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Parametric Study on Slope Reinforced With Pile

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Abstract
A slope of proposed residential building site at Bode, Bhaktapur is taken as case study to perform the stability analysis by performing parametric study on slope reinforced with piles. A residential building of load 40.47kN/m^2 is required to construct at site. Numerical Models were developed in PLAXIS 2D V20 for parametric study of vertical pile, i.e. varying the length, diameter and spacing of pile and parametric study of h-pile, i.e. varying length, diameter and length of cross beam based on Factor of Safety. Where h-pile is the combination of front and rear vertical pile and cross beam. The stability analysis of slope is performed in terms of Factor of Safety without assigning building load, i.e. Factor of Safety of the slope at natural condition and with assigning the building load at the top of slope. Comparative study of vertical pile and h-pile is performed on slope with varying the parameters and optimized the parameter of pile on slope. The result of the study is that the performance of h-pile is better than vertical pile only.

Keywords
Slope stability, Finite Element Method, Pile, Factor of Safety, Parametric Variation

1. Introduction

Nepal is a country with wide variety of geological, topographical and climatic conditions throughout the country. Almost 83% of the country is mountainous, with fragile land and rugged terrain. Geological features such as active faults, folds and bedding planes predominate in mountainous area. Triggering factors such as earthquakes and heavy monsoon rains leads to slope failure in Nepal's young and vibrant mountains. The most common slope failure phenomenon is landslides, which poses potential hazards and risk to life and property and causes traffic disruptions on highway for days. Development activities such as road construction and quarrying have caused instability such as landslides in Nepal. Steep cut slopes on the hill side of roads create unstable conditions, and although steep slopes appear stable during the dry season, vulnerability to heavy rainfall during monsoons and earthquakes associated with Nepal cause landslides.

The proposed residential building site is located at Bode, Bhaktapur. There is a slope which is unstable and there is a risk of slope failure. To prevent the slope from failure, different prevention technique can used i.e. soil nailing, piling and shot-crete. Height of slope is 36m and piles are more effective and economical than retaining wall because of high volume of excavation for retaining wall. Here, an attempt is made to stabilize the slope of proposed residence building at Bode, by using Piles where evaluation of pile is done by factor of safety.

Bode is an ancient Newar city in the east corner of the Kathmandu Valley and about eight miles from Kathmandu. Proposed residential building site is located in Bhaktapur district of Bagmati Province of Nepal of longitude 85°23'18" and latitudes of 27°41'29".

1.1 Slope stability using piles

Piles are structural members of timber, concrete, and steel that are used to transmit surface loads to lower levels of the soil mass. This Transfer occurs either by vertically distributing the load along the shaft of the pile (skin friction) or by applying the load directly to the underlying layer through the pile point (end bearing) [1]. Friction on the pile surface creates a drag force that opposes the compressive force of the slope. Pile driven into slope is called passive pile because it receives lateral force . With lateral loads, the pile behaves like a laterally loaded beam. They use the

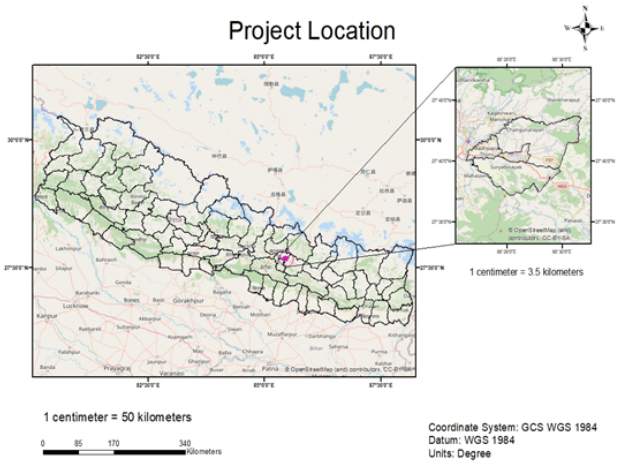

Figure 1: Location of project area (Bode, Bhaktapur)

Figure 2: Google earth image of project area

soil's lateral resistance to transfer lateral weight to the surrounding soil. When a pile is laterally loaded, some or all of the pile will tend to move horizontally in the direction of the applied force, resulting in bending, rotation or displacement of the pile. The pile pushes against the ground (a mass of soil in the direction of the applied load) in front of it, causing compressive and shear stresses and strains in the ground that resist movement of the pile.

1.2 Finite Element Method

This method is more powerful, accurate, reliable and versatile method to find the slope deformation and stress analysis. The soil mass is divided into small-node elements. This method utilizes the stress-strain relationship among the soil elements and helps better visualization of deformation of soil mass and no assumption for location of failure surface is made [2]. This method has been widely accepted for the analysis of slope stability. Strength reduction method, also called ϕ-c reduction method is used to obtain the factor of safety of the slope. In this technique, the strength parameters tan ϕ and c of the soil are reduced in steps until the soil mass fails. In this paper, we talk about the use of numerical model PLAXIS 2D based on FEM to analyze the slope.

1.3 Research Review

Many researchers have so far analyzed the stability analysis of slopes reinforced with piles using analytical or numerical models. Numerical modeling was performed using different software based on LEM or FEM to determine the safety factor. Rocscience Inc. stated that there are three important aspects that affect slope stability analysis i.e. Materials properties of model slope, Factor of Safety (FOS) and Slope failure. The shear strength of slope material in FEM is reduced by a factor .i.e. Strength Reduction Factor (SRF). A FEM model is computed. If the analysis does not converge to a solution, the SRF is reduced and recomputed. Upon converges, the SRF is incremented and recalculated. The Factor of Safety is the SRF that initiates the slope failure. Wanstreet performed finite element analysis of soil slopes and concluded that the finite element method, when used in combination with the strength reduction method, works admirably for calculating Factor of Safety and rupture areas. The safety factor of slope of soil mass can be determined using finite element analysis, a useful tool for study of slope failure [3]. Ausilio et al. used a kinematic approach to limit analysis to perform slope stability of slope and found that piles are very effective when used in the area between the bottom and the middle of the slope [4]. Surjandari et al. conducted a stability analysis of a slope reinforced with mini-piles. Variation of safety factor with different values of piles parameter i.e. dimension, depth and spacing of piles was investigated to identify optimal parameter [5]. Bo et al. conducted a study on retaining mechanism and structural properties of h type anti-slide pile (hTP pile) and concluded that this structure withstand large landslide thrust and has a good applicability[6].

2. Numerical Modeling

From the obtained geometric and material model, numerical modeling is done first for unreinforced soil slope and then to improve the stability condition of the slope, numerical modeling is done for soil slope reinforced with piles after assigning the residential building load by using PLAXIS 2D V20. Piles are modeled as embedded beam row and it is required to input the value of modulus of elasticity, poisons ratio, diameter of pile and building load is modeled as line load.

2.1 Material Model

The failure criterion of soil model is assumed as Mohr-Coulomb (elastic-perfectly Plastic). Linear elastic model is used for piles. The material model for soil are presented on Table 1 and Table 2.

Table 1: Material Model parameter of Piles

Parameters	Input value
Material Type	Concrete
Modulus of Elasticity, E(kPa)	25000000
Poisson's ratio(ν)	0.16
Unit weight, γ (kN/m$_3$)	25

Table 2: Model Parameters for soil

	Soil Type					
Parameters	SM	SW	SP-SM	Fill Material	MI	ML
Cohesion (kPa)	1.5	0	0	0	48	20
Angle of Internal Friction, ϕ(Degree)	32	37	33	32	10	15
Modulus of Elasticity, E (kPa)	15,000	38,000	20,000	8,000	10,000	4,500
Poisson's ratio,ν	0.30	0.30	0.30	0.33	0.33	0.33
Unit weight (unsaturated), γ_{bulk} (kN/m^3)	18	18	18	18	18	18
Unit weight (saturated), γ_{sat} (kN/m3)	19	19	19	19	19	19
Material type	Drained	Drained	Drained	Drained	Un-Drained	Un-Drained

2.2 Geometric Model

The cross-section of slope of proposed residential building site is formulated for numerical analysis. The geometric model is shown in figure3. The model is assumes as plain strain problem and discretized with medium mess density and 15-noded triangular element messing was done.

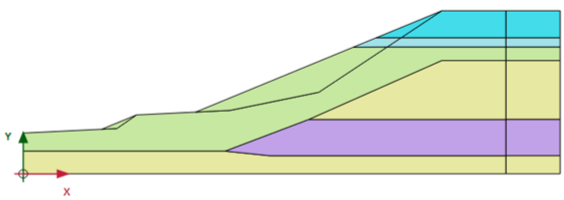

Figure 3: Geometric model of slope

2.3 Parametric Variation

2.3.1 Single Pile

A numerical model is computed by varying three parameters of the vertical pile: length, diameter and spacing of pile after finding the best position of single pile by changing the position of pile on slope. The length is 14m, 16m, 18m, 20m, and 22m and the pile diameter is 0.4m, 0.6m, 0.8m, 1.0m, 1.2m. Spacing of pile is varied in terms of diameter of pile i.e. 1.5m, 2.5m and 3.5m.

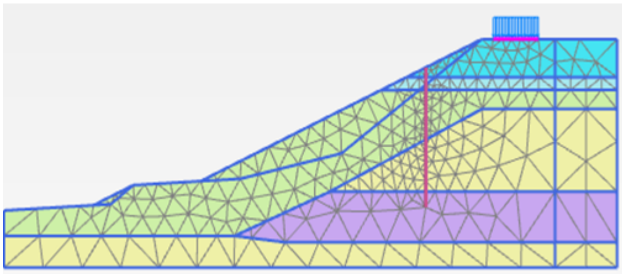

Figure 4: Single Pile of length 20m on Model slope at best location

2.3.2 h-Pile

Numerical models are computed by varying the depth of the h-pile on reinforcement slope, the length of the h-pile cross members, and the diameter of the h-pile, as shown in the figure5. The pile depth varies from 14m, 16m, 18m and 20m. The length of the crossbeam varies from 4m, 6m, 8m, 10m, 12m and 14m. Embedded beam row as a vertical member and plate as a cross beam of h-pile are taken on slope for calculation.

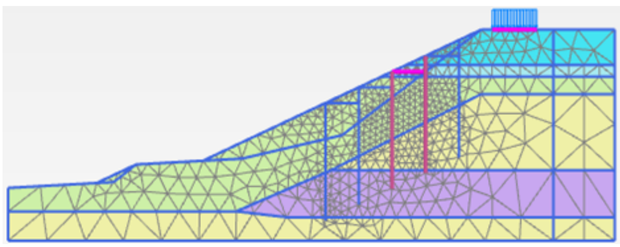

Figure 5: h-pile on Model slope of length 18m at best location

3. Result and Discussion

Factor of Safety of unreinforced slope before assigning the building load is 1.241, which is in stable condition and after assigning the building load of 40.47kN/m2, FOS found to be 1.112. Numerical models are computed by varying the dia., depth and spacing of piles and length of cross beam of h-pile. Maximum value of FOS is found to be 1.407 for single vertical pile at 1.0m diameter, 20.0m depth and 2.5m spacing. For h-pile, maximum value of FOS found to be 1.616 at 1.0m dia., 18.0m depth and 12.0m length of cross beam.

3.1 Effect of diameter of pile

During the numerical analysis, the single vertical pile and h-pile diameter is varied from 0.4 m to 1.2 m as shown in Figure 6. It is known that as the pile size increases the safety factor also increases. Surjandari et al. performed a similar study using mini piles with varying spacing and obtained similar results [5].

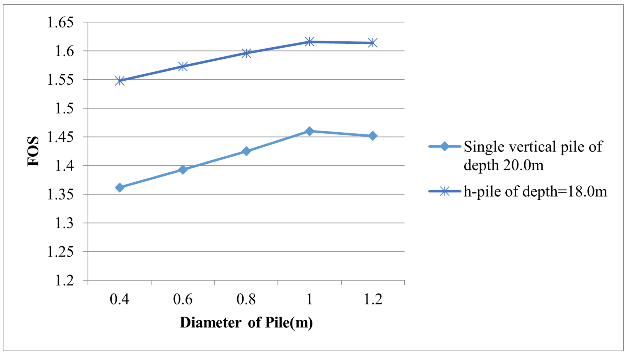

Figure 6: FOS vs diameter of pile at critical depth of pile

3.2 Effect of depth of installation of pile

During numerical analysis, depth of installation of single vertical pile is varied from 14m to 22m and 14m to 20m for h-pile as shown in figure 7. It has been found that for short distances between piles, the safety factor increases with increasing length and tends to decrease when the pile length exceeds a critical length. Liu and Liu conducted a similar study with varying pile lengths and found that the safety factor increased with increasing pile length and tended to remain constant when the pile length exceeded a critical length[7].

3.3 Effect of length of cross beam for h-pile

During numerical analysis the length of cross beam of h-pile is varied from 4m to 14m as shown in figure 8. It is found that the factor of safety increases with increase in the length of cross beam of h-pile upto critical length and remain same after exceeding optimum length of cross beam.

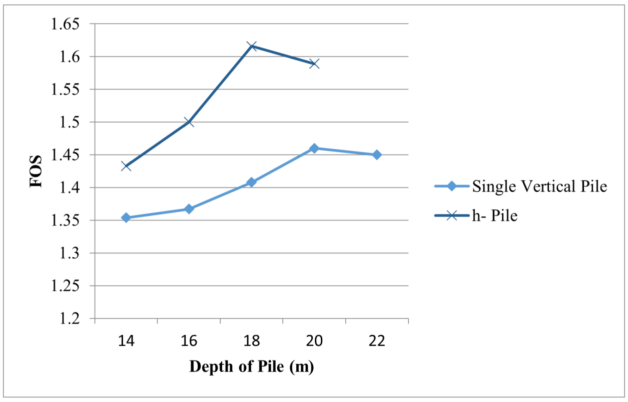

Figure 7: FOS vs depth of installation for 1.0m dia. of pile

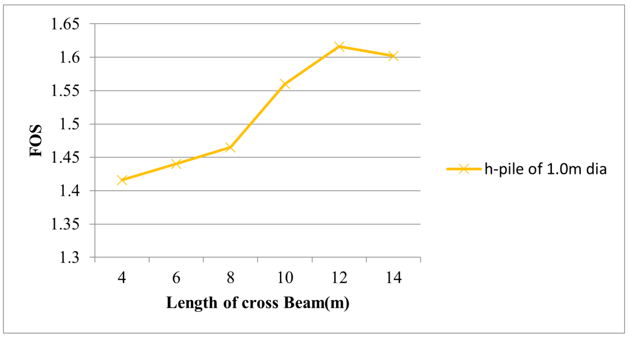

Figure 8: FOS vs length of cross beam for 18.0m depth of installation of h-pile

4. Conclusion

From Finite element analysis, based on FOS, some important conclusion drawn on the basis of results are follows:

- Factor of Safety increase with increasing depth of installation of pile and decrease when depth of installation of pile exceed the critical depth. Hence critical depth for single vertical pile is 20.0m and 18.0m for h-pile.
- Factor of Safety increase with increasing the diameter of pile and tends to decrease when diameter of pile exceed critical diameter. Hence, critical diameter for single vertical pile and h-pile is 1.0m.
- Factor of safety increase with increasing the length of cross beam up to optimum length i.e. 12m and remain constant after exceeding this optimum length of cross beam.

Hence, FOS for single vertical pile is 1.46 and 1.616 for h-pile. h-piles have proven to be an effective slope stabilization technique because the required safety is easily achieved with in permissible limit.

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