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DEVELOPING A FOUNDATION DESIGN SOFTWARE "GEOSOFT"

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Abstract

This report presents the development of a Foundation Design Software System. The preliminary objective of this project is to develop the correlation between soil profile and allowable bearing capacity for any type of foundation design. In order to achieve this target, the author decided to develop a software which can fulfill the requirements of a Geotechnical Engineer.
Key words: Soil profile; foundation design; allowable bearing capacity; software.

Introduction

All engineered structures resting on the earth, including earth fills, dams (both earth and concrete), buildings, and bridges, consist of two parts, the upper or superstructure, and the lower or foundation. The foundation is the interfacing element between the superstructure and the underlying soil or rock. In the case of earth fills or earth dams there is no clear line of demarcation between the superstructure and the foundation.

Foundation engineering is the art and science of applying engineering judgment and the principles of soil mechanics to solve the interfacing problem. It is also concerned with solutions to problems of retaining earth masses by several types of structural elements such as retaining walls and sheet piles.

Foundation engineering is also the art and science of using engineering judgment and the principles of soil mechanics to predict the response of earth masses to changed conditions of geometry and/or loads.

To calculate bearing capacity of a ground, friction angle and cohesiveness of different soil layer's have to be considered.. These two parameters can be determined by conducting field tests as well as laboratory tests. These two parameters can be correlated with field test parameters (e.g.: friction angle and cohesiveness are correlated with Field SPT 'N' value). There are many types of field tests available to determine friction angle and cohesiveness of soil layers. However, each test has few advantages and disadvantages. Two common field tests are as follows:

- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)

Standard Penetration Test (SPT) is accepted in many countries (especially most of the American and Asian countries) due to the simplicity, quickness and low testing cost. In addition, most of the field data such as Field SPT 'N' value, depth of ground water table, thickness of each soil strata, etc. can be collected by performing the Standard Penetration Test (SPT).

The theory of the SPT test provides a solid basis for the determination of the engineering behavior of soils. However, many inconsistencies within the test itself introduce a large degree of error, making the results unreliable. According to BS-1377, variations in N-values of 100% or more have been observed when using different standard penetration test apparatus and drillers for adjacent borings in the same soil formation. Variations in the N-value can most often be traced to a variation in the hammer-transferred energy. This is primarily due to a lack of standardization for the hammer and hammer drop system.

The SPT blow count value, N, has been used as a means of estimating relative density and liquefaction. Early work related relative density to blow count as a function of overburden stress. Additional research showed other factors such as vertical stress, stress history and compressibility influenced results.

The SPT 'N' value is corrected generally based on two popular methods, which are known as

- Peck et al. method
- Energy method

Among these, Peck et al. method is free from parameters such as rod length, diameter of hole, machine type, etc. Due to this, Peck et al., method is commonly practiced and generally preferred by engineers when designing foundations for supper structures.

In contrast to this method, the Energy method considers more precise input details when correcting the field SPT 'N' values. Due to this reason, this method considered as more reliable correction method than the other one.

Further more, energy method best suits for any type of soils and clays regardless of the stiffness of the clay. On the other hand, even though Peck et al. requires limited inputs, it is not suitable for the clayey soils.

When considering foundations of structures, it can be classified into two major types, as shallow foundation (generally based on footing design) and pile foundations.

The shallow foundation design is mainly based on some important parameters such as foundation width, length and the depth. In addition to these details, the magnitude of load of the intended structure should be obtained by consultation of the structural engineer.

When considering the history of the foundation analysis, there are mainly four authors who have contributed most. In software, developed here these four methods in designing the foundation are incorporated It is the option of the designing engineer to select the most appropriate method, which suits the particular circumstance. Among these, Terzaghi's equation is generally suitable for academic purposes. The equations given by Meyerhof and Hansen are popularly used for commercial design of foundations.

Settlement of foundations plays a vital role in the foundation design procedure. Foundation settlement is known as any sort of movement that a foundation makes, caused by forces in the environment. Foundation settlement must be estimated with great care for buildings, bridges, towers, power plants and other large scale structures involving high cost. On the other hand for structures like earth dams, levees, braced sheeting, and retaining walls a greater margin of error in the settlement can usually be tolerated.

There are two major components making up the final settlement quantity: i.e., immediate settlement and consolidation settlement. In consolidation settlement there are two parts: i.e., primary consolidation and secondary compression settlement. All these factors are considered in the software "Geosoft" developed here, when calculating the total settlement of the foundations.

In addition to the shallow foundation, the software can be used for pile foundation design. Pile foundations are a deep foundation type and form the part of a structure used transfer the load of the structure to the bearing ground located at some depth below ground surface.

The main components of the deep foundation are the pile cap and the piles. Piles are long and slender members, which transfer the load to deeper soil or rock of high bearing capacity, avoiding shallow soil of low bearing capacity. The types of materials used for piles are wood, steel and R/F concrete.

SPT test

The boreholes shall be cleaned out to the required depth in such a manner as to not disturb the soil at the depth at which the test is to be performed. The cleaned split-barrel sampler is then attached to the sampler rods and lowered to the bottom of the hole. The drive assembly is next connected to the rod. The sampler is next driven into the ground with blows from the hammer falling through 76 cm.

The test consists of the following steps:

- Driving the standard split-barrel sampler to a distance of 460 mm into the soil at the bottom of the boring.
- Counting the number of blows to drive the sampler to last two 150 mm distances (total = 300 mm) to obtain the N number / Field SPT 'N' value using a 63.5 kg driving mass (or hammer) falling "free" from a height of 760 mm.

After completing the field borehole investigation, the 'N' values obtained from the test has been corrected either by method proposed by Peck et al., or the good old energy method.

Peck et al. Method

$$N_{Corrected} = N_{Field} \times C_N$$

Where,

N_{Field} = SPT value at particular depth in the field

C_N = $(95.76 / Po')^{1/2}$

Po' = Effective overburden pressure

= Depth of foundation × γ_{wet}

Energy Method

$$N = N_{Field} \times C_N \times \eta_1 \times \eta_2 \times \eta_3 \times \eta_4$$

Where,

N_{Field} = SPT value at particular depth in the field

C_N = $(95.76 / Po')^{1/2}$

Po' = Effective overburden pressure
= Depth of foundation × γ_{wet}

η_1 = (Er / Erb) = (Er / 70)

Er = Actual energy ratio

Erb = Standard energy ratio

η_2 = Rod length correction

η_3 = Sampler correction

η_4 = Borehole diameter correction

Once we do the correction, the software allows the user to calculate the bearing capacity factors using four main equations.

Terzaghi's Equation

$$q_{ult} = cN_c s_c + qN_q + 0.5\gamma BN_\gamma s_\gamma$$

Where,

q_{ult} = Ultimate bearing capacity

c = Cohesion of soil

N_c, N_q, N_γ = Bearing capacity factor

s_c, s_γ = Shape factors

γ = Unit weight of material

B = Least lateral base dimensions

Meyerhof's Equation

For vertical load :

$$q_{ult} = cN_c s_c d_c + qN_q s_q d_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma$$

For inclined load :

$$q_{ult} = cN_c d_c i_c + qN_q d_q i_q + 0.5\gamma BN_\gamma d_\gamma i_\gamma$$

Where,

d_c, d_q, d_γ - Depth factor

i_c, i_q, i_γ - Inclination factor

ϕ = Angle of internal friction

$$N_q = e^{\pi \tan\phi} \tan^2(45+\phi/2)$$
$$N_c = (N_q - 1)\cot\phi$$
$$N_\gamma = (N_q - 1)\tan(1.4\phi)$$

Hansen's Equation

For general:

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

When $\phi = 0$,

$$q_{ult} = 5.14 s_u (1 + s'_c + d'_c - i'_c - b'_c - g'_c) + q$$

Where,

g_c, g_q, g_γ - Ground factors

b_c, b_q, b_γ - Base factors

$$N_q = e^{\pi \tan\phi} \tan^2(45+\phi/2)$$
$$N_c = (N_q - 1)\cot\phi$$
$$N_\gamma = 1.5(N_q - 1)\tan\phi$$

Vesic's Equation

For general:

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

When $\phi = 0$,

$$q_{ult} = 5.14 s_u (1 + s'_c + d'_c - i'_c - b'_c - g'_c) + q$$

Where,

$$N_q = e^{\pi \tan\phi} \tan^2(45+\phi/2)$$
$$N_c = (N_q - 1)\cot\phi$$
$$N_\gamma = 2(N_q - 1)\tan\phi$$

When calculating the bearing capacity, the software enables the user to consider about water table correction and eccentricity to ensure a accurate value.

After finding the bearing capacity, the next step is to calculate the allowable settlement of the intended foundation.

Settlement – Elastic Theories

$$s = q\,B\,\frac{(1-\mu^2)}{E_s}\,I_w$$

Where,

q = Intensity of contact pressure
B = Least lateral dimension of foundation
μ = Poisson's ratio
E_s = Modulus of elasticity of soil
I_w = Influence factor

Settlement –Terzaghi & Peck Method

$$\rho_B = \frac{3\,q}{N}\frac{(2B)^2}{(B+1)^2}$$

Where,

ρ_B = Settlement of foundation in inches
q = Applied bearing pressure in tons/ft^2
B = Width of the foundation in feet
N = Average SPT value over a depth of 2B

Estimation of Pile Bearing Capacity

The software can be used for the design of pile foundations. For that purpose, it is necessary to calculate point bearing capacity and frictional resistance.

The ultimate load carrying capacity of a pile is given by a simple equation as the sum of the load carried at the pile point plus total frictional resistance derived from the soil-pile interface or

$$Q_u = Q_p + Q_s$$

Where,

Q_u = Ultimate pile capacity
Q_p = Load carrying capacity of the pile
Q_s = Frictional resistance

$$q_u = q_p = cN_c + qN_q + \gamma DN_\gamma$$

Because the width D of a pile is relatively small the term γDN_γ may be dropped from the right side of the preceding equation without introducing a serious error or

$$q_p = cN_c + q'N_q$$

Note the term q has been replaced by q' in above equation to signify effective vertical stress. Hence the point bearing of piles is

$$Q_p = A_p q_p = A_p(cN_c + q'N_q)$$

Where,

A_p = Area of pill tip
c = Cohesion of the soil supporting the pile tip
q_p = Unit point resistance
q' = Effective vertical stress at the level of the pile tip
N_c, N_q = The bearing capacity factor

There are several methods for determining the bearing capacity factors N_c, N_q including Meyerhof's method, Vesic's Method and Janbu's Method.

The Frictional or Skin resistance of pile may be written as

$$Q_s = \sum p\,\Delta L f$$

Where,

ρ = Perimeter of the pile section
ΔL = Incremental pile length over with ρ and f are taken constant
f = Unit friction resistance at any depth z

The total ultimate load carrying capacity of a pile has been determined by summing the point bearing capacity and frictional resistance a reasonable factor of safety should be used to obtain the total allowable load for each pile or

$$Q_{all} = Q_u / FS$$

Where,

Q_{all} = Allowable load carrying capacity
FS = Factor of Safety (normally between 2.5 – 4.0)

Settlement of Piles

The settlement of a pile under working load Q_w is caused by three factors.

$$S = S_1 + S_2 + S_3$$

Where,

S = Total pile settlement
S_1 = Settlement of pile shaft
S_2 = Settlement of pile caused by the load at the pile point
S_3 = Settlement of pile caused by the load transmitted along the pile

Determination of S_1

$$S_1 = (Q_{wp} + \xi Q_{ws}) L / A_p E_p$$

Where,

Q_{wp} = Load carried at the pile point under working load condition
Q_{ws} = Load carried by frictional resistance under working load condition
L = Length of pile
A_p = Area of pile cross section
E_p = Modulus of elasticity of the pile material.

Determination of S_2

$$S_2 = q_{wp} D (1 - \mu_s^2) I_{wp} / E_s$$

Where,

D = Width or diameter of pile
Q = Point load per unit area at the pile point Q_{wp}/A_p
E_s = Modulus of elasticity of soil at or below the pile point
μ_s = Poission ratio of soil
I_{wp} = Influence factor

Determination of S_3

$$S_3 = (Q_{ws} / \rho L) [D (1 - \mu_s^2) I_{ws}] / E_s$$

Where,

ρ = Perimeter of the pile section
L = Embedded length of pile
I_{ws} = Influence factor $[2+0.35(L/D)^{1/2}]$
$Q_{ws}/\rho L$ = Average value of f along the pile shaft

Development of Software

The objective of a development of this foundation design software was to overcome some difficulties, which are commonly faced by geotechnical engineers in designing foundations. The aim of this software is to cater following needs:

- It should have various options, where the engineer has a freedom to select a suitable method or approach that best suits the particular site.
- It should cater to both the commercial engineers for designing purposes as well as the academics for their research purposes.
- It should best suit to the local conditions.
- It should facilitate accurate on-site recommendations.

The software was named as Geosoft and was developed using Visual Basic (VB). In Geosoft, from the first input itself room had been made for both the design engineers and the academics to fulfill their requirements.

In addition to these the software can be used for both shallow foundations and for pile design.

Geosoft permits the expert engineers to change some of the stipulated values, if he strongly feels that it is not suitable for the particular location. i.e., autonomy is there for the engineer. Another important point that the author used standard parameter values in some complex calculations. These values were practically verified for the local condition with some adequate laboratory and field tests.

The other important merit of Geosoft is that the user needs not to enter separate data for each calculation. Once the user inputs the relevant data in the first sheet of the software, the software itself acquire relevant inputs for each calculation and generate the solution without any delay. Geosoft is designed as an expert system, which requires the user to have some basic knowledge in foundation design.

Conclusion

As a whole, by developing this foundation design software Geosoft, the author has achieved the set goals with high precision. Further more it has been ensured that this software can be used in Sri Lankan conditions. It is hoped that this software will change the traditional designing methodology and yield quicker and accurate recommendations in the future.

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