

FOUNDATION DESIGN AND SLOPE FAILURE PROTECTION FOR A LARGE COMMUNITY BUILDING IN KHANOM, NAKHON SI THAMMARAT

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ABSTRACT: In geotechnical engineering, the bearing capacity of soil to support the building loads applied to the ground and slope failure behavior analysis have significance for design protection in important buildings (e.g., roads, dams, soil embankment), and land filling procedure before construction in Thailand. Frequent landslides and mistake on foundation designs occur in Khanom, causing properties damage and casualties. This study aimed to analyze ultimate bearing capacity of soil and study the influence of unsaturated slope stability on a hill range in one particular southern part of Thailand (Khanom district in Nakhon Si Thammarat province). A GIS survey, the area's geology, geotechnical laboratory results and rainfall intensity were carried out and analyzed in order to verify the use of factor of safety for an early warning indicator. Moreover, the research focuses on designing foundation and calculation ultimate bearing capacity of soil that necessary for a site engineer at large communication building in Khanom, Nakhon Si Thammarat. In the analysis result, suitable shallow foundation is 0.7 x 0.7 m² of square footing put on lower soil (SM) 70 cm with the ultimate bearing capacity 82.54 t/m².

Keywords: *Factor of Safety, Bearing Capacity, Foundation Design, Slope Failure Protection, Finite Element Method*

1. INTRODUCTION

Foundation design process is the most significant part of any structure because foundation gets the load of the total building [1]. The main objective of foundations is to structurally support the building by transferring the loads of the building through the surrounding soil. There are difficult to determine the exact ultimate bearing capacity of shallow foundation, because of variability parameters in unsaturated soil slope such as permeability behaviour (e.g., rainfall characteristics the amount of water in the soil and suction drawn on a curve called Soil Water Characteristic Curve (SWCC), k-function), soil properties (e.g., unit weight, angle of friction, cohesion of soil), hydrogeology (e.g., hydraulic conductivity, moisture content, groundwater table), and others such as vegetation cover. Overall, rainwater infiltration is among the most significant triggering factors [2].

The mistake on foundation design can lead to loss of properties and casualties. Two standards to be satisfied in the analysis and design of a shallow foundation in Khanom slope are the mechanical behaviour based on basic physical properties (grainsize distribution, sieve analysis, Atterberg's limits) and the permeability behaviour in slope stability analysis landslide triggering by rain infiltration.

Unstandardized soil properties laboratory testing or wrong procedure to determine the type of soil lead to mistake in soil data base and waste the time to design construction for a building. A bearing capacity analysis for a shallow foundation has been necessitated by the result of soil laboratory at Khanom site.

Determining permeability function at a site can be measured directly through various in-situ and laboratory tests [3]. Chollada K., Tanan C., and Panupong T. [4] used the temporal pore water pressure distributions derived from the seepage analysis. Slope stability analysis with regard to the outcome of Factor of safety (F.S.) was produced for case study area. These results indicated that unsaturated slope at case study area in Southern part of Thailand will collapse at 50 hours with F.S.= 0.940.

In this research, the permeability function from soil laboratory were used as input parameters to estimate surface infiltration rates for slope stability analysis. SEEP/W was employed to model fluctuations in pore-water pressure during a rainfall, using the computed water infiltration rates as surface boundary conditions. SLOPE/W was then carried out to compute their factors of safety. Slope at the site became unstable (F.S. less than 1) at 80 hours.

This research focuses on determining the ultimate bearing capacity of shallow foundation on

soil structure and factor of safety on slope stability analysis at Khanom district, Nakhon Si Thammarat province of Thailand for the construction of 45 large community houses and early warning of landslides.

2. DESCRIPTION OF THE STUDY AREA

This paper aimed to study and analyze the influence of unsaturated-soil slope stability on a Khanom hill range. A GIS survey, the area's geology geotechnical laboratory results and rainfall intensity data with regard to the outcome of calculated F.S. were carried out and analyzed in order to verify the use of FS_{cr} for an early warning indicator. the slope geometry in this study were based on typical residual soils in the tropical region and the works by Chollada K. [5]. Two types of soil samples were collected: Lower layer samples, to evaluate physical and basic engineering properties such as sieve analysis (D_{10} , D_{30} , D_{60}), grain size distribution (C_u , C_c), and Atterberg's limits (LL, PL, PI) ; and Upper layer samples, to evaluate the effective soil cohesion, soil unit weight and undrained shear strength of soil for estimating dimension for foundation design.

Parameters affecting shallow foundation design and landslide occurrences, such as slope geometry, related geotechnical and laboratory data, and rainfall intensity are usually needed in analytical processes that will describe in methodology (Fig. 1)

2.1 Bearing Capacity

The ultimate bearing capacity aims at determining the load that the soil under the foundation can handle before shear failure [1]. Some studies on stability of foundations have been reported by [6-8]. This paper attempts to report on analysis of shallow foundations on soil slope in Nakhon Si Thammarat. The subject shows that the majority of the bearing capacity theories involve heterogeneous soils under the foundations. Soil properties were used for the bearing capacity analysis, and therefore analytical solutions, like Terzaghi's bearing capacity theory, matched with the experimental results. [9] Developed the bearing capacity expression for footing design as follow:

$$q_{ult} = cN_c + qN_q + 0.5\gamma BN_\gamma \quad (1)$$

Where

q_{ult} is the ultimate bearing capacity

c is cohesion of soil, γ is soil unit weight of soil

B is width of footing

N_c , N_q , N_γ is Terzaghi's bearing capacity factors depend on soil friction angle (ϕ)

Indian Standard [10] recommends that for the computation of ultimate bearing capacity of a shallow foundation in general shear failure, following equation may be used:

$$q_{ult} = S_c W_c c N_c + S_q W_q q N_q + S_\gamma W_\gamma 0.5 \gamma B N_\gamma \quad (2)$$

Where

q_{ult} is the ultimate bearing capacity

c is cohesion of soil, γ is unit weight of soil

B is width of footing

N_c , N_q , N_γ is Terzaghi's bearing capacity factors depend on soil friction angle (ϕ)

S_c , S_q , S_γ is shape correction factors where

$$S_c = 1 - \frac{B}{L} \left(\frac{N_q}{N_c} \right) \text{ for rectangle shape} \quad (3)$$

$$S_c = 1 - \left(\frac{N_q}{N_c} \right) \text{ for circular shape} \quad (4)$$

$$S_q = 1 + \frac{B}{L} (\tan \phi) \text{ for rectangle shape} \quad (5)$$

$$S_q = 1 + \tan \phi \text{ for circular shape} \quad (6)$$

$$S_\gamma = 1 - 0.4 \frac{B}{L} \text{ for rectangle shape} \quad (7)$$

$$S_\gamma = 0.6 \text{ for circular shape} \quad (8)$$

$$W_c = 1.0 \text{ for water table below and upper foundation} \quad (9)$$

$$W_q = 1.0 \text{ for water table below foundation} \quad (10)$$

$$W_q = 1.0 - (0.5) \left(\frac{a}{D_f} \right) \text{ for water table upper foundation} \quad (11)$$

foundation

$$W_\gamma = 0.5 \text{ for water table upper foundation} \quad (12)$$

$$W_\gamma = 0.5 \left(1 + \frac{d}{B} \right) \text{ for water table lower foundation} \quad (13)$$

foundation

2.2 Unified Soil Classification System (USCS)

The Unified Soil Classification System is used in geotechnical engineering to explain the type and grain size of a soil. In USCS system, the basic physical parameters that can be used to identify soil characteristics and behavior are D_{10} , D_{30} , and D_{60} (Sieve analysis laboratory), C_u and C_c (Grainsize distribution laboratory) and LL, PL and PI (Atterberg limits laboratory). The details are described below.

2.2.1 Sieve Analysis

Sieve Analysis is a procedure for determining the particle size distribution of a granular material to pass through a series of sieves of progressively

smaller mesh size and weighing the amount of material that is stopped by sieve as a fraction of the whole mass.

The results of a sieve analysis are plotted as a grain size distribution curve and analyzed to determine the soil gradation of the particular soil. A particle-size distribution curve can be used to determine the following parameters for a given soil:

A. Effective size (D_{10} , D_{30} and D_{60}): This parameter is the diameter in the particle-size distribution curve corresponding to 10%, 30% and 60% finer. The effective size of a granular soil is a good measure to estimate the hydraulic conductivity and drainage through soil.

B. The uniformity coefficient, C_u is a crude shape parameter and is defined as

$$C_u = \frac{D_{60}}{D_{10}} \quad (14)$$

Where D_{60} is the grain diameter at 60% passing, and D_{10} is the grain diameter at 10% passing.

C. The coefficient of gradation, C_c is a shape parameter and is calculated using the following equation:

$$C_c = \frac{(D_{30})^2}{D_{10}D_{60}} \quad (15)$$

Where D_{60} is the grain diameter at 60% passing, D_{30} is the grain diameter at 30% passing, and D_{10} is the grain diameter at 10% passing.

2.1.2 Atterberg's limits

Atterberg limits method is a standard measure of the water content of fine-grained soils. Atterberg defined the boundaries of four states (solid, semi-solid, plastic and liquid) in terms of limits as follows:

- *Liquid Limit (LL)*, determines the water content at which the behavior of a clayey soil changes from plastic to liquid. Liquid Limit can be determined using the Casagrande cup method when the soil specimen is just fluid enough for a groove to close when jarred in a specified manner.

- *Plastic Limit (PL)* is defined as the moisture content where the thread breaks apart at a diameter

of 3.2 mm (about 1/8 inch). A soil is considered non-plastic if a thread cannot be rolled out down to 3.2 mm at any moisture possible.

- *Plasticity Index (PI)* is calculated as the Plastic Limit subtracted from the Liquid Limit and is an important value when classifying soil types.

3. METHODOLOGY

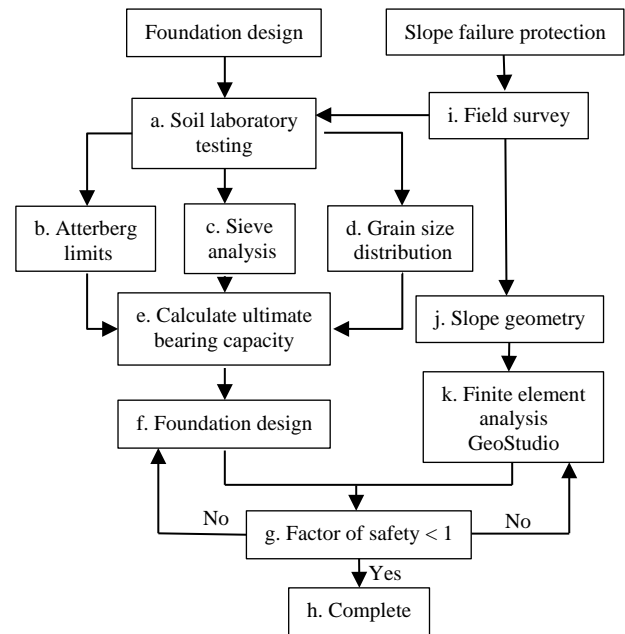


Fig. 1: Methodology

Three stages were conducted in this research: (i) Determining soil laboratory testing; (ii) Slope stability analysis from SEEP/W and SLOPE/W; (iii) Calculated ultimate bearing capacity and foundation design. These are described in more details in next section, thus:

3.1 Determining Physical Parameters Result from In-Situ Soil Sampling Laboratory on Study Area

In this topic, result from soil sampling are significant on the stability of foundation design

- Result from soil sampling laboratory

From laboratory result, SM Soil properties (Lower layer) Liquid Limit (LL) obtained from Atterberg limits laboratory testing (ASTM D 4318-04) are: 36.7, Plastic limit (PL); 26.37, and 10.33, Plastic Index (PI).

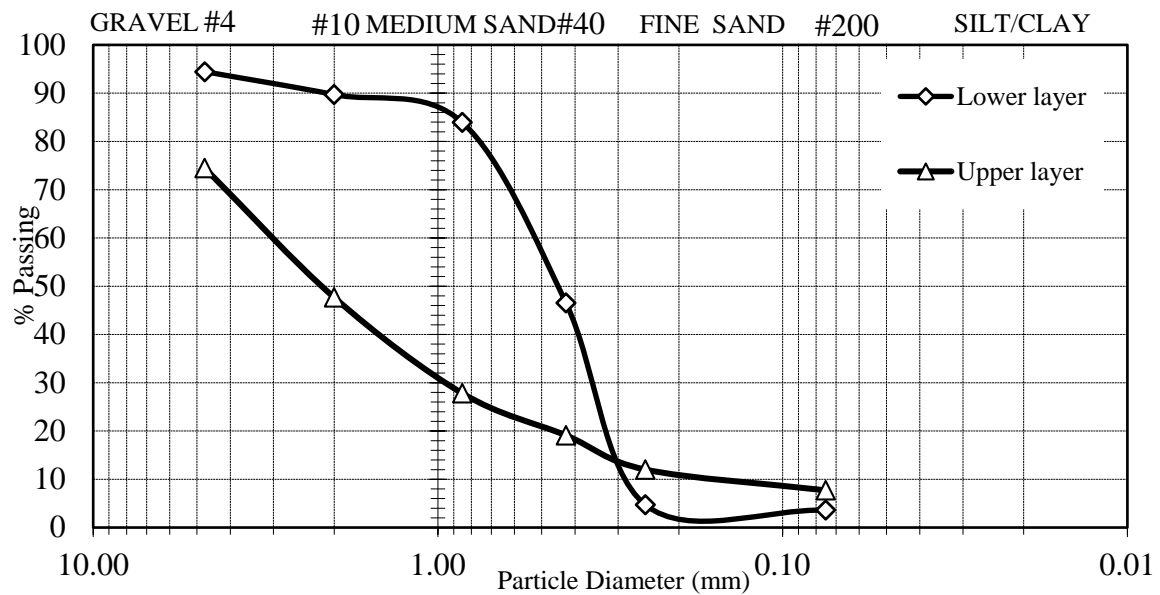


Fig. 2 Grain size distribution for upper and lower layer

As shown in Fig. 2, Soil properties size from lower layer in mm such that 10%, 30% and 60% of particles are finer than this size (D_{10} , D_{30} and D_{60}) from Sieve Analysis laboratory testing are: 2.00, 0.08 and 0.3. The coefficient of uniformity (C_u) are 0.15 and 1.01, the coefficient of curvature (C_c). From upper layer laboratory test, SP Soil properties (Upper layer) Liquid Limit (LL) obtained from Atterberg limits laboratory testing (ASTM D 4318-04) are: 35.5, Plastic limit (PL); 30.14, and 5.36, Plastic Index (PI).

Soil properties size from upper layer in mm such that 10%, 30% and 60% of particles are finer than this size (D_{10} , D_{30} and D_{60}) from Sieve Analysis laboratory testing are: 2.00, 0.80 and 0.25. The coefficient of uniformity (C_u) are 0.125 and 1.28, the coefficient of curvature (C_c).

4. Estimation Water Volume Change Characteristics of Soil from SEEP/W Results and Calculation Factor of safety (F.S.) from SLOPE/W Results

The slope geometry in this study were based on typical residual soils in the tropical region and the works by [4]. the study slope to be used in the mathematical models. There is a 80 m thick silty sand (SM) soil layer. The slope height is 80 m and the slope degree 27° . In the finite element analysis, the slope profile was divided into meshes of equal quadrilateral elements with a total number of more than 1,000 elements. The rainfall intensities 6-36 mm/hr used in the sensitivity analysis were adopted from the intensity-duration-frequency (IDF) curve for the southern part of Thailand. Boundary conditions utilized for the transient seepage analysis

are: Zero flux for the lower horizontal and the left vertical bed boundaries (there is no seepage through the base of the soil slope) and a rainfall intensity I_r for the upper horizontal boundary.

5. Calculated Ultimate Bearing Capacity and Foundation Design

Fig. 3 idealizes the foundation to be used in the mathematical models. There is a 70 cm thick graded sand (SP) of upper soil layer with the soil unit weight 2.6 t/m^3 , cohesion of soil 0 and soil friction angle 25° . In lower layer of soil, there is silty sand (SM) soil with the soil unit weight 2.68 t/m^3 , cohesion of soil 10.5 and soil friction angle 14° .

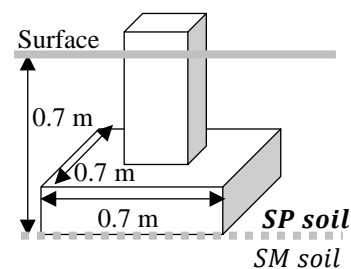


Fig. 3 Foundation and soil property of the site.

- Step by step bearing capacity problem solver

Step1 Find N_c , N_q , N_γ (In silty sand soil: $\phi=14^\circ$)
 $N_c=11$, $N_q=4$, $N_\gamma=1.2$

Step2 Find S_c , S_q , S_γ (Shape correction) When $B \times L$
 $= 0.7 \times 0.7 \text{ m}^2$

$$S_c = 1 - \frac{B}{L} \left(\frac{N_q}{N_c} \right) = 0.63$$

$$S_q = 1 + \frac{B}{L} \tan \phi = 1.25$$

$$S_\gamma = 1 - 0.4 \frac{B}{L} = 0.60$$

Step3 Find q_{ult}

$$q_{ult} = S_c c N_c + S_q q N_q + S_\gamma \frac{1}{2} \gamma B N_\gamma$$

$$q_{ult} = 82.54 \text{ t/m}^2$$

Soil laboratory parameters and Terzaghi's bearing capacity theory was adopted to calculate the ultimate bearing capacity for foundation design. The results were showing the ultimate bearing capacity 82.54 t/m^2

6. RESULT AND DISCUSSION

Two stages were conducted in this topic: (i) Results from slope stability analysis; (ii) Results from the soil sampling laboratory for foundation design. These are described in more details in the next paragraph:

6.1 Results for The Khanom Case Study

A GIS survey, the area's geology, geotechnical laboratory results and rainfall intensity were carried out and analyzed in order to verify the use of factor of safety for an early warning indicator. SEEP/W was used to model fluctuations in pore-water pressure with rainfall intensities from the Thailand's intensity-duration-frequency curve, using the computed water infiltration rates as surface boundary conditions. SLOPE/W were used to calculate factors of safety and time when slope become unstable. Results for the Khanom case study show that slope at the site became unstable at 80 hours with the factor of safety (F.S.) = 0.960.

6.2 Results from The Soil Sampling Laboratory for Foundation Design.

The basic properties results from the soil sampling laboratory (Sieve Analysis, Grain Size Distribution, Liquid Limit, Plastic Limit, Shrinkage Limit) for upper and lower soil layer were compared were shown in Table.1 for estimating dimension for foundation design that necessary for an engineer at Khanom site.

Table 1 The Soil Sampling Laboratory for Foundation Design.

Soil Properties	Soil Sample	
	Lower layer	Upper layer
Liquid Limit (LL %)	36.7	35.51
Plastic Limit (PL %)	26.37	30.15
Plastic Index (PI %)	10.33	5.36
Soil Classification	Silty-Sand (SM)	Graded-Sand (SP)
The coefficient of uniformity, C_u	0.15	0.125
The coefficient of curvature, C_c	0.01	1.28
D10	2	2
D30	0.08	0.8
D60	0.3	0.25

7. CONCLUSIONS

This paper focuses on determining factor of safety on slope stability analysis and the ultimate bearing capacity of shallow foundation on soil structure at Khanom in the Nakhon-Si-Thammarat province of Thailand for the construction of 45 large community houses and early warning of landslides. SEEP/W was employed to model fluctuations in pore-water pressure during a rainfall, using the computed water infiltration rates as surface boundary conditions. SLOPE/W was then carried out to compute their factors of safety. Increasing rainfall intensity induces increased matric suction and decreased shear strength in soil mass. Increasing amount of moisture from the rainfall leads to reduced slope stability. The F.S. is an inverse relationship with rainfall precipitation, moisture content and coefficient of permeability changes. Slope at the site became unstable at 80 hours with the factor of safety (F.S.) = 0.960. It can be used as an early warning indicator for landslide. For suitable shallow foundation in this case study, The results were showing $0.7 \times 0.7 \text{ m}^2$ of square footing put on lower soil (SM) 70 cm the ultimate bearing capacity 82.54 t/m^2 .

8. ACKNOWLEDGMENTS

I am very grateful to the Thailand Royal Irrigation Department is kindly acknowledged for providing the 30-year monthly rainfall data in its vicinity. Thanks are due to a former RMUTSV Trang lecturer, Mr. Daniel Edward Guiney, in rendering helpful reviews and in polishing up somewhat the English of the paper.

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