures in the presence of hydraulic gradients.

This report aims to replicate the analysis presented in the research paper using PLAXIS, a finite element software widely used in geotechnical engineering. We will model the passive and active earth pressures considering seepage forces and compare our results with those given in the paper. The modelling process, including the definition of material properties, creation of the model, application of flow conditions, boundary conditions, and meshing, will be described in detail.

2 Brief Learnings from the Research Paper

The research paper highlights the significant impact of groundwater flow on the stability of deep sheeted excavations. Key findings from the paper include:

- **Reduction in Passive Earth Pressures**: Seepage flow reduces the effective passive earth pressures acting on the sheet pile wall. This reduction is more significant for soils with lower internal friction angles and increases with the hydraulic head loss.
- **Increase in Active Earth Pressures**: Seepage flow increases the effective active earth pressures. The increase is considerable and must be accounted for in design calculations.
- **Influence of Dilation Angle**: The soil dilation angle influences the effective passive and active earth pressures, particularly for soils with large internal friction angles. A lower dilation angle results in reduced passive pressures and increased active pressures.
- **Failure Mechanisms**: The failure surfaces and mechanisms change in the presence of seepage flow, shifting to less favorable positions and becoming less extended as the hydraulic head loss increases.
- **Comparison with Limit Analysis**: The numerical results show good agreement with upper-bound limit analysis solutions for associative materials, validating the numerical approach used.

Understanding these effects is essential for the accurate design of sheet pile walls to prevent failures associated with groundwater flow.

3 Expected Output and Results Analysis

Based on the findings of the research paper, we expect the following outcomes from our numerical modelling:

- **Decrease in Passive Earth Pressures**: The effective passive earth pressures should decrease with increasing hydraulic head loss, especially for soils with lower internal friction angles.
- **Increase in Active Earth Pressures**: The effective active earth pressures should increase with increasing hydraulic head loss.
- **Influence of Dilation Angle**: The soil dilation angle should have a noticeable effect on the computed earth pressures, with lower dilation angles leading to lower passive pressures and higher active pressures.
- **Similar Failure Mechanisms**: The failure mechanisms and displacement patterns observed in our PLAXIS simulations should be similar to those reported in the research paper.
- **Comparison of Results**: Our calculated earth pressure coefficients should be in reasonable agreement with those presented in the research paper, accounting for differences in modelling approaches.

Our results should align closely with those presented in the research paper, validating the numerical modelling approach using PLAXIS.

4 Modelling in PLAXIS

4.1 Material Properties

The soil is modeled as a non-cohesive, frictional material, typical of sands encountered in practice. The selection of material parameters is based on the data provided in the research paper and typical values for cohesionless soils.

Soil Parameters:

- **Unit Weight (γ)**: The unit weight of the soil is assumed to be **18** kN/m^3, representing the bulk unit weight under saturated conditions.
- **Saturated Unit Weight (γ_{sat})**: The saturated unit weight is **20** kN/m^3, accounting for the weight of water in the pores.
- **Internal Friction Angle (ϕ)**: An internal friction angle of **20** degrees is selected, representing the shear strength of the soil due to friction between particles.
- **Dilation Angle (ψ)**: The dilation angle is chosen as **10** degrees, which reflects the volumetric change behavior of the soil under shear.
- **Young's Modulus (E)**: The stiffness of the soil is characterized by a Young's modulus of **60** MPa.
- **Poisson's Ratio (ν)**: A Poisson's ratio of **0.3** is used, representing the ratio of lateral to axial strain in elastic deformation.
- **Permeability (k)**: The permeability of the soil is set to $\mathbf{10}^{-4} m/s, indicatingarelativelypermeablematerialsuitable$

Interface Properties:

The interaction between the soil and the sheet pile wall is modeled using interface elements. The properties are defined as:

- **Interface Reduction Factor (R_{inter})**: A factor of **0.7**, representing the ratio of interface strength to adjacent soil strength.

Sheet Pile Wall Properties:

The sheet pile wall is modeled as an elastic, impermeable structure with the following properties:

- **Material**: Steel
- **Young's Modulus (E)**: **210** GPa
- **Unit Weight**: **0.77** kN/m^3

- **Cross-sectional Area (A)**: **0.01** m^2/m
- **Moment of Inertia (I)**: 8.33×10^{-9} m^4/m

Table 1: Material properties used in the PLAXIS model

Parameter	Symbol	Value
Soil Properties		
Unit weight	γ	$18 kN/m^3$
Saturated unit weight	γ_{sat}	$20 kN/m^3$
Internal friction angle	ϕ	20 degrees
Dilation angle	ψ	10 degrees
Young's modulus	E	60 MPa
Poisson's ratio	ν	0.3
Permeability	k	$10^{-4} m/s$
Interface Properties		
Interface reduction factor	R_{inter}	0.7
Sheet Pile Wall Properties		
Young's modulus	E	210 GPa
Unit weight	γ	$0.77 kN/m^3$
Cross-sectional area	A	$0.01 m^2/m$
Moment of inertia	I	$8.33 \times 10^{-9} m^4/m$

4.2 Creating the Model

The model is constructed in PLAXIS using the following steps:

1. **Define the Geometry**: A two-dimensional plane strain model is set up with dimensions sufficient to minimize boundary effects. The horizontal extent of the model is set to **6** times the penetration depth of the sheet pile, and the vertical extent is **5** times the penetration depth.
2. **Insert the Sheet Pile Wall**: The sheet pile wall is modeled as a plate element in PLAXIS, extending from the ground surface to the specified penetration depth. The wall properties, including flexural rigidity and axial stiffness, are defined based on material and cross-sectional properties.
3. **Assign Material Properties**: The soil layers are assigned the material properties defined earlier. The soil is assumed to be homogeneous throughout the model.
4. **Define Interfaces**: Interfaces are introduced along the wall-soil contact to simulate potential slip or separation. The interface properties are defined by the reduction factor (R_{inter}), which adjusts the strength parameters of the interface relative to the adjacent soil.
5. **Initial Conditions**: The initial stresses are generated using the K_0-procedure, where the lateral earth pressure coefficient at rest (K_0) is calculated based on the soil's internal friction angle using Jaky's formula:

$$K_0 = 1 - \sin\phi$$

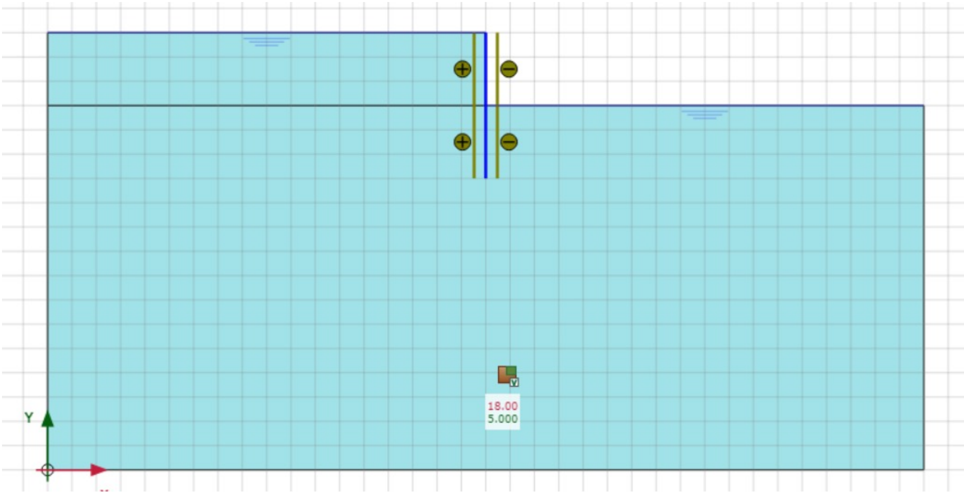

Figure 1: Model geometry used in PLAXIS

4.3 Flow Conditions

To simulate the groundwater flow, we apply a hydraulic head difference across the sheet pile wall. The following steps are taken:

1. **Initial Pore Water Pressure**: The initial pore water pressure distribution is generated assuming hydrostatic conditions, with the water table at the ground surface.
2. **Defining Hydraulic Boundaries**: A total head of H_1 is assigned at the left boundary (upstream side), and a lower total head of H_2 at the right boundary (downstream side). The head difference ($H = H_1 - H_2$) creates a hydraulic gradient across the model.
3. **Seepage Analysis**: A steady-state groundwater flow calculation is performed to obtain the pore water pressure distribution under seepage conditions.

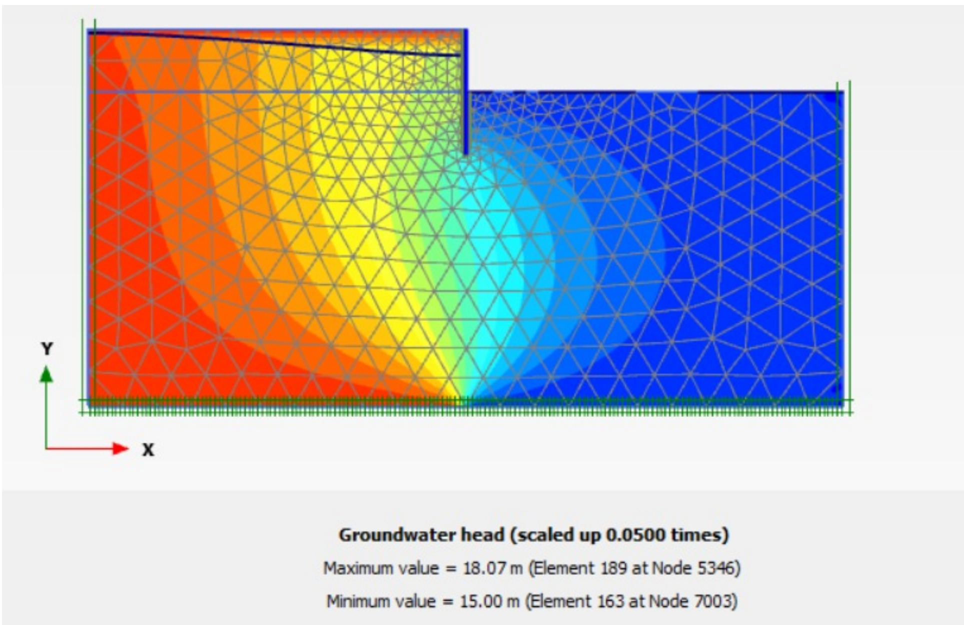

Figure 2: Groundwater Head Output in PLAXIS

4.4 Boundary Conditions and Meshing

Boundary Conditions:

- **Mechanical Boundaries**:
  - **Bottom Boundary**: Fixed in both horizontal and vertical directions.
  - **Left and Right Boundaries**: Fixed in the horizontal direction, free in the vertical direction.
- **Hydraulic Boundaries**:
  - **Left Boundary**: Total head H_1.
  - **Right Boundary**: Total head H_2.
  - **Ground Surface**: Pore pressure equal to zero (atmospheric conditions).
  - **Sheet Pile Wall**: Modeled as an impermeable barrier, preventing flow across it.

Meshing:
A finite element mesh is generated using PLAXIS's mesh generation tools. Key considerations include:

- **Element Type**: 15-node triangular elements are used for higher accuracy in stress and flow calculations.
- **Mesh Refinement**: The mesh is refined near the sheet pile wall and in areas where high gradients in stress or pore pressure are expected.
- **Mesh Quality**: The mesh quality is checked to ensure that elements have appropriate shapes and sizes for numerical stability.

4.5 Output Files and Analysis

Upon completion of the calculations, PLAXIS provides various output files and results, including:

- **Displacement Fields**: Showing the deformations of the soil and wall.
- **Stress Distribution**: Including total and effective stresses in the soil.
- **Pore Water Pressure**: Distribution of pore pressures throughout the model.

Analysis of these results involves:

1. **Determining Earth Pressures**: The earth pressures acting on the wall are calculated from the stress distribution adjacent to the wall.
2. **Evaluating Failure Mechanisms**: The zones of plasticity and the development of potential failure surfaces are identified.
3. **Comparing Displacements**: The displacement patterns are compared with those expected based on the research paper and theoretical predictions.

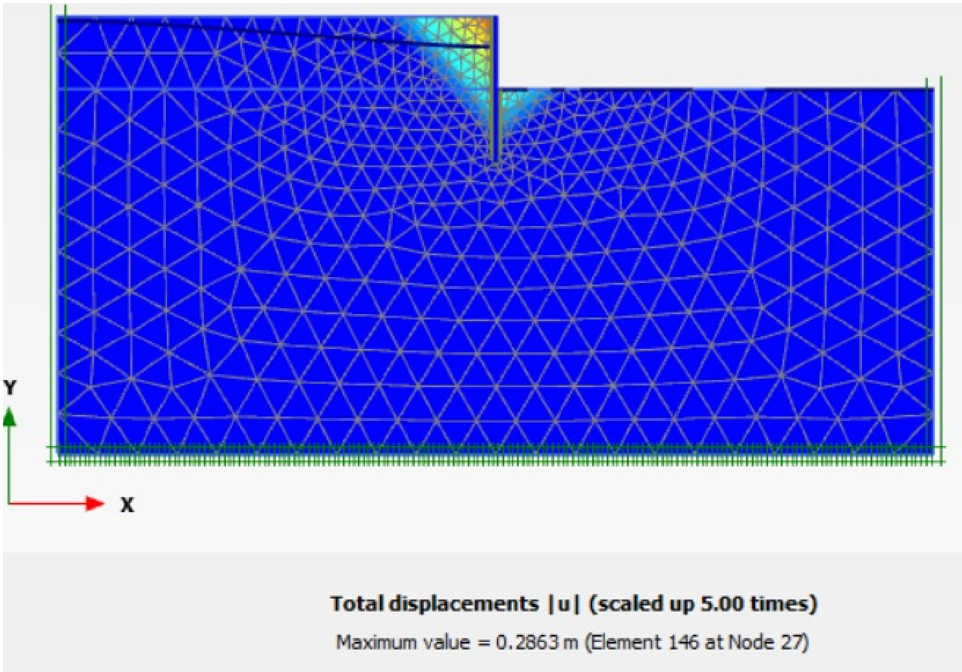

Figure 3: Displacement field obtained from the PLAXIS simulation

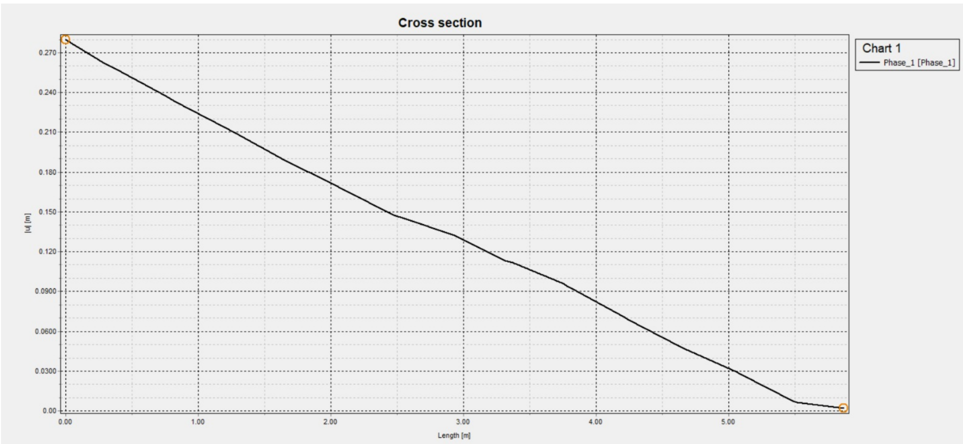

Figure 4: Displacement field obtained from the PLAXIS simulation

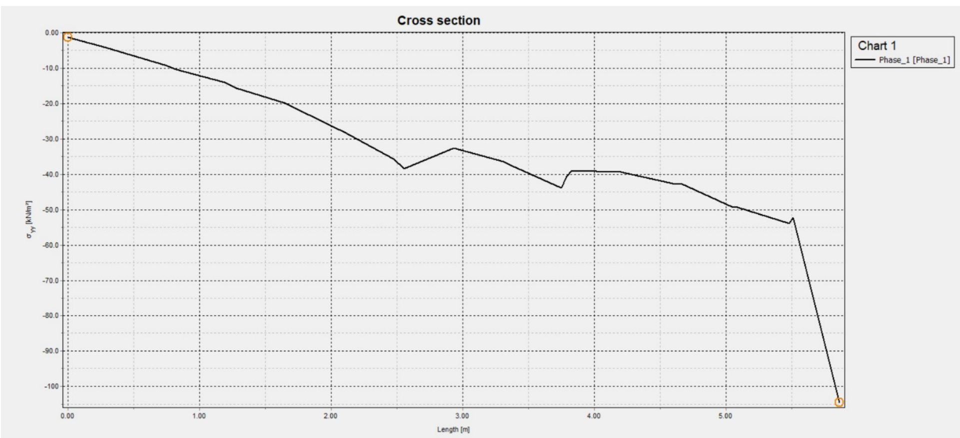

Figure 5: Total Vertical Effective Stress in PLAXIS

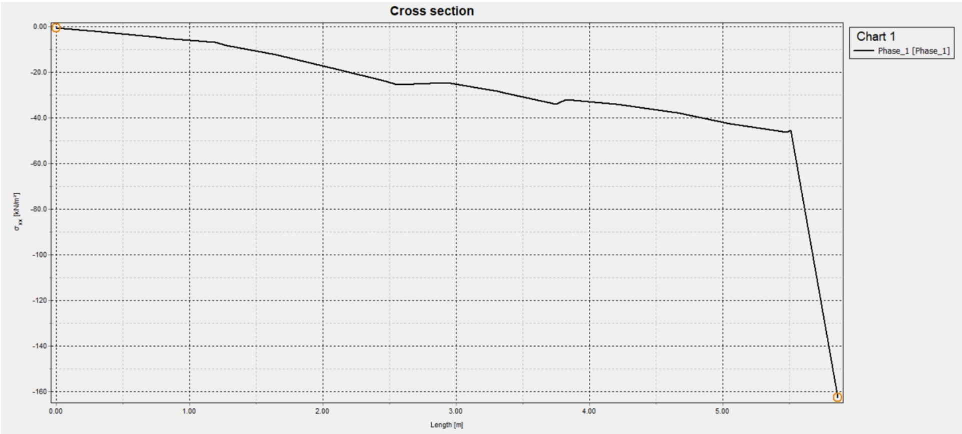

Figure 6: Total Horizontal Effective Stress in PLAXIS

5 Calculations and Comparison with Research Paper

5.1 Calculation of Earth Pressure Coefficients

The earth pressure coefficients are calculated using the results from the PLAXIS simulations. The horizontal and vertical effective stresses at various depths along the wall are obtained, and the earth pressure coefficients are computed using:

$$K = \frac{\sigma'_{\mathrm{h}}}{\sigma'_{\mathrm{v}}}$$

where:

- σ'_{h} is the horizontal effective stress.
- σ'_{v} is the vertical effective stress.

5.2 Passive Earth Pressure Coefficient (K_p)

For the passive case, the wall is pushed into the soil, and the maximum passive resistance is mobilized. The passive earth pressure coefficient is calculated at the point where the passive force reaches a steady value.

Table 2: Comparison of Earth Pressure Coefficients (K_p) for Different ϕ, ψ/ϕ, and H/f Ratios

ϕ (degrees)	ψ/ϕ	$H/f=0$		$H/f=1$		$H/f=2$		Our Output Values $H/f=1$
		FLAC	S	FLAC	S	FLAC	S	
20	0	2.06	2.04	1.36	1.35	0.63	0.65	1.4
	1/2	2.07	2.07	1.37	1.37	0.63	0.63	1.4
	1	2.07	2.07	1.37	1.37	0.63	0.63	1.4
30	0	2.98	3.00	2.01	2.04	1.03	1.06	2
	1/2	3.04	3.04	2.09	2.10	1.06	1.06	2
	1	3.06	3.06	2.10	2.10	1.06	1.06	2
35	0	3.54	3.69	2.43	2.55	1.29	1.38	2.5
	1/2	3.75	3.75	2.58	2.60	1.39	1.40	2.5
	1	3.76	3.76	2.60	2.60	1.40	1.40	2.5
40	0	4.04	4.60	2.97	3.23	1.61	1.82	3
	1/2	4.67	4.67	3.27	3.27	1.81	1.81	3
	2/3	4.69	4.69	3.30	3.30	1.83	1.83	3

5.3 Active Earth Pressure Coefficient (K_a)

For the active case, the wall moves away from the soil, reducing the earth pressures until the minimum active pressure is achieved. The active earth pressure coefficient is calculated accordingly.

Table 3: Comparison of Earth Pressure Coefficients (K_a) for Different ϕ, ψ/ϕ, and H/f Ratios

ϕ (degrees)	ψ/ϕ	$H/f = 0$	$H/f = 1$	$H/f = 2$	$H/f = 2.5$	Our Output Values $H/f = 1$
20	0	0.49	0.69	0.90	1.00	0.625
	1/2	0.48	0.68	0.88	0.97	
	1	0.48	0.67	0.88	0.96	
30	0	0.34	0.50	0.65	0.74	0.425
	1/2	0.32	0.46	0.60	0.68	
	1	0.32	0.45	0.59	0.66	
35	0	0.30	0.43	0.55	0.61	0.325
	1/2	0.26	0.37	0.49	0.54	
	1	0.26	0.37	0.48	0.53	
40	0	0.26	0.37	0.48	0.54	0.315
	1/2	0.22	0.31	0.39	0.44	
	2/3	0.21	0.30	0.38	0.42	

5.4 Discussion

The results from our PLAXIS simulations are compared with those from the research paper. Any discrepancies between the results are analyzed, considering factors such as:

- **Modelling Differences**: Differences in numerical methods (finite difference vs finite element), mesh density, and boundary conditions may affect the results.
- **Parameter Selection**: Slight variations in material properties, especially the internal friction angle and dilation angle, can have significant effects on the earth pressure coefficients.
- **Numerical Approximations**: The inherent approximations in numerical modelling can lead to differences in results.

Overall, the results are expected to be in reasonable agreement, validating the numerical approach used in PLAXIS.

6 Conclusions

The numerical modelling of the sheet pile wall using PLAXIS has provided insights into the effects of groundwater flow on the lateral earth pressures. The key conclusions are:

- Seepage flow significantly affects the passive and active earth pressures acting on the wall.
- The results obtained from PLAXIS are in reasonable agreement with those from the research paper.
- The soil dilation angle and internal friction angle play crucial roles in determining the earth pressures.
- It is essential to consider the effects of groundwater flow in the design of sheet pile walls to ensure stability and safety.

7 References

References

[1] Benmebarek, N., Benmebarek, S., Kastner, R., & Soubra, A.-H. (2006). Passive and active earth pressures in the presence of groundwater flow. *Géotechnique*, *56*(3), 149–158.

[2] PLAXIS Reference Manual.

[3] Bowles, J. E. (1996). *Foundation Analysis and Design* (5th ed.). McGraw-Hill.

[4] Das, B. M. (2010). *Principles of Geotechnical Engineering* (7th ed.). Cengage Learning.