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Bearing Capacity Mapping of Kathmandu Valley for Shallow Foundations

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Abstract

A foundation is the part of a structure which transmits the load of the structure to the ground. The type and the location where the stratum hold the foundation affect its bearing capacity value. Kathmandu valley is being converted into concrete village day by day. High rise buildings are being constructed in different locations and in many cases soil test haven't been done. Bearing capacity of soil should be checked before construction to prevent collapse and settlement. Bearing capacity zonation mapping is inevitable in every cases of newer construction. In developed countries, bearing capacity zoning of highly urbanized cities has been done. But in case of Nepal no such proper maps have been prepared yet .This study aims to map the bearing capacity of the foundation. To achieve those targets, this research uses the data in the form of soil investigation equipped with boring logs and N-SPT from 239 different borehole locations around Kathmandu valley. The performed methods are: collecting, selecting, grouping and plotting the data location in Kathmandu valley map. Different analytical and theoretical approaches have been used for estimating bearing capacity. Bearing capacity has been found using Terzaghi, Meyerhof and least value of bearing capacity is used in zonation mapping. The study shows that the bearing capacity of Kathmandu valley ranges from 49 kPa to 307 kPa.

Keywords

Bearing Capacity, Mapping, Kathmandu Valley, SPT-N

1. Introduction

One of the most significant components of any structure is its foundation. Foundations are integral to overall structural performance. A foundation is a connecting link between the structure proper and the ground supporting .In geotechnical engineering, bearing capacity is the capacity of the soil supporting the loads applied to the ground. To perform satisfactorily, foundations must have two main characteristics: they have to be safe against overall shear failure in the soil that supports them and they must not undergo excessive settlement [1]. Bearing capacity zonation mapping is inevitable in every cases of newer construction. Bearing Capacity mapping will facilitate designer for preliminary design of foundation, feasibility study, planning of detail investigation of complex formations, estimate of future disasters related to soil failure.

In general Geology, typical lithology of formation of the Kathmandu valley consists of a thick lacustrine and fluvial deposits of fine and coarse sand, sandy loam, peat, sandy silty clay, carbonaceous clay, sand and gravel, all of which are more or less consolidated. The maximum thickness of these sediments is over 600 meter in some places. Recent drilling in these sediments has shown that the subsoil of central part of Kathmandu Valley is very soft to very dense up to a depth of about 20 meter [2]. Kathmandu valley is being converted into concrete village day by day. High rise buildings are being constructed in different locations and in many cases soil test haven't been done. Various locations around Kathmandu Valley are susceptible to liquefaction hazards too. In order to cope with those problems, bearing capacity mapping of Kathmandu Valley has become an essence. The high level of demands for housing in Kathmandu due to the growing population and migration of people to urban areas require alternative construction methods that provide fast, safe and affordable quality housing for the citizens. Also, there is a need to investigate and determine the most appropriate methods to Kathmandu soil peculiarities and distinctions based on SPT results, being the most common and economical geotechnical field test used in Kathmandu. The study focused on the prediction of foundation soil bearing capacity and settlement based on Standard Penetration Test (SPT) N-values using empirical/analytical. If bearing capacity zonation map could be provided it will reduce the time and cost of project lapsed in investigations

2. Study area

The proposed study area includes different locations of Kathmandu, Lalitpur and Bhaktapur.

Figure 1: Location of site

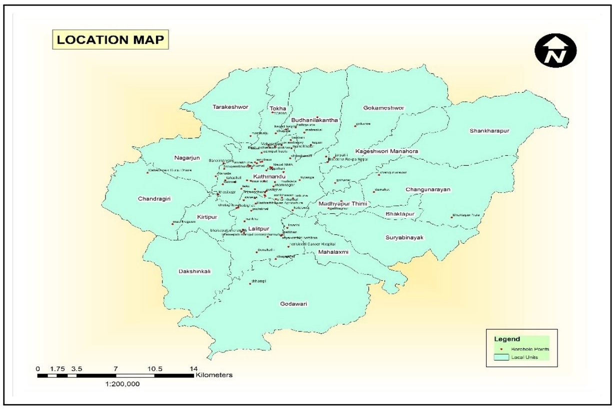


Figure 2: Digitization of BH LOGS

3. Literature Review

A foundation is an integral part of a structure. The stability of structure depends upon the stability of supporting soil. Shallow foundation is a type of foundation unit that provides support of a structure by transferring loads to soil or rock at shallow depths. Usually the depth to width ratio of foundation is less than unity and the depth of foundation is within 3m from the surface.[3] .To design a shallow footing size and shape of a structure, engineers have to know the ultimate bearing capacity of underneath soil. The ultimate bearing capacity of soil is the intensity of loading at the base of a foundation which initiates shear failure of the supporting soil. Several bearing capacity equations proposed by different authors and adopted in different codes are available to calculate the ultimate bearing capacity of soil at foundation level. But, different method of evaluating bearing capacity yields different result. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement. There are three modes of failure that limit bearing capacity general shear failure, local shear failure, and punching shear failure. A foundation is required for distributing the loads of superstructure on a large area. The foundation should be designed in such a way that there shouldn't be shear and settlement failure. Bearing capacity can be found out from different methods as Terzaghi (1943), Meyerhof (1951, 1953, 1963, 1965 and 1967), N.Teng (1962) and modification by Bowles (1996).

Ultimate bearing capacity
The ultimate bearing capacity is the gross pressure at the base of foundation at which soil fails in shear.

Allowable bearing capacity
It may be defined as the net load intensity at which no failure occurs is called allowable bearing capacity. Calculating the gross allowable load bearing capacity of shallow foundation requires the application of the factor of safety (FS) to the gross ultimate bearing capacity. q Allowable = q ultimate / FS

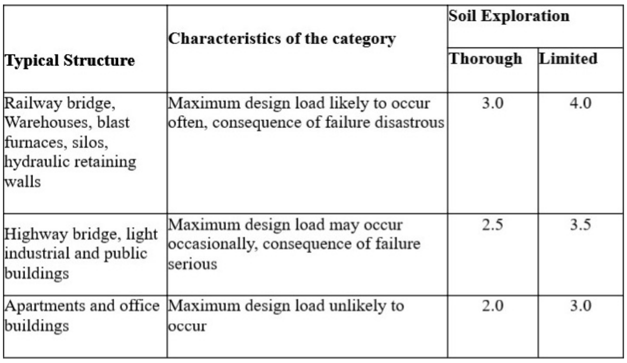
Net ultimate bearing capacity
It is defined as the ultimate pressure per unit area of the foundation that can be supported by the soil in excess of the pressure caused by the surrounding soil at the foundation level. If the difference between the unit weight of the soil and the concrete is negligible, then

q net(u) = q(u) – q
q = unit weight of soil * Depth of foundation (Df) So
q allowable (net) = (q(ultimate)-q) / FS

Safe bearing capacity
It may be defined as the maximum Pressure that a soil bears without shear failure is known as safe bearing capacity.
[4] It is recommended that the factor of safety should

be between 2 and 4. The following table may be used as a guide for permanent structures in reasonably homogeneous soil conditions (as per Vesic, 1970).

Table 1: Minimum value of safety factor for design of shallow foundations (as per Vesic, 1970)



Typical Structure	Characteristics of the category	Soil Exploration	
		Thorough	Limited
Railway bridge, Warehouses, blast furnaces, silos, hydraulic retaining walls	Maximum design load likely to occur often, consequence of failure disastrous	3.0	4.0
Highway bridge, light industrial and public buildings	Maximum design load may occur occasionally, consequence of failure serious	2.5	3.5
Apartments and office buildings	Maximum design load unlikely to occur	2.0	3.0

3.1 Standard Penetration Test (SPT)

The standard penetration test is an in-situ test that is coming under the category of penetrometer tests. The standard penetration tests are carried out in borehole. The test will measure the resistance of the soil strata to the penetration undergone. A penetration empirical correlation is derived between the soil properties and the penetration resistance. The test is extremely useful for determining the relative density and the angle of shearing resistance of cohesion less soils. It can also be used to determine the unconfined compressive strength of cohesive soils.[5]

3.1.1 SPT Correction for field procedure

$$N_{[60]} = Em\, CB\, CS\, CR\, N/0.60 \tag{1}$$

Here $N_{[60]}$ is the SPT N-value corrected for field procedures and apparatus; Em N is the hammer efficiency; CB is the borehole diameter correction; CS is the sample barrel correction; CR is the rod length correction; and N is the raw SPT N-value recorded in the field. Skempton (1986) provides charts for estimating the appropriate values of Em, CB, CS and CR

For Donut, rope and pulley Em =0.45

For standard sampler, CS =1

For dia 60-120mm, CB =1

Some correlations used Hara, et al. (1971) suggested the following correlation between undrained shear strength of clay (Cu) and N_{60}.

$$Cu/pa = 0.29\, N\, 60^{0.72} \tag{2}$$

where pa=100kN/m2

Peck, Hanson and Thornburn (1974) gave a correlation between N_{60} and in a graphical form which can be approximated as

$$\phi(deg) = 27.1 + 0.3 \times N_{60} - 0.00054 \times {N_{60}}^2 \tag{3}$$

Modulus of Elasticity (E) given by Kulhway and Mayne (1990) as E/Pa=10* N_{60}

For cohesive soil,

$$\gamma sat = 16.8 + 0.15 \times N_{60}(KN/m^3) \tag{4}$$

For cohesionless soil [6],

$$\gamma sat = 16 + 0.1 \times N_{60}(KN/m^3) \tag{5}$$

3.1.2 Terzaghis Bearing Capacity Equations

Based on Terzaghis bearing capacity theory, column load P is resisted by. shear stresses at edges of three zones under the footing and the overburden pressure, q (=γD) above the footing. The first term in the equation is related to cohesion of the soil. The second term is related to the depth of the footing and overburden pressure. The third term is related to the width of the footing and the length of shear stress area. The bearing capacity factors, Nc, Nq, Nγ, are function of internal friction angle

For square footing, q_u=1.3cN_c + γ DN_q+0.4 γ B Nγ

In case of water table The position of ground water has a significant effect on the bearing capacity of soil. Presence of water table at a depth less than the width of the foundation from the foundation bottom will reduce the bearing capacity of the soil. The bearing capacity equation incorporating the ground water table correction factors is given below.

$$qu = 1.3 * c\, Nc + \gamma DNqRw1 + 0.4 \times \gamma BN\gamma Rw2 \tag{6}$$

Where qu = Ultimate bearing capacity of soil in KN/m2

c = Cohesion of soil in KN/m2

Nc, Nq, Nγ are Terzaghi's bearing capacity constants.

D= depth of foundation in meters

B = Width of the foundation in meters

Rw1 and Rw2 are water table correction factors

1. When the water table is below the base of foundation at a distance 'b' the correction Rw2 is given by the following equation

$$Rw2 = 0.5 + 0.5(b/B) \leqslant 1 \tag{7}$$

When b =0, Rw2 = 0.5

2. When water table further rises above base of foundation, correction factor Rw1 comes in to action, which is given by the following equation.

$$Rw1 = 1 - 0.5(a/D) \leqslant 1 \tag{8}$$

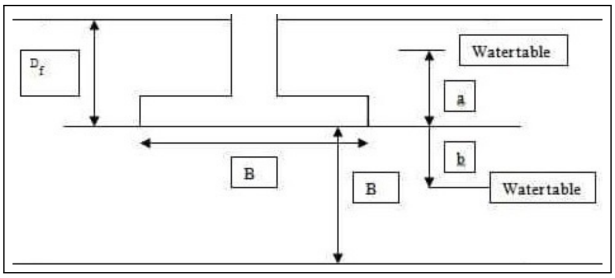


Figure 3: Effect of water table on bearing capacity

The water table correction factors can be obtained from the equations given below. 1. When the water table is below the base of foundation at a distance ‘b’ the correction Rw2 is given by the following equation

3.2 Meyerhof Bearing Capacity Equation

Meyerhof (1963) proposed a formula for calculation of bearing capacity similar to one proposed by Terzaghi but introducing further foundation shape coefficients. Vertical load:

$$qu = c\,Nc\,Sc\,Dc + \gamma D\,Nq\,Sq\,Dq + 0.5\gamma B\,N\gamma\,S\gamma\,D\gamma \tag{9}$$

Inclined load: Qu = c Nc Sc Dc Ic + γD Nq Sq Dq Iq + 0.5 γ B Nγ Sγ Dγ*Iγ. Equation 2.16 Where: Nc, Nq, Nr: Meyerhof’s bearing capacity factors depend on soil friction angle, ϕ. Nc = cot ϕ (Nq – 1) Nγ = (Nq-1) tan (1.4ϕ) Sc, Sq, Sγ: shape factors Dc, Dq, Dγ: depth factors Sc, Sq, Sγ: shape factors Dc, Dq, Dγ: depth factors Ic, Iq, Iγ: incline load factors

3.3 Location of boreholes

Anamangar, Balaju, Banes,hwor oriental Baneshwor Global College, Basbari, BBSM Anamnagar, Bhaisepati, Bhaisepati Madhab Corola, Bhaisepati Mangal Colony, Bhaisepati Sheranath, Bhaktapur Nala, Bouddha Rokpa Nepal, Budhanilakantha Ganesh School, CE Mangal Colony, Chhhampi, Chhyan Debi Nagarkot, Dahachowh Gurju Dhara, Dhapakhel, Dhapasi, Dhumbarahi, Dhobighat, Durbarmarg, Gatthaghar, Global College, Hariharbhawan Agriculture, Harisiddhi Cancer Hospital, Hattiban CG, Hattigauda CG, Hepali Height, Jorpati Shree Adarsha, Kalanki BBSM, Kamaladi BOK, Kamaladi IME, khasibazar, khumaltar V0astu Classic, Kupandole bldg, Lainchaur Hotel Le Sherpa, Lalitpur Bishal Bazar, Lazimpat British Embassy, Lazimpat CE Bldg, Lazimpat Royal Merchand, Lazimpat Bastu, Macchegaun, Maitighar St Xavier, Nagpokahari, Naxal Jgadamba, Naxal NMA, Naxal Oriental, Putalisadak Pad0modaya School, Rabibhawan Mars, Royal Orchid BC, Royal Orchid Hattiban, Sanepa Oriental , Sanepa Sangrila Housing, Sorakhutte Castor APARTMENT, TDF Babarmahal, Teku BMET, Thamel Vastukala, Thapathali CG builders, Thapathali Rotary Club, Manmohan Memorial Hospital, Mandikhatar

4. Results and Discussion

There are BH logs of 95 locations having total of 239 Bore holes. For each BH location bearing capacity has been calculated using Terzaghi and Meyerhof approaches considering depth of 1.5, 3m, 4.5m and 6 m. The least of the value between them is Bearing Capacity of that location.

At 1.5m depth the highest bearing capacity value is 342.23 kPa at Minbhawan and the lowest bearing capacity is 55.833 kPa at Balaju.At 3m depth the highest bearing capacity value is 483 kPa at Swayambhu and the lowest bearing capacity is 49kPa at Ghattekulo.At 4.5m depth the highest bearing capacity value is 684.7 kPa at Macchegaun and the lowest bearing capacity is 58 kPa at Duwakot.At 6m depth the highest bearing capacity value is 1056 kPa at Bhaktapur Nala and the lowest bearing capacity is 69 kPa at Duwakot.The bearing Capacities by Numerical Modeling have been shown in fig. The least value of bearing capacity is 55kPa at Balaju and highest value is 307kPa at Bhadrakali. The least values of all are found out. The least value of bearing capacity is 49kPa at Ghattekulo and highest value is 307kPa at Bhadrakali.

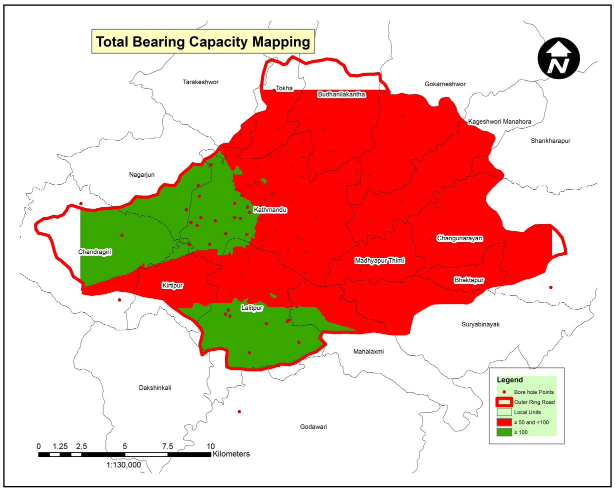


Figure 4: Bearing capacity mapping of kathmandu valley for shallow foundations

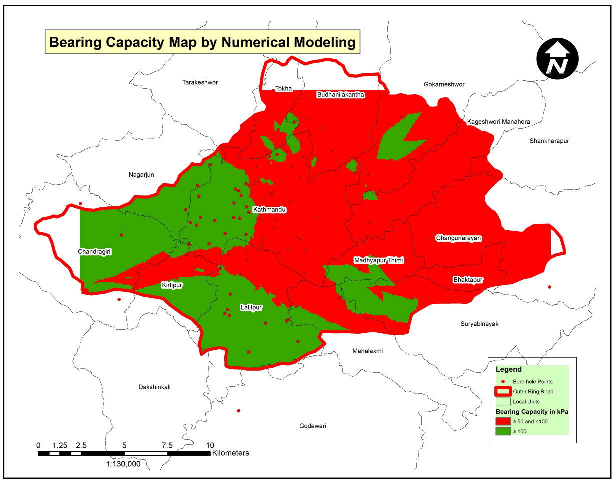


Figure 5: Bearing capacity mapping of kathmandu valley for shallow foundations based on numerical modeling

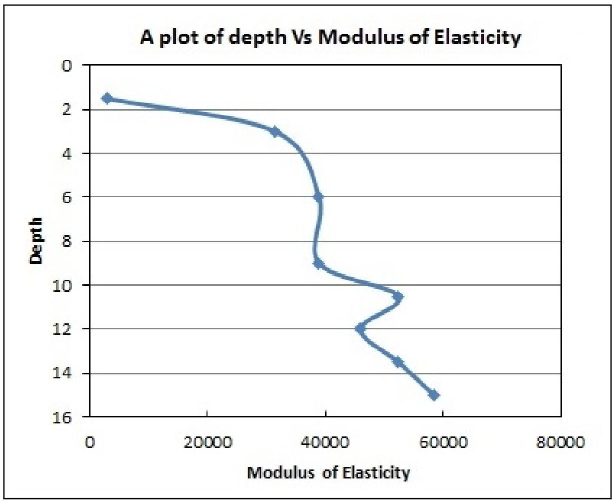


Figure 6: A plot of depth Vs Modulus of Elasticity

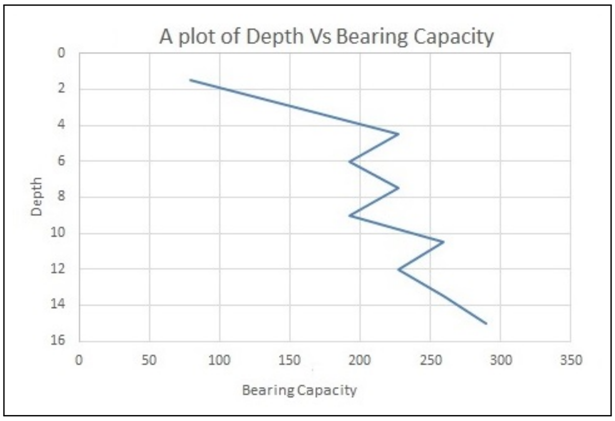


Figure 7: A plot of depth Vs Bearing Capacity

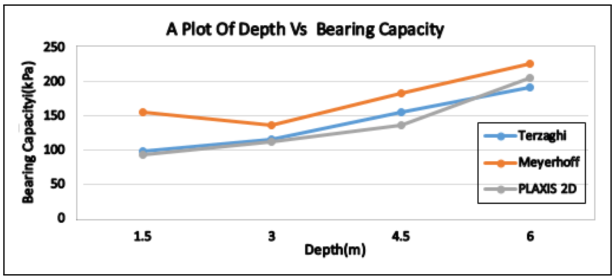


Figure 8: Comparision of bearing Capacity by different approaches

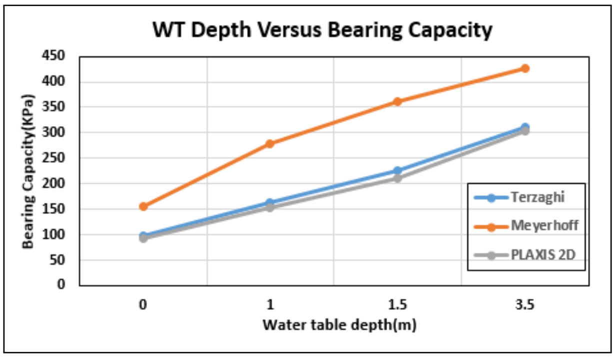


Figure 9: Effect of water table on bearing capacity

5. Conclusion and Recommendation

Using the information obtained from 239 soil test boreholes within the study area, an allowable bearing capacity map was constructed. This map can help in: Using Geographic Information System (GIS) to produce geotechnical maps provides a helpful way to predict the allowable bearing capacity in non-Spatial data areas.

Geotechnical maps produced for the study area represent a very powerful database and visual display of the collected data. Besides, using these maps will help save time, cost and effort.

The produced maps can be used as a guidance for engineers and decisions makers to decide the suitability of any construction in the study area, the best foundation design and type of suitable treatment needed.

The allowable bearing capacity of the study area ranges from 49 kPa to 307 kPa.

The areas like Imadol, Balaju and Bouddha have comparatively low bearing capacities so attention must be given during design of structures.

This map can be used in the applications of smart cities.

The value of both allowable bearing capacity and modulus of elasticity is not uniform with depth. There is noticeable contrast in their value with depth which indicates the presence of thin strata of different material. So for shallow foundation in Kathmandu valley, it is not always necessary that increase in depth makes the foundation better. Recognizing the most bearable soil layer and its thickness is necessary for safe foundation design.

The evaluated bearing capacity of soil depends highly on the method used, and therefore on the codes.

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