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CONTENTS

SRI LANKAN GEOTECHNICAL SOCIETY PROJECT DAY 2005

Geotechnical Engineering Project Day is a competition held among the undergraduate students in Sri Lankan Universities who have done final year projects in the Geotechnical Engineering field. The best project is decided by a panel of senior Engineers and Academics based on the written paper and a presentation

Stability Analysis on Watawala Landslide under Different Critical Conditions; An Application of Slope/W Software

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ABSTRACT: In this study, attention is basically paid on the stability analysis of natural slopes. However, since it takes long time to reach a final decision regarding the factors and possibility of future failure of natural slopes located in different area of the country, this project is confined only to Watawala landslide area. It can be identified that Watawala landslide was not merely occurring in particular direction. Special attention was paid to identify the potential future failure directions and locations. Though there are many methods available for stability analysis of slopes, it takes long time and also there is a possibility of making mistakes. Therefore, as a best solution SLOPE/W software can be used to analyze landslide. In this study, the variation of the factors of safety due to the variation of position of the water table and external loads are investigated for Watawala landslide using SLOPE/W software. Janbu's method is employed to obtain the minimum factors of safety for potential slip surfaces.

1. BACKGROUND

The evolution of slope stability analyses in geotechnical engineering has followed closely the developments in soil and rock mechanics as a whole. Slopes either occur naturally or are engineered by humans. Landslide is one of the most occurring slope failures in Sri Lanka. Landslides take place on slopes, and generally but not always on steep slopes, where there is already some degree of instability. Hence, landslides are commonest in the Central Hill Country of Sri Lanka, which is generally considered to be land over 300 meters above MSL. However there are seven landslide prone districts named as Nuwaraeliya, Badulla, Matale, Kandy, Kegalle, Kalutara & Rathnapura. Very recently it has been identified that Galle, Matara & Hambantota districts are also vulnerable for landslides. There is no doubt that rainfall, especially the intensity of rainfall, is the triggering factor and it helps the occurrence of landslide and other mass movements.

In this study Watawala land slide is selected as the case study. The Watawala area is located in the Western part of the Central Highlands of Sri Lanka. It occurs within the Wet Zone of Sri Lanka and in fact, experiences the highest rainfall in the Island. The upcountry railway connecting Colombo and Badulla via Peradeniya runs across the Watawala slide. This earth slides nearly a 100 meters length. The latest alarming event occurred when the Colombo- Badulla night mail train traveled with couple of thousand passengers on 3rd of June 1992. The slide follows two major joint valleys on the South- West slope of the Gallebodde- Watawala ridge. This slope extends down to the Mahaweli river and the North-East slope of the ridge drains to the Inguru Oya. The overburden of this major slope consists of colluviums, residual soil and highly weathered to completely weathered rocks. The colluviums thickness varies from a few centimeters to a few meters. The residual soil and fully weathered rocks also have similar thicknesses .Watawala landslide re-occurred on 23 rd July 1993 (NBRO report, 1994).

2. METHODOLOGY

Though there are many factors affect to the slope stability, this study mainly concern about the ground water condition and external load.
Analysis methods will be determined according to the modes of failures. As having thick residual and colluvial soil layers, circular failure surfaces can be expected. (NBRO, 1994). And also early researches had been done according to the circular failure surfaces.

NBRO had done analysis for Section XX and Section YY (Fig.1) NBRO used STABL/G program. STABL/G is the GEOSOFT version of a two dimensional, limit equilibrium slope stability program. Janbu's simplified method used to analysis the problems.

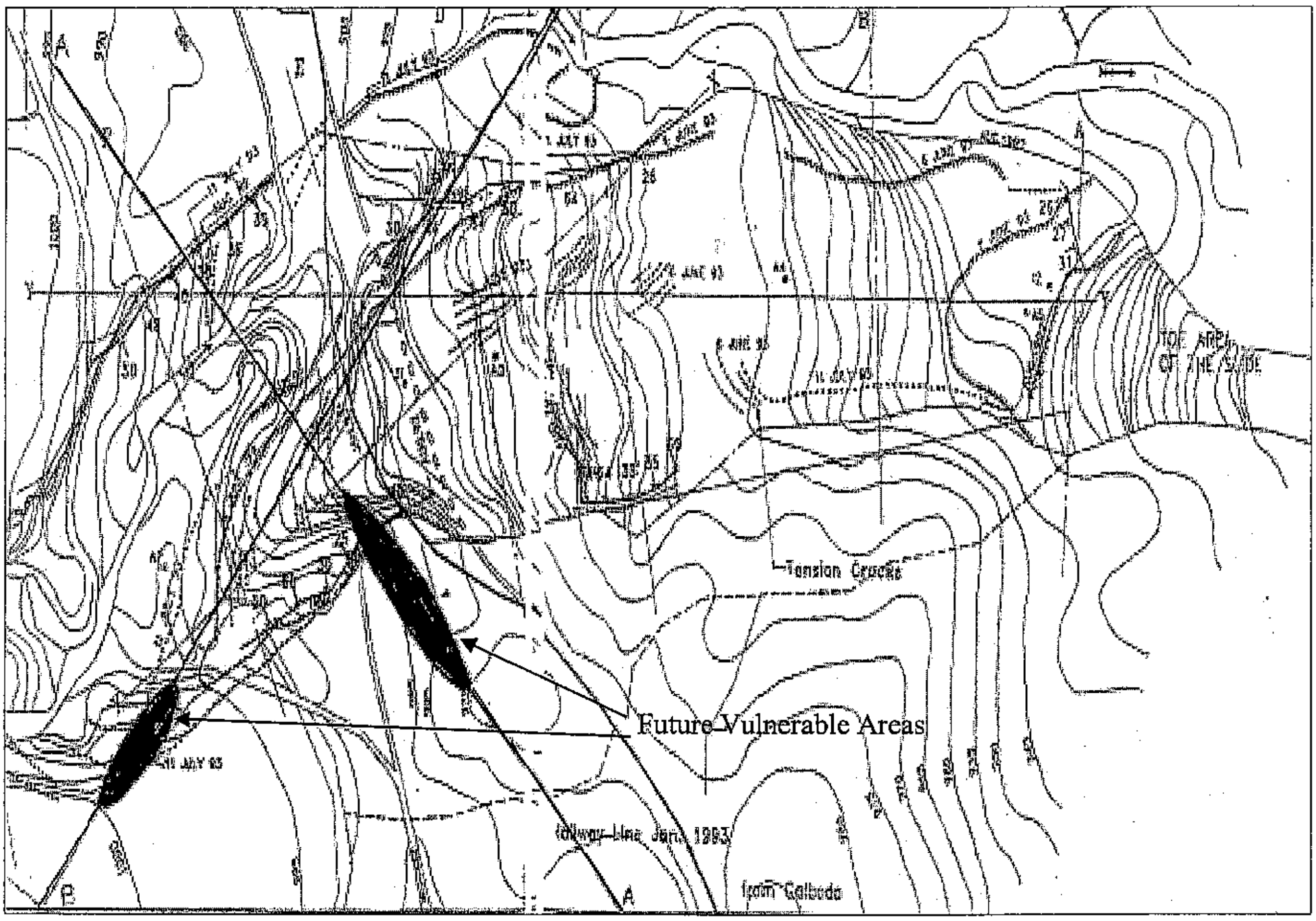

Figure 1: Plan of Watawala Landslide

NBRO had analysed considering a large area and got factor of safety values more than unity in some cases. However, NBRO had not considered surcharge load (rail load) for the analysis.

SLOPE/W is a software product that uses limit equilibrium theory to compute the factor of safety of earth and rock slopes. The comprehensive formulation of SLOPE/W makes it possible to easily analyze both simple and complex slope stability problems using a variety of methods to calculate the factor of safety.
In this study Janbu's method is used for the analysis. Because SLOPE/W software has this analysis method and it gives the minimum factor of safety values compared with other methods in the software.

Assumptions made in the Watawala Analysis,

1. Failures occur within the Colluvium layer only.
2. Shear strength parameters have been expressed in term of effective stresses.
3. Factor of safety along the slip surface is assumed to be constant.
4. The analysis is two-dimensional.
5. Ground water table

    Scenario 1
    At the surface
    Scenario 2
    At 4m below the surface

When referring to the sub slope profile at the site it could be seen that there are several layers named as Colluvium, Completely, Highly & Moderately Weathered Rock, Fresh Rock & etc. However, all slip surfaces were occurring inside the Colluvium layer. So that for the analysis, only Colluvium layer is considered. As an average its depth varying from 15m to 20m. There are significant changes in its soil properties within the considerable depth. So Colluvium layer was divided into three sub layers according to their properties. Soil properties are given in effective condition.

Table 1: Soil Properties

Types of Soil Layer	Unit Weight γ (kN/m^3)	Cohesion c' (kN/m^2)	Friction Angle ϕ'
Colluvium 1	21	0	15
Colluvium 2	21	10	29
Colluvium 3	22	10	34
Completely Weathered rock	24	15	38

(Source: NBRO)

Surcharge load

There is large scale tea plantation in Watawala. Rail way truck is passing through these plantations. Except the railway track there are small houses which are owned by labours. So there was no significant effect from the external loads against the slope stability.However, there is small vibration due to the train. It can be helped to fluctuate the ground water table. Therefore this effect was considered as a line load. A value of 22.86kN/m was used as train load. In the first part of the analysis, section YY and section XX (Figure 1) were analysed using SLOPE/W software. There were four kinds of situations according to two scenarios considering water table such as,

1. Ground water table on the ground surface with load
2. Ground water table in 4m below the ground surface with load.
3. Ground water table on the ground surface without load.
4. Ground water table in 4m below the ground surface without load.

Firstly, large slip surfaces were defined in the failure zone as NBRO's study and obtained results. Even in the failure zone, factor of safety values are more than unity. Therefore it was realized to define small failure surfaces. Then the obtained FOS values were smaller than the NBRO's research. However after doing number of progressive failure analyses real situation was obtained.

Progressive failure analyses were done by changing the slip surface and gird point; and it gave different factor of safety values for a particular location. Therefore minimum factor of safety was selected. After obtaining the required slip surface that soil mass removed to gain next critical slip surface. Similarly it was approached to the real situation by analyzing progressive failures, though there are some deviations. The obtained factor of safety values are less than the earlier values. Because defined slip surfaces were smaller than the NBRO findings .However, the depth of moving soil is almost equal.

In the second part of the analysis, section AA and section BB (Figure1) were selected to predict future failure locations in Watawala area. Those two sections were selected according to the geological features such as tension cracks (Dias, 1998) in Watawala area. In that analysis, a critical case was considered; it means Ground water table is on the ground level. Then a minimum factor of safety was found in each and every location in those paths. After that the critical locations in Watawala area were identified.

3. DISCUSSION ON THE RESULTS

Here the defined failure surfaces taken assuming progressive failures were smaller than the surfaces prepared by Dais (1998). Therefore, the obtained FOS values were smaller than those values since failures occur when the factors of safety values are less than unity. This finding gave better answers for the said Watawala landslide. Although there was a significant difference in FOS values in both methods, final depth of failure mass is equal.

There is a significant variation in FOS values with respect to the variation of GWT. However, there was no considerable effect from external load on this slope failure.

The Watawala landslide occurred in not along one direction but along many directions. Some sort of changing in soil mass movement behavior is visible. Even though some remedial actions were carried out, some failures had been initiated. So there may be some future failure along different directions .To analyze those possible paths, section AA & BB were selected according to their geological features (Figure1).

Analysis was carried out when the GWT is on the GL with the external load. Because most critical conditions had been considered while finding future vulnerable areas. Those areas can be seen in figure 1.

4. CONCLUSION

However, with careful analysis of the available data using the SLOPE/W software, it has been identified that the deviation of ground water table can make significant effect to the stability of Watawala landslide. Further, it has been identified that the effect of railway load is negligible in comparison with the effect of ground water level. When the defined failure surface is very small (about 2m) there is a considerable effect from the railway load. However, real failures occurred about 50m - 100m length. So it is not needed to analyse the small slip surfaces for the effect of the railway load. This observation tallies with many researches, which were done so far for Watawala landslide.

In addition to that , it has been selected another two sections were selected on the basis of tension cracks appeared in the ground surface and relevant to the geological features. Using the SLOPE/W software, minimum factor of safety is observed for these two sections with respect to highest position of ground water level and with rail way & train load .Analysis was carried out along the each section and found the minimum FOS value. Further, it has being identified the possible location of landslide prone area of Watawala by considering the minimum factor of safety.

The most triggering factor for Watawala landslide is found to the sudden rise of ground water table. This situation can be anticipated in Watawala area since Watawala area receives the highest rainfall in Sri Lanka. As a measure to reduce the risk of landslides it would be essential to draw down the water table, especially during the heavy rainy season. There is no considerable positive effect towards the failure of the soil mass along XX and YY sections due to railway. Similarly, no effect is observed along sections AA and BB. However, it would be essential to study the effect of dynamic loadings due to railway before making final conclusion and recommendation on the effect of railway.

5. ACKNOWLEDGEMENT

Authors are indebted to their final year undergraduate project supervisor, Dr. A.M.N Alagiyawanna and the panel for their remarkable job in giving necessary guidance and information. In addition, authors should cordially thank many industrial experts who are dealing with landslide studies in SriLanka. The industrial experts include Mr. R.M.S. Bandara, Head/ Landslide Studies and Services Division, NBRO & Eng. A.A.Virajh Dias,Engineer in Charge/ Laboratory and Site Investigation Unit, CECB.

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DEVELOPMENT OF LOW COST EARLY WARNING SYSTEMS FOR NATURAL DISASTERS IN SRI LANKA

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Designing equipment which is capable of generating an alarm of an impending natural disaster is absolutely necessary to prevent human casualties and material loss and the equipment should be affordable cost to buy by people who live in hazards prone area. In this project the early warning system is designed to give alarm for landslide, using the concept of that the precipitation of 200 mm of rainfall water in eight hours is capable of triggering a land slide. To measure the amount of rain fall and thereby decide about the possibility of land slide the permeability of the fine sand is used. The lever arm connected to the soil column triggers the electronic circuit which produces the alarm when the last eight hours rainfall precipitation reaches 200mm. This project report illustrates the way in which an early warning system which used the permeability can be designed economically attractive without significant loss in the performance. This project also suggests some ways by which the message of a possible disaster can be spread to other parts.

1. INTRODUCTION

Today it is a proven fact that natural disasters can happen at any place irrespective of the developed, developing or the least developed status of a country. It can cause unpredictable destruction to the lives and livelihoods of large population and hence, to the national economies.

The unique geo-climatic conditions have made Sri Lanka highly vulnerable to natural disasters. Central part of Sri Lanka, nearly 12,000 sq km (21%), especially hill areas are prone to landslides, a considerable amount of landmass is prone to floods, 800 km of coastline is prone to cyclones and other coastal hazards and southern part of Sri Lanka is vulnerable to droughts. In some places earthquakes has been identified. Further the recent occurrence of Tsunami on last December has worsened the situation. Only few of the earthquakes have been reported in Sri Lanka since it located in a zone where only minor seismic activities have taken place. Flood and Landslides occur mostly during the rainy seasons. Floods and landslides in Ratnapura claimed over 260 lives in the country in 28th May 2003.

The past experiences show the essential of reliable early warning systems which can provide adequate warning message before the occurrence of natural disasters. Introducing of very advance technology early warning systems at high cost is not suitable since peoples might not have awareness about new technologies. Therefore low cost equipment which could be afforded by people, who are living in these hazards prone areas, should be introduced; it should be reliable and efficient. For any early-warning system is to be efficient, it is necessary that the community is thoroughly trained, so that it gives a better response in the event of an alarm. Even before an early-warning system is installed, each step which needs to be taken upon reception of the alarm must be identified and repeatedly practiced.

2. LITERATURE REVIEW

2.1. Earthquakes

For the prediction of earthquake, dynamic behaviour of earth such as seismic activity is important. An earthquake's destructiveness depends on many factors. In addition to magnitude and the local geologic conditions, these factors include the focal depth, the distance from the epicentre, and the design of buildings and other structures.

Several techniques are available for the prediction of earthquake. They are; Premonitory changes in seismic velocities, changes in the geomagnetic field, measure the build up strains in rock adjacent to the fault (Jack Oliver, 1959). In the world, institutions such as USGS and National Earthquake Information Centre in USA are gathering and exchanging earthquake related data.

2.2. Tsunamis

Tsunamis are generated by undersea earthquakes and landslides. Tsunami behaves as shallow water wave in deep water level too. Hence it differs from the normal wave. There are many tsunami monitoring centres functioning world wide such as Alaska and Pacific Tsunami Warning Centre (ATWC and PTUC), National Earthquake Information Centre (NEIC), USGS, National Oceanographic and Atmospheric Administration (NOAA), Federal Emergency Management Agency (FEMA). The Indian Ocean already has 15 sea level gauges, which broadcast information about changes in water swells. This is enough to predict Tsunami hazard around Sri Lanka.

2.3. Floods

Floods are the most devastating and rank second disaster in Sri Lanka. Flooding risk is measured in magnitudes and frequencies. Usually, floods fall into two categories; high frequency low magnitude or low frequency high magnitude events.

The historical average daily rainfall in the South-Western corner between Ratnapura, Galle and Colombo for May is 275 mm. The heaviest rainfall on record is 600 mm during 1936; the lowest is 18 mm in 1953. The regional average rainfall for 2003 of 450 mm is high but not extreme, but last 2003 May's rainfall was concentrated in a few places in a short span of one week and particularly on the 17th. The heaviest rainfall of 899 mm was recorded at Gonapenigala Iranganie Estate and the third heaviest rainfall of 755 mm was recorded at Panilkande Estate in May 2003. The monthly rainfall in Ratnapura was 718 mm with half of that falling on the 17th of May 2003. Even though the possibility of rainfall which causes the flood exists, the chance to occurrence of flood can be minimized having good water flow control systems.

2.4. Landslide

In simple way, the landslide is stated as mass movement of land or earth from unsupported slopes. There are many types of landslides have been identified, according to the movement that takes place, landslides have been classified as translational slide, block slide, and circular failure. Change of slope gradient, excess load by embankment fills and waste dumps, shocks and vibrations, change in water content, effect of ground water, wealthy of rocks, and change in vegetation cover of slopes are important factors that controls landslide. (E.N.Branhead Feb. 1991). There are many organizations, institutes and universities involving on prediction of landslide and development of early warning system all over the world. E.g. the National Building Research Organization, (NBRO) in Sri Lanka

2.4.1. Prediction of landslide from rainfall data

After studying 64 Sri Lankan landslides, the research team at the NBRO had come to the conclusion that if the cumulative rainfall on three consecutive days exceeds 200 mm, in three or less number of days and if the rain persists, the probability landslide occurrence should be considerably high (R.K.Bandari &A.A Virajh Dias).They also examined the conclusion by Guidicini and Iwasa (1977) that rainfall events exceeding 250 – 300 mm/day should be feared to trigger landslides and, Endo (1970), based on analysis of landslides in Hokkaido between 1955 and1968, came to the conclusion that grate majority of landslides occurred when daily precipitation exceed 200 mm. Pichler (1957), Wargas (1971), Barata (1969), and Endo (1977) have all attempted correlation between landslide and precipitation levels for prediction of landslide.

2.4.2. Instrumentation for landslide prediction

The following instruments and techniques can be used for prediction of the landslides in Sri lanka; Hydraulic piezometer / Pneumatic piezometer /Electrical piezometre, Electrical Distance Measuring instrument (EDM), Tape extenso meter, Ground penetrating radar, and Deflection tube technique (R.K.Bandari &A.A Virajh Dias,1994).

The major disasters affecting Sri Lanka, namely floods, landslides, droughts and cyclones have hydro-meteorological antecedents. Last May's flooding and landslides and previous hydro-meteorological disasters such as the cyclones in 1978 and 2000 that affected the North-East and the recurrent drought that affects the South-East and North-West underscores the urgent need for local computational weather prediction.

Land slide is the disaster most commonly occurs in Sri Lanka. Available evidence suggests that the frequency and magnitudes of landslides has increased in recent years causing serious damage to life and property. NBRO which is the mandated institute for land slide hazard assessments recorded around 136 landslides during 1986 /87 period. In early June 1988, Sri Lanka experienced a devastating landslide damage, which caused over 300 deaths. So far, there were nearly 500 landslides and cutting edge failures occurred within the south-western slope of the country claming nearly 200 human lives along with considerable amount of property damage

3. DESIGNED INSTRUMENT FOR PREDICTION OF LANDSLIDE

Sri Lanka is vulnerable to so many disasters as mentioned early in this paper, in this project the early warning system is designed to give alarm only for the landslide.
The instrument is designed to give alarm by assuming that, if more than 200mm rainfall experiences in 8 hours period then there will be more chances for occurrence of landslide. Thus, instrument is designed to collect continuously eight hours rainwater; the time period of f (t)-f (t+8). The basic sensing element of the instrument is permeability of fine quarry soil and height of soil column is designed according to that the entered water travels through the soil column for eight hours.

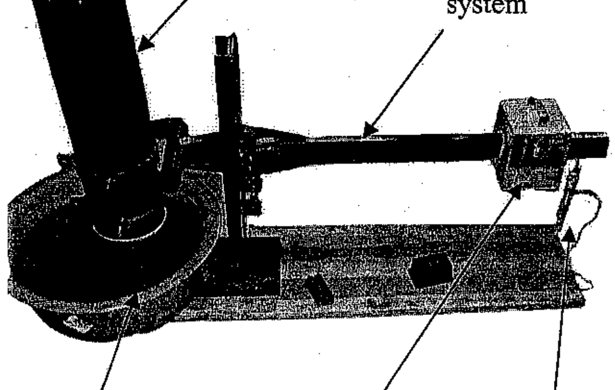

Fig 01: Instrument to give early warning for landslide

As shown in the figure 01, this instrument consists of lever arm and rain gauge arrangement. The rain gauge arrangement has vessel of water in bottom and a soil column touching the water surface. This arrangement will keep the soil in the saturated stage all the time because of the Capillary effect between soil and water (Braja M. Das, 1994). A geo textile filter is placed in the bottom of the soil column to prevent soil particle escaping down. The lever arm arrangement is fixed to the soil column and it is balanced by counter weight. A sensitive spring balance is attached to the lever arm to give indication when rainfall reaches the critical rainfall value and the alarming arrangement gives alarm at that stage.

3.1. Design detail of the instrument

3.1.1. P.V.C pipe filled with quarry soil.

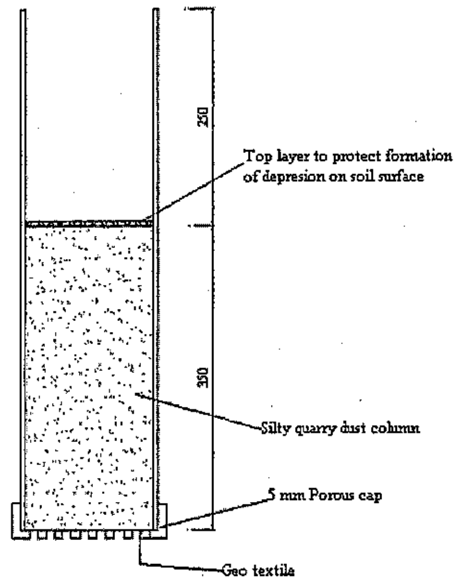

Fig 02: Typical cross-section of the soil column

The soil type and the height of the soil column were designed based on several permeability tests done on different type of soils in different particle size, and considering some other important factors which effects the permeability such as viscosity, temperature, pore size distribution and void ratio in saturated condition, and roughness of the minerals.

4. RESULTS AND DISCUSSION

4.1. Permeability Experimental Results

Suitable crusted quarry soil particles range is between150µm and 75µm. In the Constant Head Permeability Test, Coefficient of permeability for this soil was obtained as 1.36 * 10^{-5} m/s. saturated condition the void ratio was 0.876 and specific gravity of fine quarry soil was determined as 2.24.

4.2. Test result of Instrument

The instrument was tested to check the accuracy and to find out the tolerance. In that test, obtained tolerance of the instrument was 110 mm.

4.2.1. Reasons for very high value of tolerance

Rain water easily penetrates between PVC wall and soil column, since the outer surface of the soil column and inner surface of the PVC do not stick very well.

Due to large weights in both side of the lever arm, considerable amount of friction was increased at the pivot point.

PVC pipe was Inclined with vertical axis, so the water can easily reach the edge of the PVC wall and move downward

5. CONCLUSION

According to the results it can be concluded that to develop an alarming instrument to predict 200 mm of rainfall within eight hours period continuously, the instrument has to be filled with 40 cm height of crusted quarry layer which satisfies following properties.

The crusted quarry soil particles should be between 150μm and 75μm (near silt range), permeability 1.360 x 10-5 m/s, saturated void ratio nearly 0.88, and the specific gravity 2.24.

Precision of the instrument depends on the accuracy of determining the critical rainfall value for particular hazardous location.

RECOMMENDATIONS FOR FUTURE WORK

The catchment's diameter could be provided as two times the diameter of soil column. This will help to improve the accuracy while increasing the permeability by four times or reducing the height by four times for same permeability.

When designing the permeable media permeability of media and instrument height could be increased with the consideration of capillary rise.

Making the instrument with less friction at pivot will increase the accuracy and reduce the tolerance of the instrument.

It is better to avoid the particle selection into the silt range otherwise it will increase the pond and cohesive effect will cause difficulties with time. (Fine sand region is better).

Since the accuracy of instrument depends on the value of permeability, increase the number of permeability test and do it with long period of time interval for same sample; this will also reduces the tolerance.

It is better to take consideration on the following factors like temperature effect, viscosity effect of water, and method of placing the fine sand.

Instead of spring balance, a known stiffness spring or a strain gauge could be used in the alarming system.

Instrument can be placed into a room and the rainfall catching funnel could be exposure to outside, but make sure that all the water enters into the funnel reaches the instrument's permeable layer. And it can be modified for different periods of rainfall data integration like 12hours, and 24 hours for different rainfall values.

PVC pipe with rough or sticky inside surface should be used to prevent the water penetration through the edge of the PVC wall. (Clay material can be used).

To reduce the pond effect, it is better to model the instrument as shown in Fig 03.

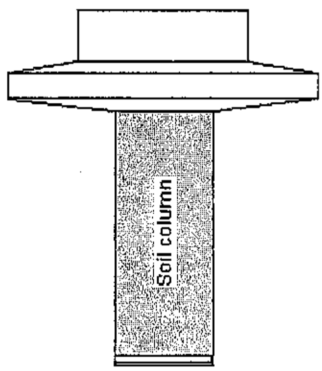

Fig 03: Alternative shape of rainwater catching funnel

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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

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

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

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

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