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Modelling Spatial Variability of Load Carrying Capacity of Soil Using GIS

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***Abstract*— Maximum load per unit area that can be imposed on a footing without causing soil rupture is known as its bearing capacity. This load may be obtained by carrying out a load test which will give a curve between average load per unit area and the settlement of the footing. Most of the bearing capacity theories are emerged from Prandtl's theory of plastic equilibrium. The most widely used method for the determination of ultimate bearing capacity is proposed by Terzaghi and Meyerhof. Terzaghi's theory is applicable only for shallow foundation whereas Meyerhof's theory can be extended for deep foundation as well. Moreover, these methods produce results for point locations only. This study aims to model and analyse the bearing capacity of soil in a spatial framework using Geographical Information Systems (GIS). The final results show the degree of load carrying capacity possible for the entire site.**

***Keywords*— Factor of Safety, Kriging, Load Bearing Capacity.**

I. INTRODUCTION

Modelling and assessment of spatial variability of Load Bearing Capacity of a region can be very crucial in site selection and design of multistoried building structures. Lack of information on soil characteristics can result in improper design leading to the instability of foundations. Urbanization coupled with scarcity of land has resulted in the construction of large number of high rise buildings. Proper and scientific study of soil bearing capacity is an essential prerequisite for planning high rise structures. Foundation, the basic component of all structures mainly resides on soil, which plays an important role in transferring load from the superstructure to the soil safely. A foundation is therefore, a connecting link between the structure and the ground that supports it [1]. Accurate estimation of soil properties is highly imperative for designing the structures. In normal procedure, physical properties of soil are analyzed by standard penetration tests conducted in boreholes. However to keep the cost of soil exploration as minimal as possible, the number of boreholes are kept as a finite set with a fair distribution across the land.

Analyzing the information generated from various borehole locations for designing the foundation can lead to inaccuracies as the soil properties in between the borehole locations are not known and assumed with limitations. For estimating the soil properties over the space, appropriate interpolation models can be used.

Geographical Information Systems offer several tools and techniques for modeling and analyzing the spatial variability and provide excellent visualization capabilities.

II. STUDY AREA

The land parcel chosen for modelling is a 4000 square meter area in the village of pallipuram, 20 kilometer north of Trivandrum city, State of Kerala, India. This site is owned by Indian Institute of Information Technology and Management, Kerala (IIITMK), an autonomous institute for higher education and Research, established by Department of Information Technology, Government of Kerala (www.iiitmk.ac.in). It is proposed to construct a residential campus with multistoried buildings for academic and hostel facilities. The site is geographically located at latitude 8° 36′ 0″ N and longitude 76° 51′ 0″ E and has a general altitude of 25 meters from mean sea level (see Figure (1)). The site has a very gentle slope from north to south.

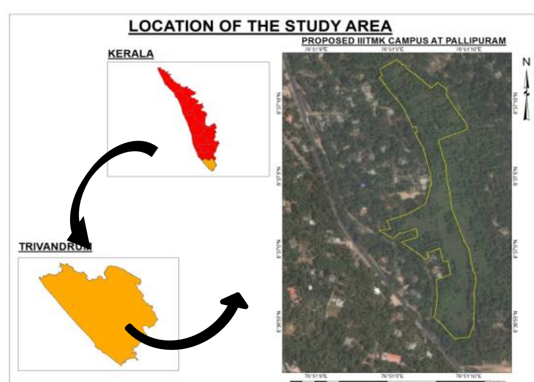

Figure (1):- location of the study area

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III. SOIL INVESTIGATION

Subsoil exploration for the site was carried out by Department of Civil Engineering, College of Engineering, Trivandrum. Boreholes of 15 cm diameter were drilled at 30 locations with a mechanical rotary type drilling rig and with necessary accessories. The boreholes were terminated at 40 meter depth from the existing ground level. The soil investigation report was based on the Standard Penetration Test (SPT), as per the procedure prescribed by Indian Standard method for standard penetration test for soils (IS Code 2131) [2]. The top layer soil was found to be very soft and loose. The ground water table was observed at about 0.5 meter to 1.0 meter even during the dry spell of the year.

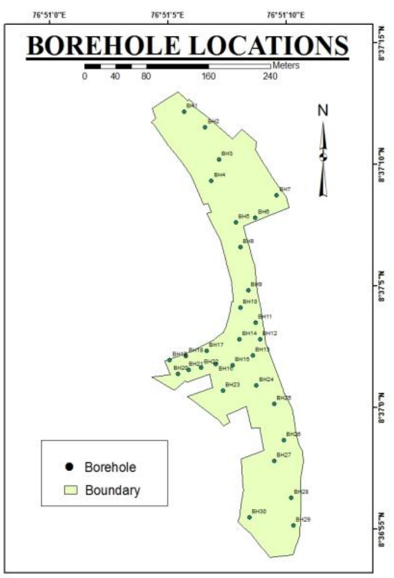

Figure (2):- Borehole locations of the site

Very soft to stiff clayey silt and silty clay and medium dense to very dense sand were encountered at different depths in these boreholes and the soil properties were almost identical. The soils for laboratory tests were taken from different depths. The laboratory test results showed physical characteristics of soil such as its depth, type, color, specific gravity, water content, atterbergs limit, unit weight of soil, cohesion and the shear parameters. The average depth taken for 30 boreholes is 18.6 meter.

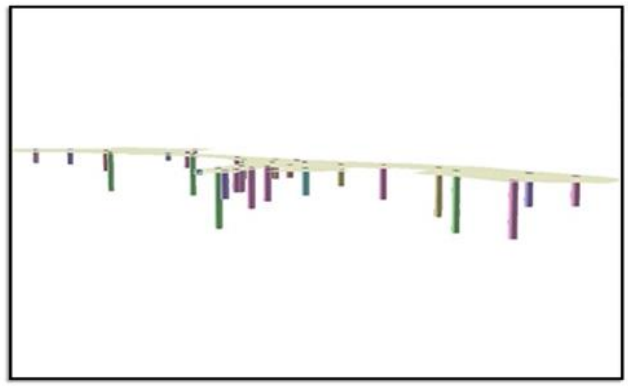

Figure (3):- Perspective sub-surface view of borehole locations

IV. BEARING CAPACITY ANALYSIS

Load bearing capacity analysis was computed using equations by Karl Terzaghi and Meyerhof.

Terzaghi's bearing capacity equation (1943) is as follows [3-4];

$$Qu=CN_c+\gamma D_f N_q+0.5\gamma BN_\gamma$$

Where;

Qu is ultimate bearing capacity
γ is unit weight of soil
C is cohesion
Df is depth of footing.
B is width of foundation.

N_c, N_q and N_γ are the bearing capacity factors, that depends upon the roughness of base, depth of footing and the shape of footing; in addition to the angle of shearing resistance ϕ. [4-6].

Meyerhof (1951) proposed a similar theory for estimating bearing capacity for strip footing at any depth. Compared to Terzaghi's theory Meyerhof included the shearing strength of the soil above the footing base for analysis. The following equation shows Meyerhof's equation for the computing ultimate bearing capacity is as follows [3], [10-11];

$$Qu=CN_cs_cd_c+qN_qs_qd_q+0.5\gamma BN_\gamma s_\gamma d_\gamma$$

Where;

d stands for empirical correction factor called the depth factor recommended by Meyerhof is given below;

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$d_c = 1+0.2(D/B)\tan(45^0+(\phi/2))$
$d_q, d_\gamma = 1+0.1(D/B)\tan(45^0+(\phi/2))$ for $\phi>10^0$
$= 1$ for $\phi = 0$

Nc,Nq and Nɣ are the bearing capacity factors are the same proposed by Prandl (1921) and Reissner (1924). It depends on the angle of shearing resistance.

q=ɣDf, q is the normal stress [3].

Safe bearing capacity was computed from ultimate bearing capacity for both the methods, using the following equation.

Safe Bearing Capacity, Qs= Qns+ɣDf

Where; Qns is the net safe bearing capacity and it was found out by

Qns= Qnu/F.S

Where; F.S is the Factor of Safety [7].
Qnu (net ultimate bearing capacity) = Qu-ɣDf

The results of safe bearing capacity revealed that Meyerhof's analysis gave slightly higher values than Terzaghi (see figure 4).

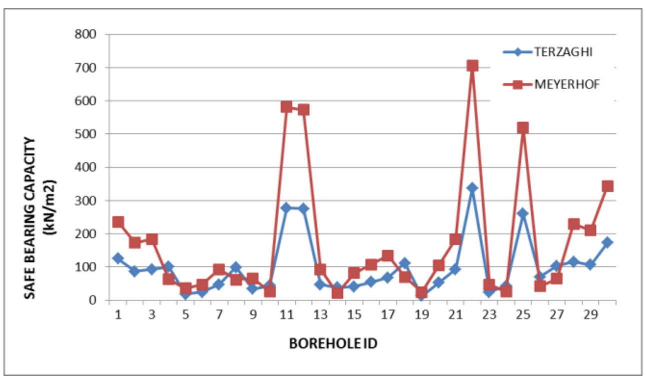

Figure (4):- Safe Bearing Capacity for Borehole locations

V. Geographic Information System Analysis

Geographic Information systems provide tools and techniques for analyzing the spatial relationships and thereby modeling spatial processes. The Geographic coordinates of the bore locations were collected using GPS and the waypoints were plotted as event layer in ArcGIS Desktop software.

The event layer was converted to ESRI Shapefile format and the soil test result was joined using Borehole ID. Since there was no in-build function in ArcGIS to perform bearing capacity analysis, the computations were programmed using python script within the ArcGIS environment. The computed safe bearing capacity using both Terzaghi and Meyerhof methods were stored as separate columns in the attribute table of the Point Shapefile.

Spatial Analysis

The safe bearing capacity for 30 bore locations were geostatistically interpolated using kriging, using the Geostatistical Analyst module of ArcGIS.

The general formula for kriging [12] is calculated as a weighted sum of the measured data:

$$\dot{Z}(S_0) = \sum_{i=1}^{N} w_i Z(S_i)$$

Where;

$\boldsymbol{Z(s_i)}$ = the measured value at the *i*th location

$\boldsymbol{w_i}$ = an unknown weight for the measured value at the *i*th location

$\boldsymbol{s_0}$ = the prediction location

$\boldsymbol{N}$ = the number of measured values

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. It is the most appropriate method when a spatially correlated distance in the data is known and is used for the applications in the field of soil science and geology. The predicted values are derived from the measure of relationship in samples using sophisticated weighted average technique. Kriging responds both to the proximity of sample points and to their directions [8-9].

Kriging converts point observations to a continuous surface with each pixel carrying predicted values.

VI. Results And Discussion

The kriged results show very low safe bearing capacity for most of the area as per the Terzaghi model revealing that the entire area is not suitable for shallow foundation structures (see figure 5).

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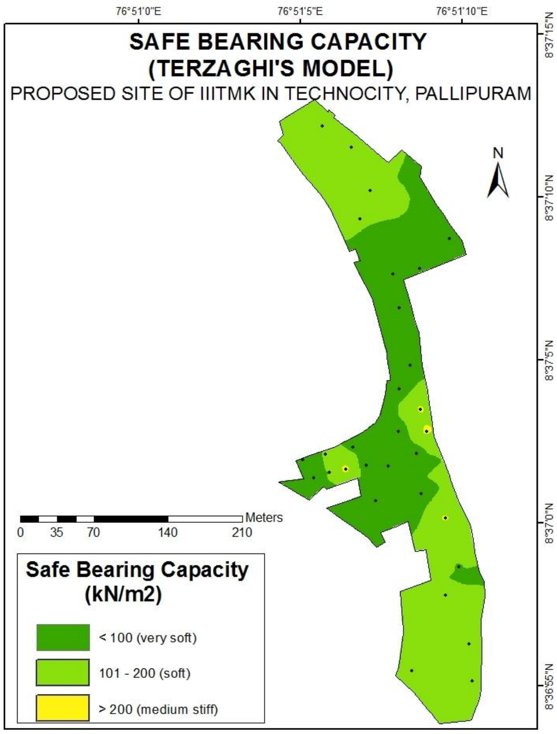

Figure (5):- Spatial Variability of Load Bearing Capacity

The Mayerhof's output suggests that the southern, northern and some patches in the middle of the site (yellow, orange and red) are suitable for shallow foundation as the values are above 200kN/m^2. It is highly recommended for high rise building with deep foundation for the rest of the areas (see figure 6).

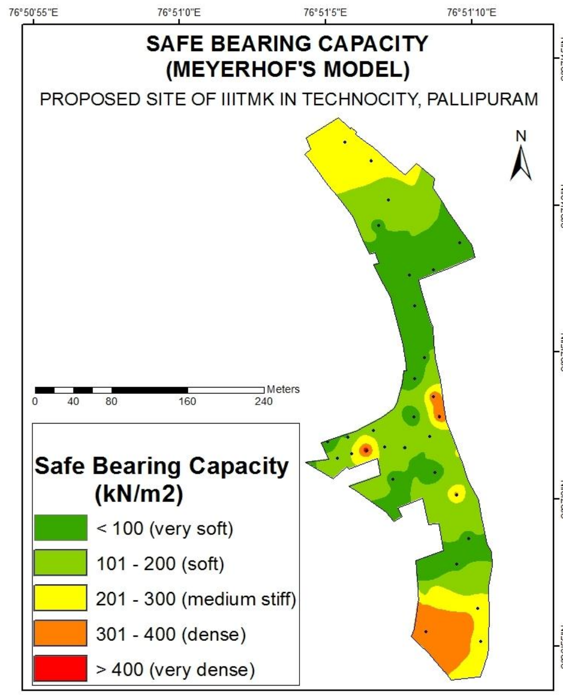

Figure (6):- Spatial Variability of Load Bearing Capacity

VII. CONCLUSION

The integration of Geographic Information Systems techniques with computational modeling allowed manifestation of spatial variability of safe bearing capacity. The spatial assessment will help decision-making for identifying specific locations and strata for a firm and safe placement of footings with minimum cost and time for construction.

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