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Numerical Analysis of Pile Wall for Excavation Support in Soft Ground

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Abstract
Cantilever pile walls are one of the earth support structure which can be beneficial to reduce excessive deformation during ground excavation.In many cases construction of basement and underground structures nearby existing old buildings are proposed. In such a case the influence zone of the old building exerts earth pressure into the new excavation area and to retain such a lateral earth pressure cantilever pile wall is provided. The most populated city and capital city of Nepal, Kathmandu, where mostly the buildings are built over soft ground composed of grey to dark silty clay and clayey silt. The city is on the verge of developing high-rise building so for the proper excavation without hampering the old building near the construction site well designed cantilever pile wall are studied using three-dimensional finite element (3D FE).Pile wall is used in this study as excavation support system. The choice of cantilever pile wall is as it is common and relatively easy to be used in cohesive soil. Parametric study was performed considering soil property, excavation depth, pile embedded depth and adjacent building foundation stress.

Keywords
Excavation,Cantilever pile wall, FEM, Adjacent building

1. Introduction

The influence of construction-related ground movements on surrounding structures and utilities is a major consideration when excavating in metropolitan environments. Although excavation will result in both horizontal and vertical soil movement, the horizontal displacement is thought to be more important for the excavation supporting pile wall. As a result of the earth movements, nearby structures will deform and perhaps receive damage. When excavating in urban areas,precise soil movement control is frequently required to limit damage to nearby buildings. When soft clays lie beneath a site, this requirement necessitates the construction of robust excavation support walls. The size and distribution of projected deformations during the project, as well as their impact on nearby structures, define the needed stiffness of an excavation support wall. Figure 1 shows the problem under investigation, including lateral soil movement toward excavation, supporting wall bending, and ground movement beneath a nearby building due to excavation in clay soil. As shown, significant differential settlement induced by soil movement may cause damage to the surrounding building. The degree and severity of damage due to excavation is determined by building type, support walls performance and its type, soil conditions, and construction works. The use of various forms of retaining structures to prevent or reduce damage to surrounding buildings and subterranean utilities is a key concern. Sheet pile walls, contiguous piles, secant piles, and diaphragm walls are all common wall forms. The support wall is also subjected to lateral soil movement, which causes lateral force.As a result, the magnitude of horizontal displacement and its impact on the pile wall supporting excavation must be quantified or predicted. The lateral stresses caused by soil movements cause bending moments and deflections in the pile-supporting excavation, potentially causing structural distress or failure of both the old building and the excavation-supporting wall.

There have been numerous reports of structural damage to piles in the literature, according to Poulos and Chen (1997)[1]. Many theoretical and empirical techniques has developed to address specific excavation difficulties, such as those by Stewart et al.

(1994)[2], Poulos and Chen (1995, 1996)[3, 4] , and Chen and Poulos (1997)[5]. Cantilever walls are an excellent choice for either short term and long term excavation work. They keep the excavation area clear of internal struts, allowing construction to proceed smoothly. Long et al.(2012)[6] suggest excavations of up to 4.5 m when using cantilever walls in soil mechanics textbooks . Long et al. (2001)[7] examined a data base of cantilever wall cases available in the literature. Long et al. (2012)[6] reported on the successful construction of 7.5 m high cantilever walls in Dublin boulder clay. These cantilver walls move more slowly than expected.They advised using cantilever walls for higher maintained heights, at least temporarily. These are depth of excavation, soil paramters, and nearby building's foundation level and its type. According to Poulos and Davis (1980)[8], the secant modulus of elasticity ranges from 15 c_u to 95 c_u (where c_u is undrained shear strength),with less for very soft clay and more for stiff clay. A value of 50 c_u was used in the current analysis.Soft soils are typically stiffer in the vertical direction than in the horizontal (Parry 1995)[9]. According to Ou's recommendation, the presence of CPW only reduced rotation values to acceptable levels in soft clay cases (2014)[10].

Based on elastic displacement theory, a closed-form method for predicting excavation-induced ground settling profile is proposed.The superposition method is utilized to adapt the basic solution for translation wall deflection mode to general wall deflection mode. The displacement boundary of the problem is determined by assuming that the wall deflection in braced excavation is subject to a piecewise quadratic function. Then, an explicit solution that is simple to use is created chang ji xu (2021)[11]. Chang-Yu Ou and Bor-Yuan Shiau (1998)[12] presents three-dimensional finite-element excavation research.

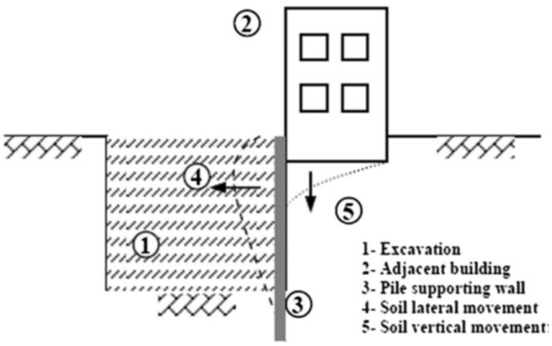

Figure 1: Model of Excavation, Adjacent Area and Building

Large amounts of computer storage and calculation time are typically required for traditional finite-element analysis, which requires the boundary to be set far enough away from the excavation zone to achieve convergence. The infinite element is introduced into a three-dimensional finite-element computer program in this research to reduce the number of elements used. According to the research findings, appropriate convergence for wall deflection and ground surface settlement is attained for infinite elements situated one wall depth apart.

1.1 Need of Research

The basin was filled by fluvio-lacustrine sediments from the late Pliocene period through the Quaternary. In ascending order, the basin formations are: Dharmasthali, Kalimati, Gokarna, Thimi, Tokha, and Patan [13]. Patan (also known as Lalitpur) is made up of fluvial deposits dating from 14-19 kyr [14] to 10 kyr (last glacier), whereas Gokarna began in the Middle Pleistocene. The age of Kalimati formation, made up of lacustrine sediments, 2.8 myr (late Pliocene) 30 kyr (pliostocene) Kalimati, also known as "black mud" in Nepal, is primarily formed of black organic clay, silts, sand, and gravel, and is the only formation spread in the central basin [15].

As per the Engineering and Environmental Geological map of Kathmandu Valley, the project site lies in slightly consolidated sediment of Plio Pleistocene age in Kalimatiformation is made up of grey to black silty clay and clayey silt with calcareous character and Phosphate mineral. Organic clay, fine sand beds, and

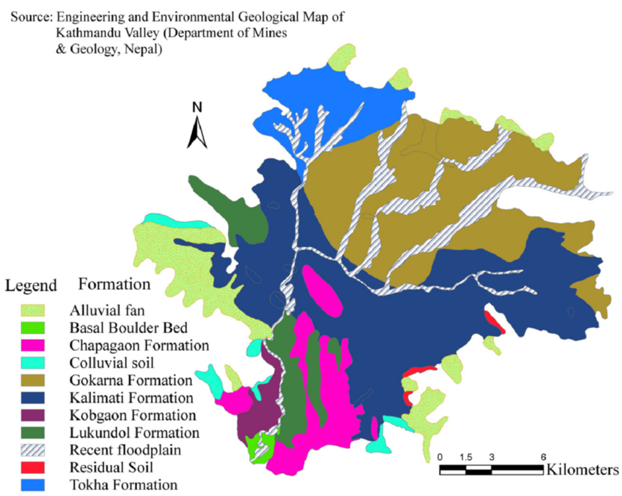

Figure 2: Engineering and Environmental Geological Map of Kathmandu valley(Department of mines and geology)

peat layers are typical. Further the project area lies in hazards and foundation instabilities area with areas of low bearing capacity where site is prone to settling due to soft, silty clay, peat, and plastic clay beneath the soil cover. Buildings need special foundations. Heavy construction requires protection measures. Therefore, the aim of this study is to generalize the behavior of soil-pile integrated response under different loading condition in Kalimati Formation.

1.2 Objectives

The main objective of this research work is to study the behaviour of pile wall for excavation support in soft ground with respect to:

- Undrained shear strength
- Depth of excavation
- Stresses under foundation of the adjacent building
- Pile embedment depth

1.3 Research Motivation

In advancement of construction practices in Kathmandu valley, protection piles are often being used to retain unsupported excavation in large construction projects like mega structures, road protection etc. It is also being used to retain the surcharge load from nearby existing structures. Therefore, motivation of the study is to gather the behavior of laterally loaded pile in soft soil of Kathmandu Valley.

2. Numerical Modelling

In order to conduct the numerical modeling of pile wall adjacent to excavation, various approaches have been adopted. The data required for the parametric analysis was taken from borehole test conducted at Teku site. The soil properties are then generalized from the literature of Engineering and Environmental Geological map of Kathmandu valley, the project site lies in slightly consolidated sediment of Plio Pleistocene age in Kalimati formation, made up of grey to black silty clay and clayey silt with calcareous character and Phosphate mineral. Organic clay, fine sand beds, and peat layers are typical. Further the project area lies in hazards and foundation instabilities area with areas of low bearing capacity where site is prone to settling due to soft, silty clay, peat, and plastic clay beneath the soil cover . The 3D Finite Element Method software has been taken into consideration as the primary tool for the analysis of data for this study. The pile wall adjacent to excavation was analyzed using 3D finite element analysis software.

2.1 Geometry and Meshing

The size of the finite element model were chosen so that the boundaries are far enough apart to produce any limitation or strain localization in the analysis. The current building was anticipated to have a shallow footing at 1.5 m depth and a 10 × 10 m excavation area. It should be noticed that the adjacent building's foundations comprise three strip footings, each one is 10 meters in length and 2 meters in width (Bf). Any of these strip footings should cause more strains and deformations in the soil in the short direction of the footing than in the long direction.At least 2B should be used for the boundary conditions , or 4 meters, away from the footing in the short direction. In the current analysis, the boundary conditions are 5 m from the footing in both the short and long directions. Such a distance is sufficient to prevent any localization of strain or stress. Figure 3 shows a section view of the finite element model for the excavation, support wall, and nearby structure. Pile walls were only used to support the excavation site adjacent to the building's foundation. The lateral perpendicular mobility of the other three sides was restricted. Only to show the footing shape and pile arrangement, soil above the foundation level was removed. However, the analysis took the removed soil into account.

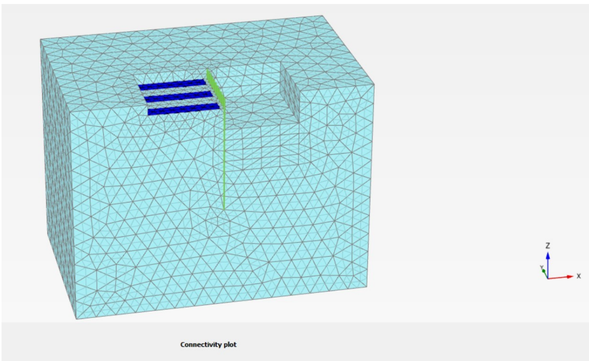

Figure 3: Finite element mesh for the model of excavation-cut view

2.2 Soil Model

Soil property obtained as secondary data are used for the modeling. Also three specific type of soil namely, cohesionless soil, cohesive soil and purely cohesive soil are used for the material modeling. Firstly, Purely Cohesive soil was used in the FEM analysis.

Table 1: Input Properties

Parameter	Symbol	Soil (0m-30m)	Unit
Material Model	Material Model	Mohr-Coulomb	
Saturated weight	γ_b	18	kN/m^3
Unsaturated weight	γ_b	16	kN/m^3
Modulus of Elasticity (Stiffness)	E	50 C_u	kN/m^2
Stiffness Increment	E_{inc}	0	kN/m^2
Cohesion	C u	27 &54	kN/m^2
Friction angle	ϕ	0 for clay	Degree
Friction angle	ϕ	15 for silt	Degree
Poisson ratio	ν	0.3	-
Interface stiffness ratio	R_{inter}	1	-
Drainage Type	Drainage Type	Undrained	-

2.3 Excavation Supporting System

As an excavation supporting wall in this investigation, pile walls were used. It was modeled as a massive discrete circular concrete pile with an outside soil interface. In the investigation, piles with a diameter of 500 mm and pile walls that varied in length were taken into account. The piles are modeled with a center-to-center distance of two pile diameters. The concrete pile was represented as being made of linear elastic material with an elastic modulus of 2.5 x 10E07 kN/m^2, a Poisson's ratio of 0.2, and a unit weight of 25 kN/m^3. The rough soil contact surface was taken into account.

2.4 Adjacent Building foundation

It was considered that the adjacent building had isolated, shallow footings. For simplicity of modeling, the adjacent building's foundation is represented as three strip footings. In order to imitate the strip footings, 10m long, 2m wide, and 0.5m thick plates were used. A rough interface element that is automatically generated was employed to represent the contact between the footing components and soil. Modeling of the footing used concrete with a linear elastic modulus of elasticity of 2.5 x 10e7 kN/m^2, a Poisson's ratio of 0.2, and a unit weight of 24 kN/m^3.

2.5 Stage Construction

Analysis procedure was divided into four stages.First, apply the first stressors condition during the initial step. The second stage involves activating and loading the nearby building footings. The third stage is to activate piles in soil. The final step is to excavate the soil to the appropriate depth.

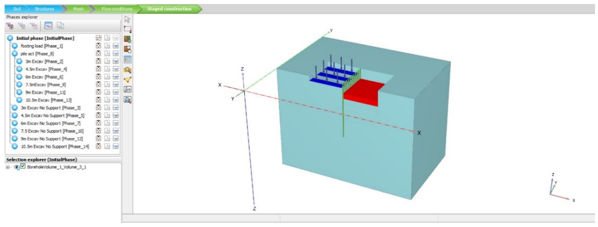

Figure 4: StageConstruction

3. Results and Discussion

Parametric analysis has been carried with the variation of design parameters. The considered parameters were the pile wall length (Lp) = 16, 20, 22 and 24 m, pile embedded depth (D), pile diameter (d) = 500mm, excavation depth (H)= 3, 4.5, 6, 7.5, 9 and 10.5m, undrained cohesion of soil = 27kN/m^2 and 54 kN/m^2 and stress at adjacent building foundation qs = 100 kN/m^2 and 200 kN/m^2.

3.1 Importance of support system

The soil displacement distribution at various excavation depths (H=3, 4.5, 6, 7.5, 9, and 10.5 m) with and without an excavation supporting wall at a vertical stress of 100 kN/m^2 at the adjacent building foundation level is shown in the figures below. When the excavation is supported by a cantilever pile wall, soil movement is reduced above the excavation level, that is, beneath the foundation level of the neighboring building.

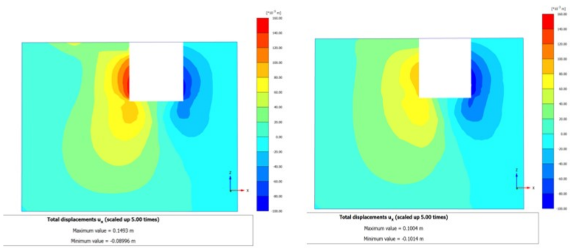

Figure 5: lateral deflection distribution for different excavation depth with and without pile wall support system

3.2 Effect of Excavation Depth

The distribution of lateral deflection for soft and medium clay examples is shown in Figure 6. It has been found that for a given embedded depth, increasing excavation depth results in higher lateral deflection values. This can be taken to mean that the lateral pressure on the pile wall will increase as excavation depth increases.

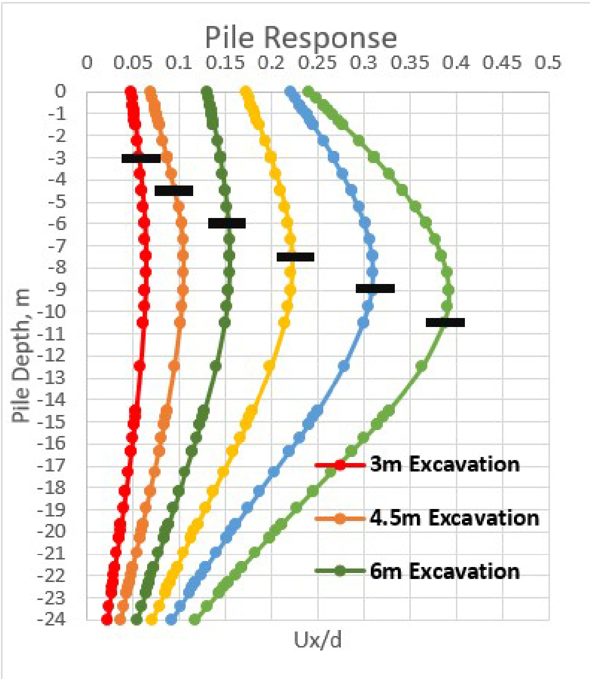

Figure 6: Lateral deflection for excavation depth 3, 4.5, 6, 7.5, 9 and 10.5m, pile length 24m, cu = 27kN/m^2 and qs = 100 kN/m^2

3.3 Effect of Clay Undrained Shear Strength

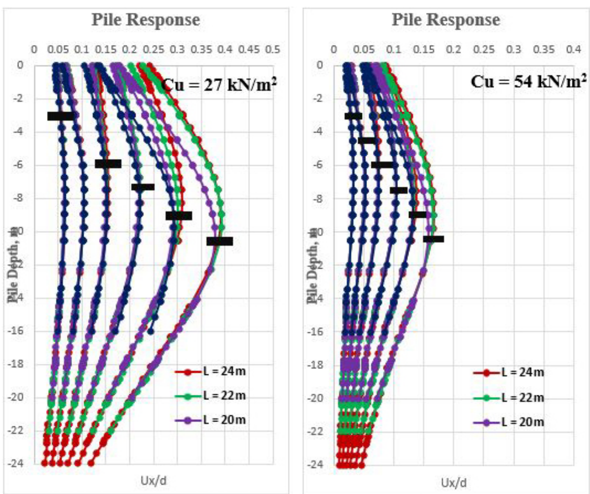

Figure 7: Lateral deflection distribution of pile wall for different cohesion value, cu = 54, and 27 kN/m^2 for excavation depth 3, 4.5,6, 7.5, 9 and 10.5m

Figure 7 illustrates how much soil's undrained shear strength influences lateral soil movement. The distribution of pile wall lateral deflection for different cohesion values, cu = 54 and 27 kN/m2, at various pile wall lengths is shown in Figure 7. It has been found that as the undrained shear strength (cu) increases, the lateral wall deflection reduces because there is less soil movement, as Poulos and Chen determined (1995).

3.4 Effect of Applied Building Foundation Stresses (q_s)

The The lateral pressure, lateral soil movement, and straining activities in the pile wall are significantly influenced by the applied stress at the adjacent building foundation level (qs). Figure **??** shows the distribution of lateral deflection of a pile wall for different wall lengths at various values of qs at the foundation level of an adjacent building (-1.5 m) for piles with a diameter of 500 mm and c_u = 27 kN/m^2. These graphs show that the magnitude of lateral deflection is significantly influenced by the amount of applied stress. It has been established that as applied stress increases, the lateral deflection also rises, making the lateral deflection directly proportional to the vertical stress on the foundation.

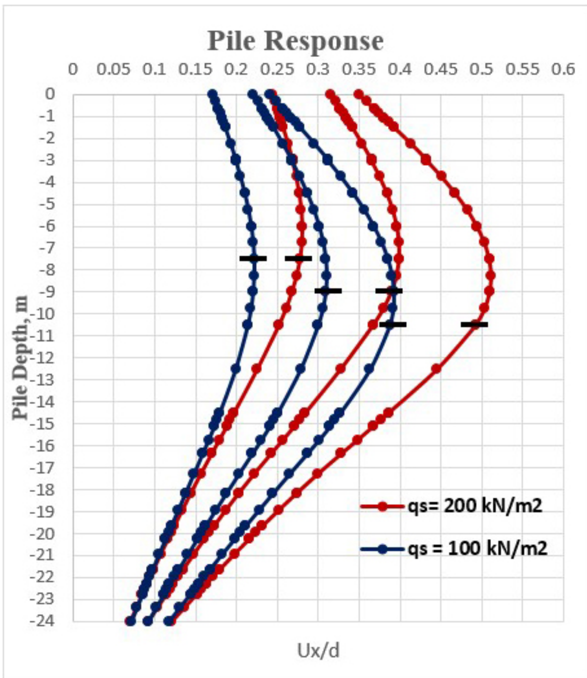

Figure 8: Lateral deflection distribution of pile wall for excavation depth 7.5,9 and 10.5m, qs = 100 kN/m^2 and 200 kN/m^2 and cu = 27 kN/m^2.

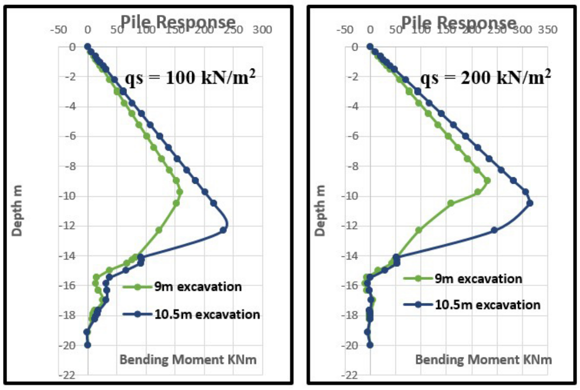

Figure 9: Bending moment for 20m pile length and excavation depth 9 m and 10.5 m, c_u =27 kN/m^2 and qs = 100 kN/m^2 and qs = 200 kN/m^2

4. Conlusion

Pile Walls were investigated as an excavation supporting system in this study. For constructions with budget constraints, a cantilever pile wall is commonly utilized in cohesive soil since it is common and relatively inexpensive. Additionally, when a cantilever stage is present at the start of a building sequence, it typically results in excessive movements for deep excavation. Therefore, excessive movements may also be primarily caused by over-excavation. The investigation was conducted using three dimensional finite element modeling (3D FEM). A parametric analysis was conducted taking into account the wall stiffness, pile embedded depth, and excavation depth, adjacent foundation stress. The effectiveness of cantilever Pile Wall in reducing vertical settlement of the adjacent building's foundation was investigated. It was discovered that cantilever Pile Wall greatly minimizes the footing's rotation and vertical settlement. For rigid systems (low relative stiffness ratio "R"), situations of medium clay, and greater pile diameters, the effect is more noticeable.

Lateral displacement of the excavation face after the installation pile wall support reduces upto 3 times than that of without pile wall support.

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