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Bearing Capacity Zonation of Urban Areas of Dhulikhel and Banepa for Shallow Foundation

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Abstract

Most of the construction of residential and commercial buildings in Banepa and Dhulikhel is being increased continuously without evaluating bearing capacity of the particular zone. The target of this study is to prepare the Bearing capacity zonation map of urban areas of Dhulikhel and Banepa. Bore log secondary data (SPT-N) from various 72 locations are taken. Terzaghi(1943), Meyerhof(1963), Hansen(1970) and Vesic(1973) approaches have been used to evaluate Bearing capacity. Least value for Bearing Capacity is taken and plotted in map using GIS. The results have been verified from numerical modeling using Plaxis 2D, a Finite Element Program. The parameters of soil that should be well-thought-out in Plaxis models and theoretical approaches are Cohesion, Angle of Internal Friction, unit weight, Poisson's ratio and modulus of elasticity. Finite Element Method takes into account stress strain behavior and displacement observed and hence analyzes the soil structure interaction. Finite Element Analysis is executed using Mohr-Coulomb failure criteria. The Bearing capacity shall be obtained from Load Displacement curve taken as effective stress.The Allowable Bearing capacity of Dhulikhel ranges from 33 kPa at Dhulikhel-3 (85.554919E, 27.632540N) to 198 kPa at Dhulikhel-4 (85.5400E, 27.6256N) and Banepa ranges from 57 kPa at Banepa-5 (85.53183 E, 27.635798 N) to 201 kPa at Banepa-11 (85.516919 E, 27.623785 N) for shallow foundation.

Keywords

Bearing capacity, Settlement, Dhulikhel, Banepa, SPT(N), Mapping, Plaxis

1. Introduction

The prerequisite of every engineered structure is robust and stable foundation to carry the load above. The soil below the structure must have the potential to carry the loads without shear failure and with tolerable resulting settlement. The other factors we need to be careful are location and depth of water table, erosion of flowing water, underground defects, layering of soils, soil compressibility, expansive soil occurrence, size and shape of the foundation etc. The load at which the shear failure of the soil below the foundation takes place is known as ultimate bearing capacity [1].

The haphazard construction of buildings without evaluating bearing capacity is a serious problem in municipalities. The planned settlement is necessary in regions with high bearing capacity. In today's world, where we need to be economical, these maps which provide Bearing capacity at various depths will at least help the geotechnical engineers/designers for the preliminary choice of location, preliminary design of foundation, feasibility study, preparation for devastating situation.

Bearing capacity zonation map has been prepared of Kathmandu and Lalitpur only. This study have been attentive in thought of applying numerical modeling for quick approaches in the future soil works. Urban areas of Banepa and Dhulikhel are chosen to prepare the zonation maps because these areas are emerging cities with increasing population.

2. Research objectives

The main aim of this research is to map the bearing capacity of the shallow foundation. To achieve this target, this research uses the data in the form of soil investigation equipped with boring logs and N-SPT from several locations of the municipalities and finally use GIS. The general objectives of this study is:

- To identify the geotechnical characteristics of shallow foundation soil material.
- To determine the distribution of soil bearing capacity on shallow fondations and plot on the maps of Dhulikhel and Banepa using GIS i.e. prepare zonation map based on N-SPT data.
- To comapare the bearing capacity of shallow foundation at different location using different semi-analytical, empirical correlations and also finding if the numerical modeling values are realistic
- To analyze the model and suggest possible foundation strengthening and failure mitigation measures.

3. Literature Review

The substructure is built below the ground level and superstructure above. For the strong and stable superstructure, the substructure on particular soil plays an important role. The supporting soil should not get overstressed and deformed.

During design of buildings, the evaluation of the ultimate bearing capacity of the footing is very much important. This examines the stability of the structure-earth system. The pioneers were Prandtl (1921) and Reissner (1924) for this work. Terzaghi (1943) introduced ultimate bearing capacity formula which is widely used in real practice. The ultimate bearing capacity of shallow footings were then given by Meyerhof (1951, 1953, 1963, 1965 and 1967) including methods by Hansen (1961and 1970) and Vesic (1973) with modification by Bowles (1996) [2]. Skempton (1951) showed that the bearing capacity factor N_c in Terzaghi's equation tends to increase with depth for a cohesive soil.

There is currently no method of obtaining the ultimate Bearing capacity of a foundation other than as an estimate. Different methods gives different results.

Standard Penetration Test (SPT) is one of the field tests done to access geotechnical engineering properties of soil.

Finite Element model (or Mesh) is supposed to be made for the analysis. The numerical model will be prepared using PLAXIS 2D which is a Finite element program. ABAQUS have also been used in numerical modeling [3].

Mahato S. K. [4] used different analytical and empirical correlations to estimate the bearing capacity at 1.5m and 3m depths from existing ground level and these methods were also compared. Bearing capacity map for raft and deep foundation was recommended where soil bearing capacity was not sufficient.

In research of Danai R.K. [3], Bearing capacities evaluated from theoretical approaches were compared with numerical modeling values. The values were realistic and found the modeling gives the value of bearing capacities only in short duration and in easy manner. Hence, numerical modeling could be used in the calculations. Depth have been varied in this research. The author recommends to vary D/B ratios in future researches.

Vilas., Moniuddin K.M. [1] used Plaxis to estimate the bearing capacity of soil with Mohr-Coulomb's failure idealization with considerable success. Medium mesh generation was found to provide reasonably accurate results satisfying the desired convergence criteria. Advanced soil models such as Hardening Soil model, Soft Soil Creep model and user defined models could be used in future researches as per author.

The bearing capacity mapping is popular in many countries of the world. But such practice is rare in Nepal. Only mapping of Kathmandu and Lalitpur have been prepared. The results showed Teku, Wotu-ktm, Rabibhawan, Soltimod, Balambu, Dhapasi, Ghattekulo and sites near to river banks had bearing capacities less than 50kN/m^2 [3].

4. Materials and Methodology

4.1 Study Area

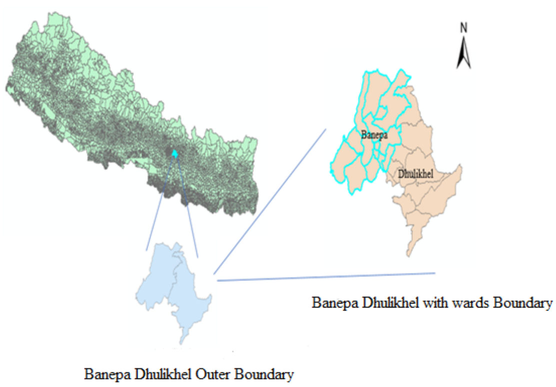

Figure 1: Location map of Study Area.

The two very popular municipalities of Kavrepalanchowk, Banepa and Dhulikhel are taken for study. Geographic coordinates of Dhulikhel is latitude 27.6253°N and longitude 85.5561°E and similarly of Banepa is 27.6332° N and 85.5277° E.

4.2 Methodology

The methodology includes secondary data collection as major time taking task in this research. Several procedures are followed to achieve the target of the study. The steps are:

- Collection of Study Materials.
- Literature Review.
- Planning.
- Collection of Secondary data from different locations.
- Collection of Primary data from houses ready for preparing shallow foundation.
- Filtering and Interpretation of data. (SPT-N values, soil characteristics)
- Use of traditional approaches for finding Bearing Capacity.
- Numerical Modeling in Plaxis-2D software for varying parameters. i.e depth.
- Comparision of results between theoretical approaches and software based.
- Data Analysis
- Finding the coordinates from Department of Survey through Plot No. and using GPS.
- Plotting the results from GIS software.(Use of least value in GIS mapping)
- Validate the results using Literature Review and software based modeling.

The most important step now is calculating the bearing capacity in each location. In this research work, square footing shall be used. Usually, buildings in Dhulikhel and Banepa areas have foundation depth of 5ft (i.e. nearly 1.52 m). We shall consider 1.5 m. Footing dimesnsion shall be considered 5ft by 5ft (1.5 X 1.5 m). The water table may vary in depth from time to time. Hence, we shall be conservative and shall take it at the surface as this is the most critcical one.

The various parameters of soil like cohesion and angle of internal friction was taken from secondary data. The other parameters; Young's modulus, Unit weight and Poisson's ratio were interpreted from SPT-N value through various correlations.

Table 1: Soil Elastic Parameters

Type of Soil	Modulus of Elasticity(MN/m^2)	Poisson's ratio
Loose sand	10-25	0.2-0.4
Medium dense sand	15-30	0.25-0.4
Dense sand	35-55	0.3-0.45
Silty sand	10-20	0.2-0.4
Sand and Gravel	70-170	0.15-0.35
Medium clay	20-40	0.2-0.5

For cohesive soil;

$$\gamma_{sat} = 16.8 + 0.15 * N_{60}(kN/m^3) \quad (1)$$

For cohesionless soil;

$$\gamma_{sat} = 16 + 0.1 * N_{60}(kN/m^3) \quad (2)$$

Where;

γ_{sat} = staurated unit weight of soil
N_{60} = SPT number corrected for field conditions

Kulhawy and Mayne (1990) relationship:

$$\frac{E_s}{p_a} = \alpha N_{60} \quad (3)$$

Where

E_s = Modulus of Elasticity
α = 5 for sands with fines
α = 10 for clean NC sand, 15 for clean OC sand
p_a = Atmospheric Pressure (100 kN/m^2)

The estimation of bearing capacity using traditional and theoretical approaches shall be done. The ultimate bearing capacity is the theoretical maximum pressure which can be carried without failure.

Terzaghi's Ultimate Bearing Capacity :

$$q_{ult} = cN_c + qN_q + \frac{1}{2}B\gamma N_\gamma \quad (4)$$

where; c, q, B and #γ are cohesion, surcharge, width of footing and unit weight respectively.

Meyerhof (1963) presented a simple general Bearing capacity equation for the bearing capacity of shallow foundation;

$$q_u = cN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma \quad (5)$$

where, s, d, and i are empirical correction factors called the shape factor, depth factor and inclination factor respectively.

Hansen (1961) gives the values of ultimate bearing capacity

$$q_u = cN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma \quad (6)$$

where, N_c, N_q and N_γ are Hansen's bearing capacity factors

The above equation is applicable only for $\phi > 0$. For $\phi = 0$, Hansen recommends the equation,

$$q_u = cN_c(1 + s_c + d_c - i_c) + q \quad (7)$$

Vesic (1973)gave the following Bearing capacity equation:

$$q_u = cN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma \quad (8)$$

where s, d and i are Vesic's shape, depth and inclination factors respectively.

Finite Element Method (FEM) is on one of the accurate and economic ways to analyze the soil structure interaction. The program does not consider seismic effects and limited to static condition only. Progressive mathematical procedures are applied in this method considering a mesh including similar geometrical shapes which are called elements. After this, the critical elements are inspected to find the consequence of soil subjected to structural loads. User can define complex soil profiles. It has made easier in developing a numerical model. The estimation of Bearing capacity of soil is done with Mohr Coulomb's failure idealization [5]. Foundation is modelled as square footing and load increment is applied till the soil model fails.
Effective stress is considered as an ultimate bearing capacity in model. Since, we are to work on two dimensional meshes, Axisymmetric model is taken into consideration.

5. Results and Discussion

Sample Calculation: The least Bearing capacity obtained from various analytical approaches and from software are compared.

Table 2: Least BC values and from Plaxis

S.N.	Location	Coordinates	Min. BC (kN/m2)	BC from Plaxis (kN/m2)
1	Dhulikhel-8	85.564441 E 27.621501 N	82.34	90.07
2	Dhulikhel-8,	85.571187 E 27.615593 N	69.43	74.40
3	Dhulikhel-3	85.547190E 27.631433N	57.51	64.80
4	Dwarika,D-8	85.574494E 27.619188N	74.75	62.40
5	Banepa-11	85.517458 E 27.626458 N	92	96.62
6	Banepa-8	85.524064 E 27.630397 N	110.12	94.08
7	Banepa-7	85.528687 E 27.626266 N	63.98	60.91
8	Bhimsenthan, B-7	85.528352 E 27.62627 N	92	96.62

Figure 2: Plot of Least BC values at 1.5 m depth (Borehole Digitization of 72 locations)

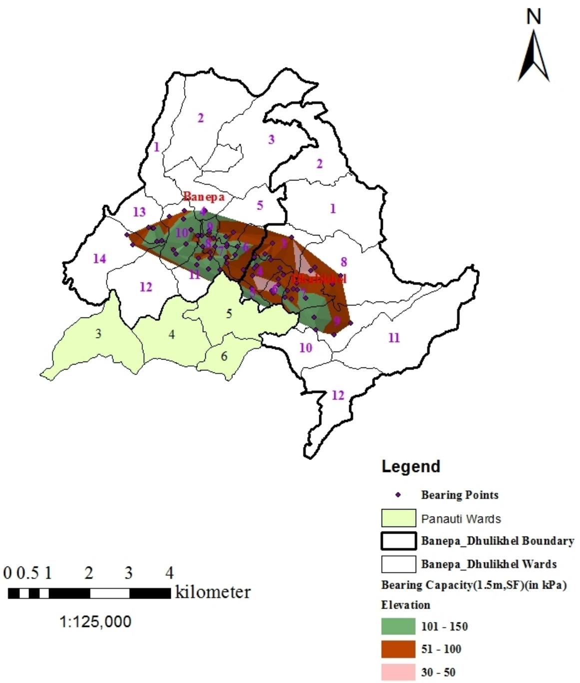

Figure 3: Bearing capacity zoning of Banepa and Dhulikhel urban areas

Table 3: Properties of Material calculated Empirically from Borehole data (Sample)

Name	Symbol	Value
Permeability in horizontal direction	k_x	1 m/day
Permeability in vertical direction	k_y	1 m/day
Modulus of Elasticity	E	16000 kN/m^2
Poisson's ratio	v	0.27
Cohesion (constant)	C	$1kN/m^2$
Friction angle	*phi*	30°
Dilatancy angle	φ	0
Mesh type	Medium mesh	15 Noded
Material model	Model	Mohr-coulomb
Material behavior type	Type	Drained
Soil dry unit weight	γ_{dry}	$13.58kN/m^3$
Saturated unit weight	γ_{sat}	16.71 kN/m^3

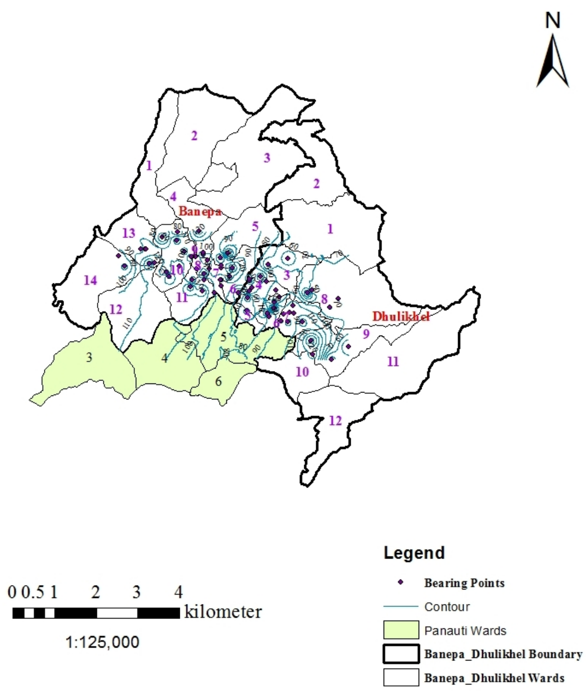

Figure 4: Contour map of Urban areas

Material Model for soil (PLAXIS-2D)

Properties of material calculated empirically from borehole data.

Failure Criteria: Mohr-Coulomb

modeling in FEM

Finite Element Model was prepared for analysis.

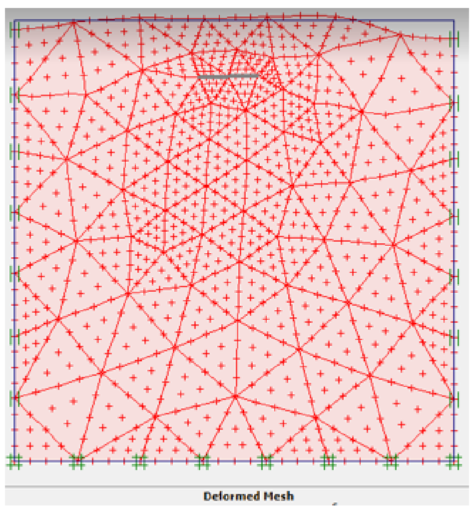

Figure 5: Deformed Mesh (Plate)

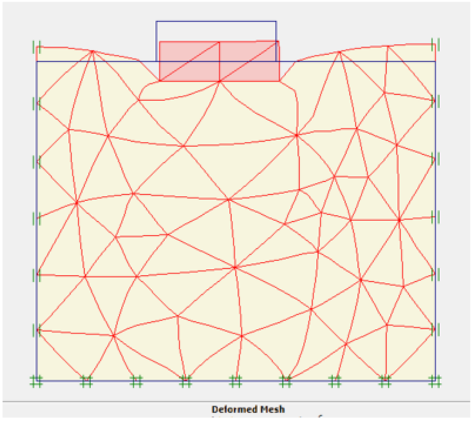

Figure 6: Deformed mesh under loading

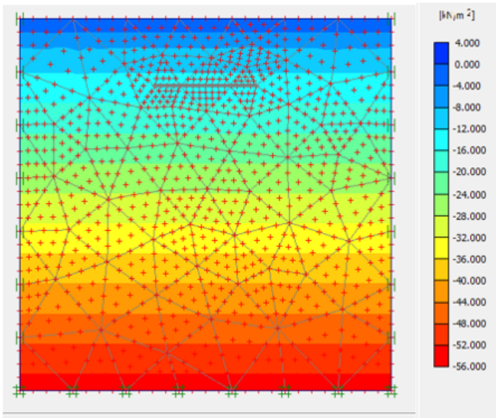

Figure 7: Effective stress generation(Mean Shading)

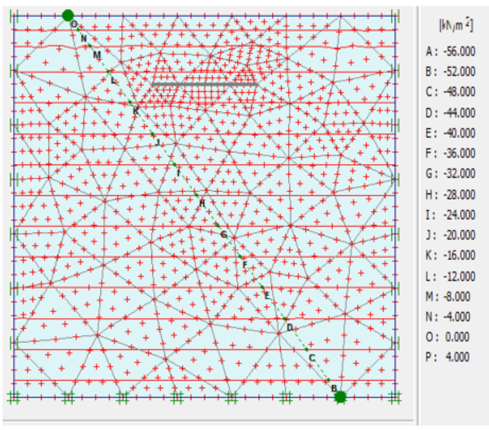

Figure 8: Effective stress generation (Mean Contour)

6. Conclusions

- The Allowable Bearing capacity of Dhulikhel ranges from 33 kPa at Dhulikhel-3 (85.554919E, 27.632540N) to 198 kPa at Dhulikhel-4 (85.5400E, 27.6256N) and Banepa ranges from 57 kPa at Banepa-5 (85.53183 E, 27.635798 N) to 201 kPa at Banepa-11 (85.516919 E, 27.623785 N) for shallow foundation.
- The maps can be useful for the shallow foundation only. It's not necessary that Bearing capacity always increases with the Depth.
- This map will reduce the time and cost of the project lapsed in investigations. This will also help in providing planned settlement in future.
- Terzaghi(1943) and Meyerhof(1963) approach gives higher values whereas Hansen(1970), Vesic(1973) approach gives lower values.
- Plaxis 2D is very useful for easy and fast calculation of ultimate Bearing capacity. The comparison with theoretical approaches shows only difference of maximum 15 %.
- The soil characteristics of different borehole location have been recorded.
- Deep foundations or Mat foundations are recommended where Bearing capacity is too low.
- It is recommended to have centralized settlement in areas having high bearing capacity.

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