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APPROVAL PAGE

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Bearing Capacity Zonation of Urban Areas of Dhulikhel and Banepa for Shallow Foundation"** submitted by Suvarna Singh Raut (074MSGtE020) in partial fulfillment of the requirements for the degree of Master of Science in Geotechnical Engineering.

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ABSTRACT

The stability of every structure depends upon the stability of the supporting soil. Properties of soil and its bearing capacity is the major factor in selection of type of foundation. The soil beneath the structure should sustain the loads without causing shear failure and also with tolerable resulting settlement to be safe from structural damage.

Construction of residential and commercial buildings in Banepa and Dhulikhel are 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 around Araniko Highway periphery of Dhulikhel and Banepa. This map will be useful for the municipalities for preliminary design of foundation, feasibility study, planning of detail investigations. To prepare this, bore log secondary data (SPT-N) and available soil parameters from various seventy-two locations are taken. Terzaghi (1943), Meyerhof (1963), Hansen (1970) and Vesic (1973) approaches have been used to evaluate Bearing capacity from Shear Failure Criteria whereas Meyerhof (1965) and Bowels (1987) approaches from Settlement Criteria. Least value for BC is taken and plotted in map using GIS. The BC have been further calculated from Plaxis 2D. The verification is done from laboratory tests. 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 for each 1.5 m and 3m depth. Plaxis is used to create numerical model. The soil is presented as 2D soil model and drained behavior with axisymmetrical model are being taken into attention. Finite Element Analysis is executed using Mohr-Coulomb failure criteria. Load is applied on Foundation, till the failure takes place in the soil. The Bearing capacity shall be obtained from Load Displacement curve. The research shows that Allowable Bearing capacity of Dhulikhel ranges from 83 kPa at Dhulikhel-3 (85.547190E, 27.631433N) to 447 kPa at Dhulikhel-9 (85.564935E, 27.599648N) and Banepa ranges from 134 kPa at Banepa-10 (85.505769 E, 27.641141 N) to 439 kPa at Banepa-11 (85.516919 E, 27.623785 N) for shallow foundation with square footing of width 1.5m.

Keywords: Bearing capacity, Settlement, Dhulikhel, Banepa, SPT-N, Mapping

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LIST OF ABBREVIATIONS AND SYMBOLS

C: Cohesion

ϕ: Angle of Internal Friction

E: Young’s Modulus

WT: Water Table

γ: Unit Weight

Df : Depth of Foundation

B: Width of Foundation

SPT: Standard Penetration Test

FOS: Factor of Safety

GIS: Geographical Information System

ν: Poisson’s ratio

N: Measured Penetration Number (SPT-N value)

N_{60}: Corrected SPT number for field conditions

P_a : Atmospheric Pressure

amsl : above mean sea level

BH: Bore Hole

2D: Two Dimensional

NC: Normally consolidated

OC: Over Consolidated

FEM: Finite Element Method

NBC: National Building Code

CMTL: Central Material Testing Laboratory

TU: Tribhuvan University

1. INTRODUCTION

1.1 Background

The prerequisite of every engineered structure is robust and stable foundation to carry the load above. This means clearly that the selection of the type of foundation is the critical decision, the designer has to make in any project. In selecting any type of foundation, the properties of soil beneath and bearing capacity should be considered. Bearing capacity is the ability of soil to sustain the loads applied to the ground. It should be checked before the construction of the buildings to prevent from settlement and collapse. The soil below the engineered structure must be likely to carry the loads without causing shear failure and with acceptable subsequent settlement to avoid the damage to the structure (Bowels, 1996). 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. This verifies that geotechnical inquiry is unavoidable for safety of structure during and after construction.

Allowable bearing pressure is the pressure which the soil can safely endure from the load applied to it. Ultimate bearing capacity of the soil can be defined as the intensity of loading or gross pressure at the base of foundation which initiates shear failure of the supporting soil. When we divide ultimate bearing capacity by a factor of safety, we get allowable bearing capacity. At sites having soft soils, large settlements may happen under loaded foundations without shear failure occurrence. In this type of cases, the allowable bearing capacity is actually based on the maximum allowable settlement. The stability of a structure is contingent upon the stability of the supporting soil. A foundation is the substructure which transmits the load of the structure to the earth such that the supporting soil is not overstressed and also does not cause excessive settlement of the structure. Every structure constructed on soil are supported on foundations. Hence, a foundation connects the structure and soil which supports it. Bearing capacity is the most used parameter in the design of foundation.

According to the report from Governance Social Development Humanitarian Conflict (GSDRC) Nepal belongs to one of the least urbanized countries in the world. Yet, it is also one of the top ten fastest urbanizing countries (Bakrania S., 2015). Dhulikhel, a blissful place in Kavrepalanchowk district, State Province 3 is the heaven due to its tremendous natural beauty and widely popular for sightseeing especially mountain view. From the central capital city i.e. Kathmandu valley, it is located towards 30 km south-east. The place is situated at an altitude of 1550 m amsl. Similarly, Banepa also lies in Kavrepalanchowk district at 1500 m amsl. It is located at about 25 km east from the central capital Kathmandu. There are 12 wards in Dhulikhel and 14 wards in Banepa. There are reasons for rapid urbanization in these areas. Dhulikhel is a famous tourist place. Banepa is a famous historical place. Both places are famous for culture and trade. There are popular schools, colleges, universities and hospitals. The climate is favorable. The six lane road of Koteshwor to Suryabinayak further accelerated the urbanization. The haphazard construction of residential and commercial buildings is at high rate without appropriate soil test, without assessing bearing capacity. Some people have been found to add storeys in a random manner without the municipality consent. This is due to lack of consciousness. Awareness campaigns seem to be necessary.

In general, the soil of Dhulikhel and Banepa at upper portion is brown to grey silty clay. Sometimes greyish brown color silty sandy-clay is found too. Brownish yellow mix grey colored soil is also found.

The objective of the design engineer is to build the foundation that keeps the stresses in foundation soil within the limits of safe bearing capacity. The world today has limited resources and time. Hence, we need to be economical. Bearing capacity zonation map will at least be helpful to the geotechnical designers for the preliminary choice of location and illustration of strata encountered. The map saves time and expenses as it gives basic idea about the primary design of foundation including tentative cost. The planning of thorough investigation for major projects can be done during desk study. Preparing feasibility study reports will not be a hectic task. The most important thing is we can prepare ourselves for devastating situation. Due to absence of such maps, geotechnical engineers spend a lot of time and money even in the basic phase of the project.

The target of this research is to prepare the Bearing capacity zonation map of Dhulikhel and Banepa urban areas at Araniko Highway periphery. This is for the prediction of bearing capacity of foundation in specified location. We do this basically from the borelog data. The Bearing capacity is calculated based on the empirical relations. The empirical methods will calculate the results based on SPT N values. Also, the numerical modelling shall be done and bearing capacity results shall be compared with those of empirical or analytical methods. Bearing capacity zonation map will provide a clear idea even for the planned settlement in future. The centralized settlement is very necessary in Nepal.

1.2 Study Area:

1.2.1 Location 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. Dhulikhel, a place in Kavrepalanchowk district, State Province 3 is the paradise for its natural beauty and famous for mountain view. It is located towards 30 km south-east from the central capital city Kathmandu. Its altitude is 1550 m amsl. Banepa lies in Kavrepalanchowk district too at 1500 m amsl. It is located approximately 25 km east from the central capital Kathmandu valley. Banepa and Dhulikhel are emerging cities having historical, cultural, traditional background with maximum people involved in trade and business. The number of wards in Dhulikhel is 12 and Banepa 14. Secondary data are mostly limited to urban areas of Banepa and Hotel areas of Dhulikhel.

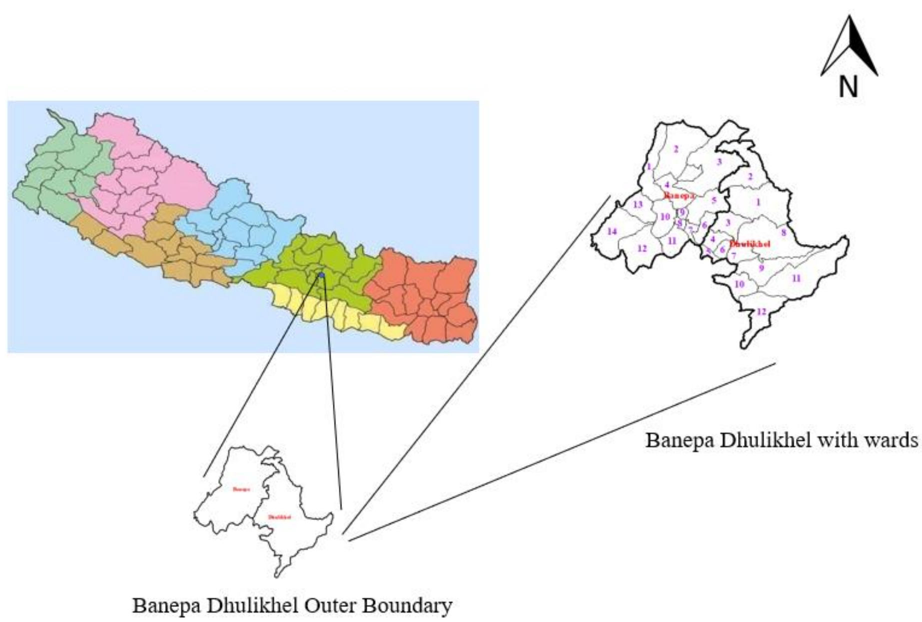

Figure 1. 1 :Location of Study Area (Map not into scale)

1.2.2 Geology:

In general, the soil of Dhulikhel and Banepa urban areas at upper portion is brown to grey silty clay. Sometimes greyish brown color silty sandy-clay is found too. Brownish yellow mix grey colored soil is also found. The municipalities lie in the lesser Himalaya. The area consists consolidated phyllite and sandstone. The carbonaceous clay deposit can be found in the regions with sediment of gravel and sand. The district as a whole is major supplier of construction aggregates and sand. Quaternary deposits and Tistung formation are found in Banepa whereas Raduwa formation is found in Dhulikhel. The Quaternary sediment consists of black carbonaceous lacustrine clay deposits and alluvial fine to coarse sand and gravel. This black carbonaceous clay indicates lacustrine deposits. The rocks are low grade metasedimentary (phyllite and metasandstone) belonging to the Tistung formation. Tistung consists of thin to thick bedded, laminated, fine grained, micaceous, light grey, sandstone and silt stone interbedded with phyllite horizons. Raduwa formation consists of dark grey, highly foliated, garnetiferous schist and some horizons of thin bedded slabby, white biotite-muscovite quartzite.

1.3 Objectives of the Study

The main aim of this research is to prepare the Bearing capacity zonation map of Dhulikhel and Banepa urban areas at Araniko Highway periphery. To achieve this goal, this research uses the soil investigation data with boring logs and N-SPT from several locations of the municipalities. Finally, GIS is used to plot the data.

The general objectives of this study are:

- To compute and compare the bearing capacity of shallow foundation at different locations using different analytical, traditional, theoretical, deterministic approaches and empirical correlations. Also to examine if the numerical modelling values are representative and realistic.
- To identify the geological formation of area and its bearing capacity for shallow foundation.
- To know about the geotechnical characteristics of soil for shallow foundation.

1.4 Scope and Limitations of the Study:

The scope of the research area is as follows but are not limited to:

- Assessment of Foundation soil characteristics.
- Bearing Capacity Evaluation and zonation map preparation of the urban areas of Dhulikhel and Banepa.
- FEM based software modelling with 2D footing consideration.
- Geological Study.
- Recommendations for centralized settlement with reference to Bearing capacity map.

Deep foundations are probable where bearing capacity at shallow depth is less. But such analysis is not being considered in this research. Other limitations are:

- Layered soils, soil with irregularities are not considered.
- Effect of ground water table at worst condition is only considered.
- The research has limitation of 2D footing consideration.
- Footing subjected to static loading only is being considered.

1.5 Statement of Problem

The haphazard construction of residential and commercial buildings in Dhulikhel and Banepa areas without evaluating bearing capacity is a thoughtful problem in the municipalities. We have very limited technical guidelines. The unavailability of Bearing capacity maps has made geotechnical engineers spend a hectic time and money even in the preliminary stage of the project. Planning and calculation of approximate cost of the future project have been a chaotic task to do. This research prepares the Bearing capacity zonation map of urban areas of Dhulikhel and Banepa. This map will be useful to designers for initial design of foundation, feasibility study and prearrangement of detail surveys.

1.6 Organization of the study

The whole thesis is divided into five chapters. The first chapter consist of introduction, details of study area and its general geology, objective, scope and limitations of thesis work. The review of literature about the topic is shown in second chapter. The third consist of methods and steps for doing research work. In the fourth chapter, number of approaches shall be used for determining bearing capacity. Then the result will get analyzed, plotted using GIS, and verified using FEM based software and primary data in this last chapter. Finally, in the fifth chapter, proper documentation will be done along with last but not the least the significant conclusions and recommendations.

2. LITERATURE REVIEW

There are two parts in every structure, substructure and superstructure. 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. So, the choice of the kind of foundation is the significant decision, the designer has to take at the time of the design of the structures. Properties of supporting soil and its bearing capacity is the major factor in selection of type of foundation. Bearing capacity is the ability of soil to sustain the loads applied to the ground. Shallow foundations and Deep foundations are the two types of structural foundations. We shall deal with only shallow foundations in our thesis. According to Terzaghi (1943) definition, a shallow foundation is the one which is laid at a depth, D_f, not exceeding the width B of the foundation. Also, the depth of foundation must be within 3m from the surface. For economy reason, shallow foundations are more popular in our country for residential buildings. But they must be adequate to use and shall be recommended by the Engineer. For satisfactory performance by the foundation, the settlement of the soil caused by load must be within tolerable limit and shear failure of the soil supporting the foundation should not occur. It is usually seen that when the D/B ratio increases, the bearing capacity also increases. Until now, there is no exact method of finding the ultimate Bearing capacity of a foundation. We just estimate the foundation from different approaches. For the design of shallow footing size and shape, designers have to know the ultimate bearing capacity of underneath soil. The pioneers were Prandtl (1921) and Reissner (1924) for this. Terzaghi (1943) introduced ultimate bearing capacity formula which is widely used in real practice. The ultimate bearing capacity of a shallow footing were then given by Meyerhof (1951, 1953, 1963, 1965 and 1967) including methods by Hansen (1961 and 1970) and Vesic (1973) with modification by Bowles (1996). Terzaghi presumed that, during the calculations of ultimate soil bearing capacity, the weight of the soil above the base of the footing shall be replaced by a uniform surcharge, $q=\gamma Df$. The terms Nc, Nq, and $N\gamma$ (also called bearing capacity factors) are, respectively, the contributions of cohesion, surcharge, and unit weight of soil to the ultimate load bearing capacity and these are functions of angle of internal friction. Skempton (1951) showed that the bearing capacity factor Nc in Terzaghi’s equation tends to increase with depth for a cohesive soil. Different methods give unlike results.

Proper design of structure foundation is essential. For this, the designer should have thorough understanding of the subsurface conditions. This is achieved by examination which consists of subsurface investigations through various processes like borings, in situ testing and sampling for lab test. Then, geotechnical analysis of data is made. After going all through these, design recommendations are prepared. Time and expenses should always be considered.

2.1 Principal modes of Shear Failure

Accordng to Vesic (1973), Bearing capacity failure, which are based on the pattern of shearing zones has been classified into three classes;

a. General Shear Failure:

   This type of failure is frequent in brittle stress-strain behavior type soil. The main characteristics are sudden, calamitous failure followed by tilting of foundation. Usually, this type is seen in dense, stiff soil. At a certain load intensity, q_u, the settlement increases unexpectedly. Then at that particular load, the shear failure occurs in the soil. Also, the failure surface extends to the ground surface.

b. Punching shear failure:

   This type of failure is seen in plastic stress-strain behavior type soil. The main characteristic is substantial movement of wedge-shaped soil underneath the foundation and poorly defined shear planes. At a certain load intensity, q_u, the failure of footing occurs. At this stage, the load-settlement curve becomes steep and more importantly linear. There is no clear recognition of ultimate load. Usually, this type is seen in is seen in loose sand and soft clay. The failure surface here neither extend upto the ground surface nor heave is observed. Only the vertical penetration of footing occurs.

c. Local Shear Failure:

   This type of failure is seen in somewhat plastic stress-strain behavior type soil. It bears the partly characteristics of both the above mentioned general and punching shear failure. At a certain load intensity, q_u, the failure of footing occurs. A substantial movement of the footing is necessary for the extension of failure surfaces upto the ground surface. Beyond this point, an addition of load is accompanied by a tremendous increase in settlement. Considerable vertical settlement is the necessary condition for heave to occur. The ultimate load is not clear from the load settlement curve. This mode is quite often in medium dense sand and on a clay of medium consistency.

2.2 General requirements of foundation:

There are general criteria that the foundation must have to give well performance. They are:

a. Shear failure, also known as bearing capacity criterion:

   Any foundation must be safe against shear failure i.e. soil rupture criterion. Usually designer provides sufficient factor of safety to prevent bearing capacity failure. The value ranges between 2 to 4.

   Bearing capacity of soil can be evaluated by analytical methods using equations of Bearing capacity. Or it can be calculated from field test data. Approximate values are calculated from codes, especially building codes. NBC 201 suggests not to construct the building if the proposed site is Water logged area, Rock-falling area, River bed area, Swamp area, Fill area and Landslide prone area. There are also some site investigation requirements given by the code. Minimum two test pits shall be dug for site exploration. The number of pits shall be increased if there is significant variation on subsurface soil type. Minimum depth of exploration is said to be 2 m as by MRT. But in hilly areas exploration shall be done up to the depth of sound rock whether less than or greater than 2m. The soils that come across from the test pits are classified as per Table 2.1 below:

Table 2. 1:Foundation soil classification and Presumed safe bearing capacity (NBC:201:1994)

S.No.	Type of Foundation materials	Foundation classification	Presumed Safe Bearing Capacity (kN/m^2)
1.	Rocks in different state of weathering, boulder bed, gravel, sandy gravel and sand-gravel mixture, dense or loose coarse to medium sand offering high resistance to penetration when excavated by tools, stiff to medium clay which is readily indented with a thumb nail.	Hard	≥ 200
2.	Fine sand and silt (dry lumps easily pulverized by the finger), moist clay and sand-clay mixture which can be indented with strong thumb pressure	Medium	≥ 150 and < 200
3.	Fine sand, loose and dry; soft clay indented with moderate thumb pressure	Soft	≥ 100 and < 150
4.	Very soft clay which can be penetrated several centimeters with the thumb, wet clays	Weak	≥ 50 and < 100

Above table shows that the foundation soil has been categorized only into four categories. The full application of presumptive bearing capacities as per the available building codes are actually discouraged. The main reason is these values are fully relied on soil description rather than actual soil/geotechnical properties. Also, probable influence of weaker soil layer below the base of foundation is not encountered.

b. Settlement criterion

Settlement can be defined as the total vertical displacement that occur at foundation level. The settlement of foundation, more importantly differential settlement must be within the tolerance limit. If the structure settles as a whole uniformly into the earth, there might not be any unfavorable effects on the structure. The only effect it can have is there might be breakage on the service connections such as sanitary, water pipe lines etc. This type of uniform settlement is possible when the subsoil is homogenous and the load distribution is uniform. Settlement outside the permissible limit affect the structure and may damage partly or fully. The load from the foundation can produce three types of settlement and they are:

i. Immediate or elastic settlement: It is also denoted by S_i. It takes place immediately within short span, less than 7 days after the placement of load. In clay type soil, it is termed as distortion settlement. This is because, there occurs modification in only shape of the soil without any changes in volume or water content. Since, its value is small in comparison to long term consolidation settlement, it has been found neglected. It occurs in granular soils. It ends up within the construction period. It is not time dependent.
ii. Primary consolidation settlement or Primary consolidation, S_c: It is due to gradual expulsion of pore water from the voids of soil, resulting in dissipation of excess pore water pressure and an increase in effective stress. The time range is 1 to 5 years or more. It usually occurs in inorganic clays. It is time dependent.
iii. Secondary compression settlement, S_s: The occurrence of this type of settlement is at constant effective stress, with changes in volume due to the rearrangement of soil particles. It is time dependent. It has huge significance on organic soils.

The total vertical settlement denoted by S_t, is the sum of S_i, S_c, and S_s.

2.3 Shallow Foundation

According to Terzaghi (1943), a shallow foundation is placed at Depth, D_f, not greater than width B of the foundation. i.e. D_f/B ratio less than or equals to 1. Also, in this type of foundation, depth of foundation is within 3m from the surface. Moderate Deep foundations have D_f/B ratio greater than 1 and less than 15. The transmission of load is not fully to the base of the foundation in deep foundation. Part of the load is taken by frictional resistance around the foundation and part by bearing at its base. The construction method is fully visible in shallow foundation but not in deep. The disturbance of soil is minimum in shallow foundation but spreads to a greater zone all along the length in deep foundation.

Shallow foundations are classified into various types according to their shape, size and general configuration such as Spread footing, Strip or continuous or wall footing, Combined Footing, Mat or Raft foundation and Floating foundation.

2.4 Standard Penetration Test (SPT)

It is one of the field tests done to access geotechnical engineering properties of soil. This is the most commonly used subsurface exploration drilling test performed in maximum countries. This in-situ test is done mostly for cohesionless soil such as gravels, sands, silts as this type cannot be sampled easily for undisturbed sample. The test is useful for evaluation of relative density and angle of shearing resistance of cohesionless soil. And it is useful in determining the unconfined compressive strength of cohesive soil.

First of all, borehole is drilled and driven to the required depth. Then the drilling tools are removed. The test is conducted now in a bore hole with the lowering of standard split spoon sampler to the bottom of hole. By the means of split-spoon sampler, soil samples are obtained. These soil samples are usually disturbed but representative. The tool consists of a steel tube that is split longitudinally into two halves. The commonly used tube has an inside diameter of approx. 35 mm and outside diameter of approx. 51 mm. The sampler is driven into the soil by drop hammer of 63.5 kg mass. The mass is allowed to fall from the height of 750 mm at the rate of 30 blows per minute. This rate is given by IS:2131-1963. The number of blows required to drive spoon sampler 150 mm is taken into record. Similarly, the number of blows required to drive spoon sampler further 150 mm is taken into record. Once again, the same process is repeated as above and number of blows for final 150 mm is recorded. The number of blows recorded for first 150 mm is not taken into account and number of blows necessary for last two intervals are added to give the Standard Penetration number at that depth, *N*. The number is popularly termed as *N* value. The SPT is conducted at every 750 mm interval vertically. It can be done upto 1500 mm if the borehole depth is large. We should note that if the number of blow counts gets higher than 50 and 10 successive blows produce no advance, the data is not taken into consideration. The test is ended. The sampler is then withdrawn and the soil sample obtained from the tube. The sample is placed in bottle and taken to the lab for further soil properties. The process is not favorable in fine grained cohesive soils. Therefore, careful attention is required during calculations.

The SPT *N* value is very much useful and widely used as many parameters of soil such as relative density, undrained shear strength, friction angle, elastic modulus etc. are correlated. There are many factors that contributes to standardize Field Penetration value. The factors are Hammer type and efficiency, Borehole diameter, Sampling Method and Rod length (Skempton, 1986; Seed et.al., 1985). The relations can be presented as;

$$N_{60} = \frac{N_{rec}\eta_H\eta_B\eta_S\eta_R}{60} \text{..................Equation 2-1}$$

where;

N_{60} = Standard Penetration number corrected for field conditions

N_{rec}= Measured Penetration number

η_H= Hammer efficiency

η_B= Correction for Borehole diameter

η_S=Sampler Correction

η_R= Correction for Rod length

Also, the value should be corrected for Dilatancy and Overburden correction before using in empirical correlations or design charts.

a. Overburden Correction:

The effective overburden pressure (σ'_o) has influence on penetration resistance '*N_{60}*' value in the granular soil. When two granular soils with the same relative density but different confining pressures are tested, the one which possess greater confining pressure gives greater value. The confining pressure being directly proportional to overburden pressure increases with depth. Hence, the *N* value at shallow depths is underestimated and overestimated at greater depths. The correction is needed to achieve standard effective overburden pressure for uniformity. The corrected *N* is given by;

$$(N_1)_{60}=C_N N_{60} \text{……………………Equation 2-2}$$

where;

N_{60}=Standard Penetration number corrected for field conditions given by $(N*\eta_{H}*\eta_{B}*\eta_{S}*\eta_{R})/60$

N=Measured Penetration Number

η_H= Hammer efficiency (%)

η_B=Correction for Borehole diameter

η_S=Sampler Correction

η_R=Correction for Rod Length

$(N_1)_{60}$=value of N_{60} corrected to a standard value

$\sigma'_a=p_a(\approx 100 kN/m^2)$

C_N=Correction factor for overburden pressure

Though there are number of empirical correlations for C_N, the most widely used are given by Liao and Whitman (1986) and Skempton (1986).

We have taken the relationship given by Liao and Whitman (1986):

$$C_N=\left(\frac{1}{\left(\frac{\sigma'_o}{p_a}\right)}\right)^{0.5} \text{……………………Equation 2-3}$$

The values for η_H, η_B, η_S and η_R are given by Seed et al. (1985) and Skempton (1986).

b. Dilatancy Correction:

Dilatancy is the volume change we observe in the granular soils when subjected to shear deformations. We call the material soil dilative if it increases its volume when there is increasing shear. Similarly, the material should contract in presence of decreasing shear. Hence, this type of correction can be applied only when the SPT is conducted in fine or fully saturated sand. Most importantly, the dilatancy correction is applied when $(N_1)_{60}$ value obtained after overburden correction is greater than 15.

Terzaghi and Peck relationship for $(N_1)_{60}>15$,

$$(N_1)_{60}' = 15 + 0.5[(N_1)_{60} - 15] \text{............Equation 2-4}$$

where;

$(N_1)_{60}'$=Final corrected value to be used in correlation and design charts

If $(N_1)_{60} \leq 15$, $(N_1)_{60}' = (N_1)_{60}$.

$(N_1)_{60}>15$ is an indicator for dense sand.

Limitations of SPT:

- SPT value do not represent physical properties of soil.
- The use in gravels, cobbles and cohesive soils are limited.
- The sample collected is disturbed.
- Operator can vary the value.

2.5 Correlation between N_{60} and Relative Density (Dr) of Granular soils

Meyerhof (1975) relationship:

$$N_{60} = [17 + 24(\sigma_o'/p_a)]D_r^2 \text{.............Equation 2-5}$$

2.6 Correlation between N60 and Angle of Friction (ϕ'):

Peck, Hanson and Thornburn (1974) has given a correlation between N_{60} and ϕ' ;

$$\phi' \text{ (deg)} = 27.1+0.3N_{60}-0.00054[N_{60}]^2 \text{............Equation 2-6}$$

2.7 Correlation between Modulus of Elasticity (Es) and SPT-N

Kulhawy and Mayne (1990) relationship:

$$\frac{E_S}{p_a} = \alpha N_{60} \text{ ....Equation 2-7}$$

α= 5 for sands with fines,10 for clean NC sand, 15 for clean OC sand

p_a= Atmospheric Pressure (100 kN/m^2)

Table 2. 2 : Interpretation of SPT according to Terzaghi and Peck for Sand

N	Density	Relative Density (%)	Friction angle (°)
<4	Very loose	<20	<30
4-10	Loose	20-40	30-35
10-30	Normal	40-60	35-40
30-50	Dense	60-80	40-45
>50	Very dense	>80	>45

For cohesionless soil;

$$\gamma_{sat} = 16 + 0.1 * N_{60} (kN/m^3) \text{................. Equation 2-8}$$

2.8 Correlation for N_{60} in Cohesive soil

The consistency of clay soils can be predicted from N_{60}.

Table 2. 3: Approximate correlations between Consistency Index (CI), N_{60} and unconfined compression strength (qu)

N_{60}	Consistency	CI	q_u (kN/m^2)
<2	Very soft	<0.5	<25
2-8	Soft to medium	0.5-0.75	25-80
8-15	Stiff	0.75-1.0	80-150
15-30	Very stiff	1.0-1.5	150-400
>30	Hard	>1.5	>400

Note: The unconfined compressive strength value is two times undrained shear strength. The ultimate bearing capacity is approximately six times the undrained shear strength where C in CNc is the undrained shear strength. The value of Nc is 5.14 and 5.7 respectively by Meyerhof and Terzaghi. Just after the construction, or say at undrained conditions, the soil is at the maximum critical condition and we get undrained shear strength(s_u) equal to cohesion. Only after the passage of time, the pore water dissipates gradually and there will be increment of intergranular stress (σ') and we get drained shear strength (sum of c and $\sigma' tan\phi$). c' and ϕ' are drained shear strength parameters.

For cohesive soil;

$$\gamma_{sat} = 16.8 + 0.15 * N_{60} \text{(kN/m}^3\text{)} \quad \text{……..……. Equation 2-9}$$

2.9 Relationship between Modulus of Elasticity and Poisson's ratio

Table 2. 4: 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

2.10 Development of Terzaghi's Bearing Capacity Theories

The pioneers for Bearing capacity theories work were Prandtl (1921) and Reissner (1924). The theory of plasticity was used by Prandtl to develop ultimate bearing capacity expressions. For this, Prandtl assumed strip footing and curved part of the slip surface had the shape of logarithmic spiral. The shape becomes circular for pure cohesive soil.

Terzaghi (1943) was the first investigator to present inclusive theory that can be used to evaluate the ultimate bearing capacity of rough shallow foundations. It was developed as general theory of Bearing capacity. The soil above the base was replaced by uniform surcharge γD_f. He assumed that the shear strength of the soil is governed by Mohr-Coulomb equation. Also, he assumed that the loading on the footing is vertical and uniformly distributed. The footing is long i.e. continuous or strip with L/B ratio infinite. Terzaghi's theory became so popular that modern theories are based on Terzaghi's theory. We can notice that Terzaghi's theory is based on Prandtl's theory.

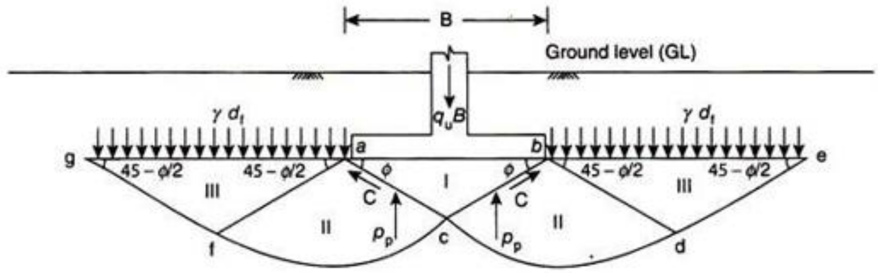

Figure 2. 1: Failure Surface as per Terzaghi's theory (after Arora, 2010)

In the figure above, we can see a wedge-shaped mass of soil abc. This mass does not undergo lateral displacement but sinks vertically down as soon as the footing is loaded by pressure q_u, equal to the ultimate bearing capacity of soil. The sides ca and cb rise making angle ϕ with the horizontal. The mass of soil abc is termed as zone I and is in a state of elastic equilibrium. This wedge behaves as if it were the part of the footing. The failure surface is not prolonged up the horizontal plane passing through the base ab of the footing. Hence, the shearing strength of the soil located above the base can be neglected and no need to take into consideration. The effect of the soil located up the base of footing is taken into account and has equivalence to surcharge γD_f. It is possible when γD_f is relatively small. This limits the theory to shallow foundation. Shear strength of the soil above the base of the footing can never be neglected in deep foundations. If neglected, it will lead to blunder.

The failure surface above consists of zone II, known as radial shear zone on both sides of Zone I. The zone III is on the external side of footing end-to-end to Zone II. The sides ca and cb behave as retaining walls. The sides push the soil in Zone II in the downward and outward direction. The zone I, zone II and zone III can be termed as zone of elastic equilibrium, zone of radial shear state and zone of Rankine passive state respectively. The equilibrium of the wedge abc was considered to determine the ultimate bearing capacity of continuous footing. The Terzaghi's bearing capacity equation is written as;

$$q_u = c'N_c + qN_q + 0.5\,\gamma BN_\gamma \text{ .... Equation 2-10}$$

where;

c'= Cohesion

γ = Unit weight

q = Overburden Pressure = γD_f

The bearing capacity factors N_c, N_q and N_γ are the dimensionless numbers and respectively the contributions of cohesion, surcharge and unit weight of soil. These are dependent only on the angle of shearing resistance ϕ of the soil. The ultimate bearing capacity can be calculated in both total stress or effective stress terms.

To find the q_u of circular and square foundations;

$q_u = 1.3\ c'N_c + qN_q + 0.3\gamma BN_\gamma$ (Circular foundation) ……….. Equation 2-11

where B equals the diameter of foundation.

$q_u = 1.3\ c'N_c + qN_q + 0.4\gamma BN_\gamma$ (Square foundation) ………… Equation 2-12

where B equals the dimension of each side of foundation.

The equations above are based on the assumption that the Bearing capacity failure of soil takes place by general shear failure. Punching shear failure is not common in practice as footings are not placed on loose sands. However, for local shear failure, Terzaghi (1943) recommended empirical adjustments to shear strength parameters c and ϕ. Now, the shear strength parameters $c_m\ and\ \phi_m$ are used in the equation.

Mobilized cohesion, $c_m = \frac{2}{3}c$ …………… Equation 2-13

For mobilized angle of shearing resistance, $\phi_m\ or\ \phi'$;

$\tan\phi_m = \frac{2}{3}\tan\phi$ ………………………… Equation 2-14

The bearing capacity factors are indicated as $N_c', N_q'\ and\ N_\gamma'$ corresponding to local shear failure to differentiate from general shear failure.

The ultimate bearing capacity equation can be written as;

$q_u = \frac{2}{3}cN_c' + qN_q' + 0.5\ \gamma BN_\gamma'$ ………… Equation 2-15

Many design engineers still prefer Terzaghi's equation as this provides fairly good results for the soil conditions with uncertainties at several locations.

2.11 Modifications of Bearing capacity equations for water table

The ultimate bearing capacity has been developed based on the assumption that the water table is located much below at great depth, greater than width, *B* of the footing. When water table is located at this depth, water will have no effect on the ultimate bearing capacity. The effective shear strength is reduced if the water table is located to proximity of the foundation. The modifications in bearing capacity equation will be necessary in second and third terms of general bearing capacity equation. Three different conditions arise and they are:

Case I: The water table is located at distance D above the bottom of the foundation. The q will be now;

q = effective surcharge = $\gamma\left(D_f - D\right) + \gamma' D$ ………………… Equation 2-16

where $\gamma' = \gamma_{sat} - \gamma_w$ = effective unit weight of the soil

γ_{sat} = saturated unit weight of soil

γ_w = Unit weight of water

Also, the unit weight of soil, γ that appears in the last term has to be replaced by γ'.

Case II: The ground water table coincides the bottom of the foundation, $q = \gamma D_f$ and γ of third term is replaced by γ'.

Case III: The water table is located at depth *D* below the bottom of foundation. The $q = \gamma D_f$ and γ of third term becomes γ_{av}.

$\gamma_{av} = \frac{1}{B}[\gamma D + \gamma'(B - D)]$ for $D \leq B$………………… Equation 2-17

$\gamma_{av} = \gamma$ for $D > B$ …………………………………..... Equation 2-18

2.12 Meyerhof's Bearing capacity equations

Meyerhof (1951) presented a general theory of bearing capacity for a strip footing at any depth. Meyerhof's contemplation of failure mechanism was alike to that of Terzaghi's supposition. The variance was Meyerhof extended the failure surfaces above the foundation level. This means he took into consideration the shear strength of the soil above the footing base for analysis.

Meyerhof (1963) recommended the general bearing capacity equation. This takes into consideration the shape and the inclination of load. The general form is presented as:

$$q_{ult} = cN_c s_c d_c i_c + q' N_q s_q d_q i_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma i_\gamma \text{ ……………Equation 2-19}$$

where, s, d, and i are empirical correction factors called the shape factor, depth factor and inclination factor respectively. The bearing capacity factors $N_c, N_q \text{ and } N_\gamma$ depend upon the roughness of base, depth of footing and the shape of footing in addition to the angle of shearing resistance $\emptyset'$. The main advantage of this theory is that it can also be used for deep foundations and for footings on the slopes.

Meyerhof (1965) gave the following equations for Settlement criteria to find the Bearing capacity:

For B≤1.22 m;

$$q_{net(all)}\left(\frac{kN}{m^2}\right) = 11.98(N_1)_{60} \text{……………… Equation 2-20}$$

For B >1.22 m;

$$q_{net(all)}\left(\frac{kN}{m^2}\right) = 7.99(N_1)_{60}\left(\frac{3.28B+1}{3.28B}\right)^2 \text{………Equation 2-21}$$

The theoretical solution was proposed by Meyerhof (1957) to find the ultimate bearing capacity of a shallow foundation located on either face of the slope or near the top edge of the slope.

$$q_u = C'N_{cq} + \frac{1}{2}\gamma B N_{\gamma q} \text{ ....Equation 2-22}$$

For purely granular soil, c'=0;

$$q_u = \frac{1}{2}\gamma B N_{\gamma q} \text{ ....Equation 2-23}$$

For purely cohesive soil, $\phi = 0$ (the undrained condition),

$$q_u = C'N_{cq} \text{ .... Equation 2-24}$$

$$where\ c = undrained\ cohesion.$$

Where $N_{cq}, N_{\gamma q}$ are bearing capacity factors.

The above mentioned equations are for strip footings. But it can be used for square, circular and rectangular footings using empirical shape factors given by Meyerhof.

2.13 Hansen's Bearing capacity equations

Hansen (1957,1970) recommended a general bearing capacity equation which was quite similar to Meyerhof's. Compared to Meyerhof and Hansen, Terzaghi's results were found conservative. Even though Terzaghi's equations are popular as it is simple to apply. For cohesive soils, Hansen's equations give better results compared to Terzaghi's. Hansen's equation can be presented as;

$$q_{ult} = cN_c s_c d_c i_c + q'N_q s_q d_q i_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma i_\gamma \text{ .... Equation 2-25}$$

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

For the continuous footings located at the edge of the slope, Hansen (1970) gave the following equation to determine the ultimate bearing capacity:

$$q_u = cN_c\lambda_{c\beta} + qN_q\lambda_{q\beta} + \frac{1}{2}\gamma B N_\gamma \lambda_{\gamma\beta} \text{ .... Equation 2-26}$$

Where;

Nc, Nq and Nγ are bearing capacity factors given by;

$$N_q = e^{\pi tan\phi}\left(\frac{1+sin\phi}{1-sin\phi}\right) \text{……………… ...Equation 2-27}$$

$$N_c = \left(N_q - 1\right)cot\phi \text{ ……....... Equation 2-28}$$

$$N_\gamma = 1.5N_c \tan^2 \phi \text{……... …..Equation 2-29}$$

$\lambda_{c\beta}, \lambda_{q\beta,}\ \lambda_{\gamma\beta}$ are slope factors given by;

$$\lambda_{q\beta} = \lambda_{\gamma\beta} = (1\text{-}\tan\beta)^2 \text{ ……………….... Equation 2-30}$$

$$\lambda_{c\beta} = \frac{N_q\lambda_{q\beta}-1}{N_q-1} \text{ (For } \phi > 0\text{) ……......... Equation 2-31}$$

$$\lambda_{c\beta} = 1 - \frac{2\beta}{\pi+2} \text{ (For } \phi = 0\text{) ……......... Equation 2-32}$$

The above-mentioned equations are for strip footings. But it can be used for square, circular and rectangular footings using empirical shape factors given by Hansen.

2.14 Vesic's Bearing capacity equations

Vesic (1973) used the failure surface similar to that used in Terzaghi's theory, except that the slope of elastic wedge (zone-I) is assumed to be (45 + ϕ/2) with horizontal instead of ϕ. The equation can be presented as;

$$q_{ult} = cN_c s_c d_c i_c + q'N_q s_q d_q i_q + 0.5\gamma B'N_\gamma s_\gamma d_\gamma i_\gamma \text{……….Equation 2-33}$$

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

2.15 Skempton's Bearing capacity analysis for clay soils

Skempton(1951) proposed the equation for saturated clay soils in which $\phi = 0$. N_c is given by theory, lab tests and field observations.

$$q_{nu} = c_u N_c = \frac{q_u}{2} N_c \text{ ……………………………………………..…Equation 2-34}$$

where, q_u= unconfined compressive strength of clay.

2.16 Settlement of Shallow Foundations

Shallow foundation must be safe in regard to shear failure and also, they must not undergo extreme settlement. The design of the shallow foundations is more often governed by settlement criteria than bearing capacity.

If the foundation is assumed to be perfectly Flexible, the settlement may be expressed as per Bowles, 1987;

$$S_e = q_o(\alpha B')\frac{1-\nu_s^2}{E_s} I_s I_f \text{.....................Equation 2-35}$$

Where;

qo = Net applied pressure on the foundation
ν_s= Poisson's ratio of soil
Es= Average Modulus of Elasticity of the soil
B′ = B/2 for centre of foundation
= B for corner of foundation
Is = Shape factor (Steinbrenner, 1934)

$$I_s = F_1 + \frac{1-2\nu_s}{1-\nu_s} F_2 \text{...........................Equation 2-36}$$

To calculate settlement at the centre of foundation; we use α=4.
To calculate settlement at the corner of foundation; we use α=1.
The elastic settlement of the rigid foundation can be predicted as;

$$S_{e(rigid)} \cong 0.93\, S_{e(flexible,center)} \text{..............Equation 2-37}$$

The flexible footing undergoes differential settlement while a rigid footing will undergo uniform settlement or we can say at every point settlement will be same in rigid footing while it will differ in flexible footing.

Bowles (1977) proposed the modified form of bearing equation based on Settlement Criteria and can be expressed as:

For B$\leq$ 1.22 m;

$$q_{net(all)}\left(\frac{kN}{m^2}\right) = 19.16(N_1)_{60} * F_d * \left(\frac{S_o}{25.4}\right) \quad \text{…………………….. Equation 2-38}$$

For B>1.22 m;

$$q_{net(all)}\left(\frac{kN}{m^2}\right) = 11.98(N_1)_{60}\left(\frac{3.28B+1}{3.28B}\right)^2 * F_d * \left(\frac{S_o}{25.4}\right) \quad \text{…………….. Equation 2-39}$$

where;

F_d = depth factor = 1+0.33$\left(\frac{D_f}{B}\right)$

B = foundation width, in meters

So = settlement, in mm

Eurocode 7 recommends that the maximum total settlement can be 25 mm for serviceability limit state.

For the elastic settlement of Shallow foundation, Jambu et al. (1956) proposed the equation;

$$S_e = A_1 A_2 \frac{q_o B}{E_s} \quad \text{……………………..Equation 2-40}$$

where;

A_1= f(H/B,L/B)

A_2= f(D_f/B)

L=Length of Foundation

B=width of foundation

D_f=Depth of foundation

H=Depth of the Bottom of the foundation to a rigid layer

q_o=Net load per unit area of the foundation

2.17 Settlement of Foundation on Sand Based on SPT:

Meyerhof (1965) proposed the Settlement equation as;

$$S_e(mm) = \frac{2q_{net}\left(\frac{kN}{m^2}\right)}{N_{60}F_d}\left(\frac{B}{B+0.3}\right)^2 \quad \text{(For B} \geq 1.22\text{m)} \ldots\ldots\ldots\text{Equation 2-41}$$

$$F_d = 1 + 0.33\left(\frac{D_f}{B}\right) \ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 2-42}$$

where;

s = settlement in inches

q = footing stress (in ton per square foot)

B = Footing width in ft

2.18 IS 6403-1976 (Settlement Criteria):

The bearing capacity of the soil based on the settlement criteria is given by the IS code as follows.

$$Q = (N-3)\left(\frac{B+0.3}{2B}\right)^2 W \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2-43}$$

This value is for settlement of 40 mm. For other values;

$$Q = \frac{1.7645N^{1.4}}{B^{0.75}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2-44}$$

2.19 Tolerable settlement of Buildings:

Skempton and Mc Donald proposed the following limiting values for maximum settlement;

Table 2. 5:Table for Maximum Settlement

Type of Soil	Maximum Settlement $S_{T(max)}$
Sand	32 mm
Clay	45 mm

Large differential settlement at different parts in a structure is a disaster due to additional moment developed. Prediction of maximum settlement is easier than predicting differential settlement. Hence, differential settlement is obtained from indirect methods. The differential

settlement has never exceeded 75 percentage of maximum settlement from the observations made. Mostly, differential settlement is less than 50 percentage of maximum settlement. Thus, if we can control maximum settlement, differential settlement is self-controlled.
IS 1904 (1966) allows maximum settlement of 40 mm for isolated foundations on sand and 65 mm for clays. The reason for higher permissible settlement in clays is that progressive settlements on clayey soil permit better strain adjustments in the structural members. The settlement in sand occurs almost immediately on placement of load while on clay, consolidation settlement occurs over a long period of time.

2.20 PLAXIS 2D

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.

Finite Element Method (FEM) is one of the accurate and economic ways to analyze the soil structure interaction. FEM takes into account stress strain behavior and displacement observed. 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. PLAXIS is one of the available powerful softwares which enables the geotechnical engineers to utilize FEM in the shortest time. Geotechnical engineers are frequently required to solve complex soil-interaction problems. PLAXIS is abbreviated for 'Plasticity Axi-Symmetry' that enables elastic-plastic calculations for plane strain problems based on high order elements. Plaxis 2D is a finite element program that can be used for two-dimensional analysis of deformation(settlement) and stability (bearing capacity) of shallow foundation. In this software, two-dimensional soil models are used to simulate the soil behavior. User can define complex soil profiles. The estimation of Bearing capacity of soil is done with Mohr Coulomb's failure idealization. Foundation is modelled as square footing and load increment is applied till the soil model fails.

The input process is in simple graphical manner. It creates a complex finite element model (or mesh) quickly. The geometry is divided into elements. The calculation is automatic which is based on vigorous numerical actions. A transformation of input data (Properties, Boundary conditions, Material Sets, etc.) from the geometry model (Points, lines and clusters) to the finite element mesh (elements, nodes and stress points) takes place. Finite element mesh of the Geometry around the footing is created. Mesh can be generated in PLAXIS. Five types of mesh density such as very coarse, coarse, medium, fine and very fine mesh can be generated. PLAXIS uses predefined structural elements and loading types. PLAXIS has certain direction that guides the user to create models with geotechnical workflow. The automatic Finite element mesh is created through the automatic meshing procedure. Then after assigning the material properties and boundary conditions, finite analysis is done. Medium mesh generation is the most suitable one that gives relatively accurate output. The input parameters in PLAXIS can be obtained from SPT *N* value as we have many correlations with the required parameters. The data needed are index, elastic and strength parameters of soil. It gives the result where patterns of deformations and stress distribution can be identified during deformation and at ultimate state. The stress distribution in soil and displacement experienced at different locations are obtained. The Bearing capacity shall be obtained from Load Displacement curve. Axisymmetric model is taken into consideration.

3. METHODOLOGY

3.1 Preparation and Planning

Different consultancies were communicated to get the bore log data to meet the target. Hence, we can say that the research is mainly based on secondary data.

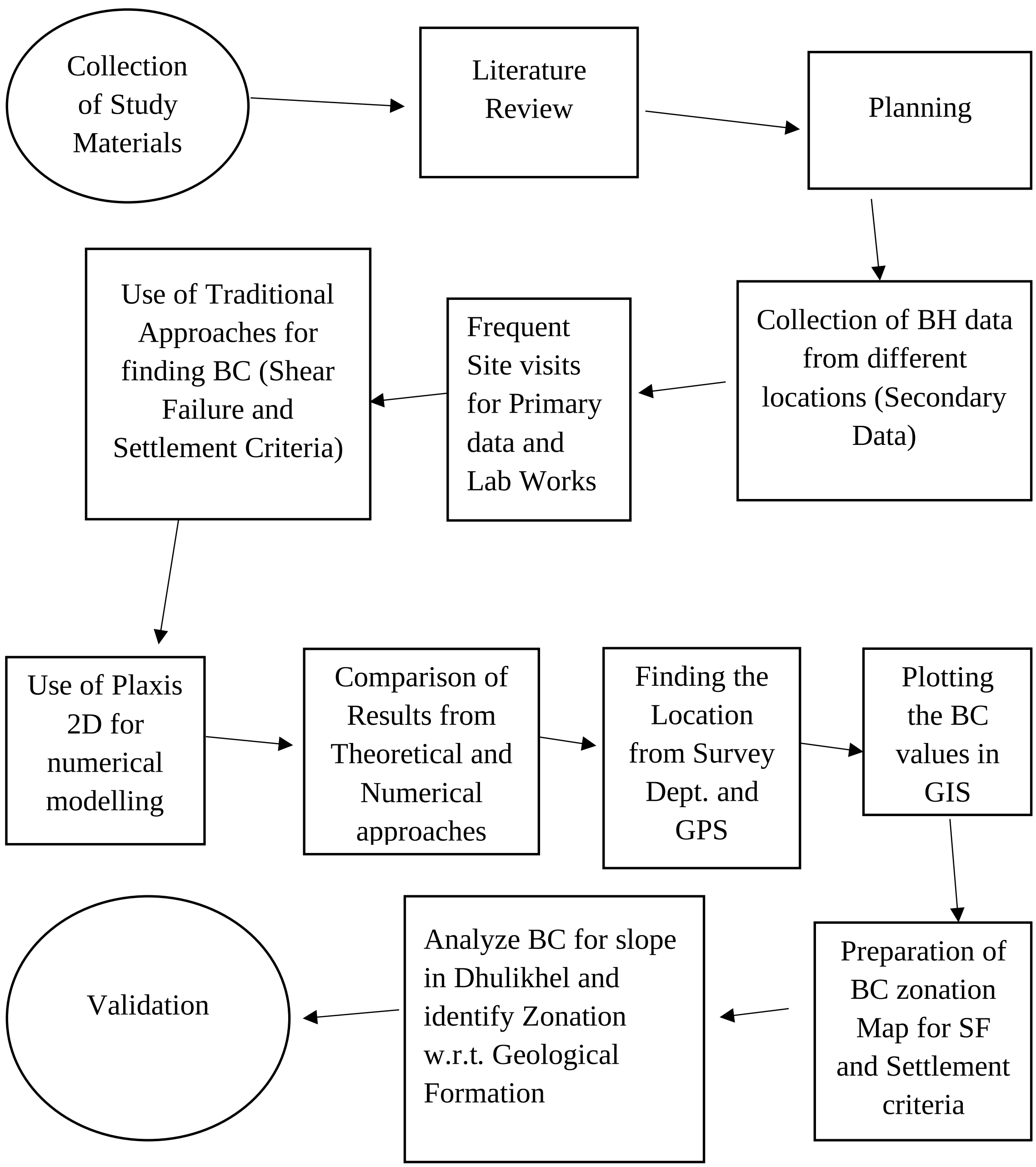

Figure 3. 1: Flowchart of Methodology

3.2 Borehole Data Collection

The study area of this research is major urban areas of Dhulikhel and Banepa around Araniko Highway. The borehole data were collected from these locations. Secondary data were provided by multiple labs and consultancies. The data collection procedure was of major important task in this research. The consultancies which provided secondary data i.e. borelog with SPT 'N' value for the research are Drafters Engineering, Krist Engineering Consultancy, Viswa Consult Pvt. Ltd., Concrete Builders and Engineering Service Pvt. Ltd., RIGC, Agni Boring and Soil Test Pvt. Ltd., Soil Tech Consultant, G.S. Engineering and Construction, New Planet Geotech, Geotech and Associates, Mayur Builders. Since, there was very less practice or say the houses have just started to do soil test, not much data was collected. Thirty Five BH locations from Banepa and Twenty seven locations from Dhulikhel was taken into study. Ten location was chosen for primary data. The values were analyzed and bearing capacity was calculated.

3.3 Finding the Coordinates of BH location

The next major task was to find the coordinates of the BH location. Since all the consultancies or say data provider to this research didn't have the coordinates, we made the team with Geomatics Engineer, ward representative and local friends to find the house location, took GPS and found the coordinates. The table shows the location of Boreholes.

Table 3. 1: Sample Table for Location of Secondary and Primary data; Boreholes and manual digging locations

S.N.	Location	Coordinates	S.N.	Location	Coordinates
1	Dhulikhel-8;	85.564441 E 27.621501 N	8	Banepa-8	85.518747 E 27.634434 N
2	Dhulikhel-8, Bhattedanda	85.571187 E 27.615593 N	9	Banepa-8	85.523421 E 27.633188 N
3	Dhulikhel-3	85.547190E 27.631433N	10	Banepa-8	85.519024 E 27.630252 N
4	Dwarika Resort, Dhulikhel-8	85.574494E 27.619188N	11	Bhimsenthan - 7, Banepa	85.528352 E 27.62627 N
5	Dulikhel-6	85.546603E 27.613532N	12	Banepa-6, Bhimsen Marg	85.533088 E 27.6295 N
6	Dhulikhel-7	85.554606E 27.610757N	13	Banepa-8	85.521986 E 27.62634 N
7	Dhulikhel-3	85.554919E 27.632540N	14	Banepa-7	85.528348 E 27.625971 N

3.4 Bearing capacity determination from theoretical approaches:

From the SPT-N values collected from various Geotech consultancies; Cohesion, angle of internal friction, unit weight, Young's modulus, Poisson's ratio were correlated. Bearing capacity factors were evaluated including empirical correction factors. Shear failure criteria and settlement criteria have been used. For the shear failure criteria, the methods used are of Terzaghi(1943), Meyerhof(1963), Hansen(1970) and Vesic(1973). For settlement criteria, Meyerhof(1965) and Bowels(1987) methods have been used.

Also, five soil samples were taken from different locations in Banepa and five from Dhulikhel as primary data at Araniko Highway periphery. Among these, eight were disturbed and two were undisturbed sample. The soil samples were taken to the lab to find index and engineering properties. Cohesion and Angle of internal friction were found from Direct Shear Test.

The residential buildings in Dhulikhel and Banepa has foundation size of 1.52m by 1.52m. The depth of foundation is also most commonly 1.5m. We have taken the depths of 1.5m and 3m into consideration. The foundation we have taken in study is square foundation with width 1.52m. For the conservative and safe design, water table has been taken to the most critical case and that is at the surface.

Table 3. 2: Representative Table of Bearing capacity calculation of Banepa areas (Shear Failure and Settlement Criteria) at 1.5 m and 3 m depths

Location	Coordinates	Depth (m)	SAFE ALLOWABLE (Shear Failure Criteria)					Plaxis		SAFE ALLOWABLE (Settlement Criteria)		
			Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum (kN/m2)	From Plaxis 8.2	Diff.(%)	Meyerhof (1965) (kN/m2)	Bowels (1987) (kN/m2)	Minimum (kN/m2)
Banepa-11	27.626458 N	1.5	146.57	201.06	198.81	216.94	146.57	126.5	-13.68	69.10	136.23	69.10
	85.517458 E	3	256.58	374.07	361.18	388.39	256.58	265.67	3.54	103.65	209.38	103.65
Banepa-8	27.630397 N	1.5	145.47	187.76	197.55	207.26	145.47	164.08	12.79	57.58	93.69	57.58
	85.524064 E	3	206.21	305.80	297.38	311.21	206.21	225.95	9.57	138.20	279.17	138.20
Banepa-7	27.626266 N	1.5	142.84	196.43	192.82	212.90	142.84	160.91	12.65	92.13	149.90	92.13
	85.528687 E	3	262.56	381.18	371.75	401.86	262.56	155.72	-40.69	299.43	604.88	299.43
Banepa-7	27.62358 N	1.5	158.52	201.63	206.38	219.25	158.52	151.75	-4.27	69.10	112.43	69.10
	85.52865 E	3	252.45	341.92	329.32	348.14	252.45	230.36	-8.75	103.65	209.38	103.65

Table 3. 3: Representative Table of Bearing capacity calculation of Dhulikhel areas (Shear Failure and Settlement Criteria) at 1.5 m and 3 m depths

S.No.	Location	Coordinates	Depth (m)	SAFE ALLOWABLE (Shear Failure Criteria)					Plaxis		SAFE ALLOWABLE (Settlement Criteria)		
				Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum (kN/m2)	From Plaxis 8.2	Diff.(%)	Meyerhof (1965) (kN/m2)	Bowels (1987) (kN/m2)	Minimum (kN/m2)
D1	Dhulikhel-8	85.564441 E	1.5	151.50	192.31	196.39	209.55	151.50	169.07	11.60	80.62	131.16	80.62
		27.621501 N	3	247.32	332.18	321.55	340.78	247.32	270.00	9.17	115.17	232.65	115.17
D2	Dhulikhel-8, Bhattedanda	85.571187 E	1.5	151.38	187.45	189.27	203.92	151.38	174.40	15.20	80.62	131.16	80.62
		27.615593 N	3	260.59	334.99	324.72	346.39	260.59	225.02	-13.65	115.17	232.65	115.17
D3	Dhulikhel-3	85.547190E	1.5	82.95	214.44	207.02	211.30	82.95	78.80	-5.00	69.10	112.43	69.10
		27.631433N	3	109.86	233.59	233.10	243.62	109.86	104.88	-4.53	115.17	232.65	115.17
D4	Dwarika Resort,	85.574494E	1.5	130.86	179.79	177.21	194.37	130.86	148.40	13.40	80.62	131.16	80.62
		27.619188N	3	204.88	340.84	330.59	356.34	204.88	225.07	9.85	172.75	348.97	172.75

Table 3. 4: Table of Bearing capacity calculation of samples collected from ten locations

Site Location (Source of Primary Data)				Safe Allowable(Shear Failure Criteria)				
S.No.	Location	Location	Depth (m)	Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum (kN/m2)
S1	27°38'13.554"N	Banepa-13	1.50	150.78	182.80	205.50	210.60	150.78
	85°29'50.581"E							
S2	27°38’04.73’’ N	Banepa-14	1.50	136.24	158.18	175.94	180.37	136.24
	85°29’18.72’’ E							
S3	27°37’55.92’’ N	Banepa-13	1.50	150.73	188.24	210.22	214.68	150.73
	85°30’10.38’’ E							
S4	27°37'38.745"N	Banepa-10	1.50	168.54	170.63	212.31	221.00	168.54
	85°30'29.918"E							
S5	27°37'17.635"N	Banepa -11	1.50	131.02	154.65	172.91	176.50	131.02
	85°31'33.563" E							
S6	27°37’17.36’’ N	Dhulikhel-6	1.50	132.26	153.79	170.87	175.25	132.26
	85°32’07.95’’ E							
S7	27°36’59.70’’ N	Dhulikhel-7	1.50	122.11	154.25	173.17	176.58	122.11
	85°33’24.84’’ E							
S8	27°36’51.75’’ N	Dhulikhel-7	1.50	130.47	151.27	168.04	171.85	130.47
	85°33’19.26’’ E							
S9	27°36’49.76’’ N	Dhulikhel-7	1.50	132.93	153.98	171.05	174.78	132.93
	85°33’11.65’’ E							
S10	27°37’10.93’’ N	Dhulikhel-6	1.50	139.00	175.96	183.88	194.44	139.00
	85°33’5.78’’ E							

3.5 Bearing capacity of Foundation in slopes:

Civil engineering structures at many times are bound to be constructed on slopes or near to the slopes. In lack of plain lands in Dhulikhel, the construction of residential and commercial buildings, resorts, academic institutions, hospitals are in hilly region or say in slopes. The safety of buildings on slopes is of prime importance. Two case studies of Bearing Capacity of shallow foundations resting on slopes in granular soil and cohesive soil are taken in this section and compared with the ones derived considering plain ground. The estimation of BC on sloping ground was proposed by Meyerhof at beginning as pioneer. The different failure surfaces are formed. The parameters that are taken in consideration are the footing geometry, slope and soil characteristics.

3.6 Plaxis 2D Modelling:

The input process is simple graphical manner. It creates a complex finite element model (or mesh) quickly. The geometry is divided into elements. The output facilitates the user with presentation of computational results in detail. The calculation is automatic which is based on vigorous numerical actions. A transformation of input data (Properties, Boundary conditions, Material Sets, etc.) from the geometry model (Points, lines and clusters) to the finite element mesh (elements, nodes and stress points) takes place. Finite element mesh of the Geometry around the footing is created. The square footings are taken as approximately circular footings with soil footing contact area equivalence. This means the corresponding square footing 1.5m X 1.5m will have corresponding circular footing with diameter 1.69 m. The differences in stresses at the same depths due to the use of circular instead of square footing will be less than 2%. This difference is based on Linear Elastic Calculations.

The axisymmetric model means the lateral or more precisely radial strains of the model are equal in all directions. The footing in the model is symmetrical along the vertical Y axis and the model is rotated as the Y axis. Hence, the model results in circular excavation. In Plaxis, the rotating axis is always the left boundary. On the other hand, it will result in plane excavation if the plane strain model is adopted. The plain strain model means the strains takes place only in xy plane. Along the longitudinal axis i.e. out of plane direction, the strain is assumed to be zero. Therefore, the length of excavation will be larger than the width of excavation. Here, we have square footing. So, we have used axisymmetrical modelling. When the analysis is done by Axisymmetry model, the output of load vs displacement is obtained by kN/rad. It is multiplied by 2pi and get load in kN. In our case, square footing is half.

Sign Convention: In all the output data, compressive stresses, pore pressures are taken as negative.

The Bearing capacity shall be obtained from Load Displacement curve. The vertical load displacement curve obtained is transformed to average vertical stress-displacement curve. The load at which the shear failure of the soil occurs is called the ultimate bearing capacity of the foundation.

Material Model:

To present soil model, we need to choose the failure criterion of the soil model. Here, Mohr-coulomb criterion is chosen. The criterion is used to compute BC and collapse loads of footing. Young's modulus (E), Poisson's ratio (ν), Angle of internal friction (ϕ), Cohesion (C) and Dilatancy angle (ψ) are important five parameters needed for this Mohr coulomb model used here. Axisymmetric model with square footing is taken into consideration.

Material Model for soil: (Failure criteria: Mohr-Coulomb)

Table 3. 5: Soil Parameters for Numerical Modelling (Sample)

Name	Parameter Symbol	Input Value	Unit
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	ν	0.27	-
Cohesion (constant)	C	2	kN/ m^2
Friction angle	ϕ	30°	Degree
Dilatancy angle	Ψ	0°	degree
Mesh type	Medium mesh	15 Nodded	
Material model	Model	Mohr Coulomb	-
Type of material behavior	Type	Drained	-
Soil dry unit weight	γ_{dry}	13.58	kN/m^3
Saturated unit weight	γ_{sat}	16.7	kN/m^3

A sample mesh can be seen in figure below. Loading is applied without eccentricity. Initial stresses are developed.

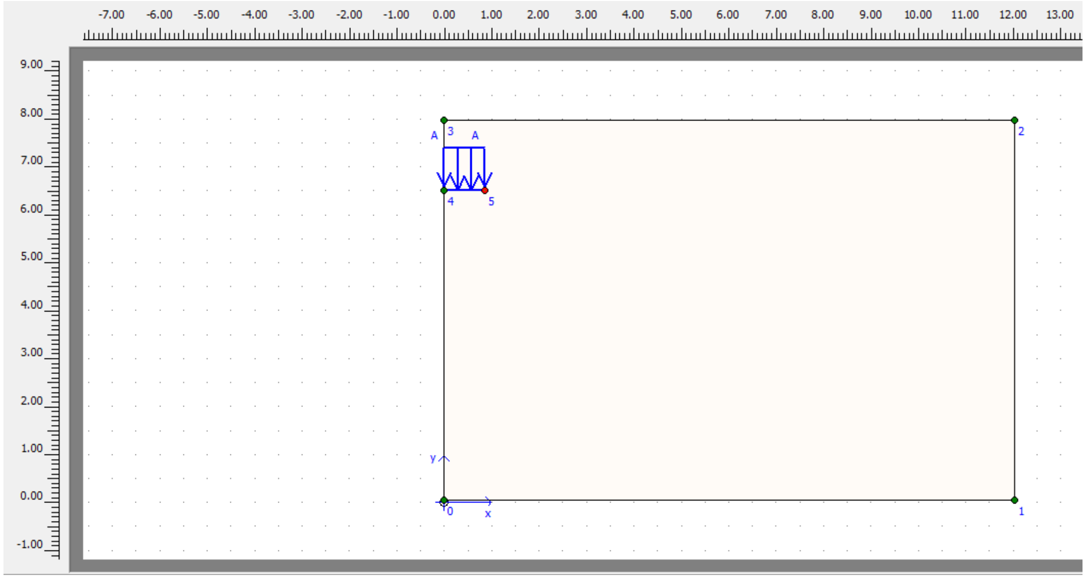

Figure 3. 2: Sample of Material soil model and footing

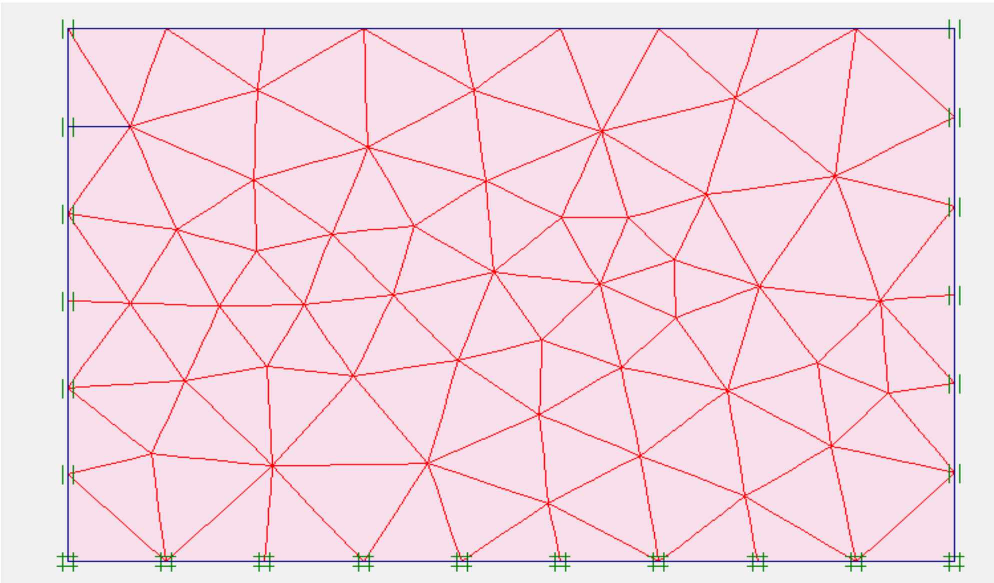

Figure 3. 3 Mesh Generation

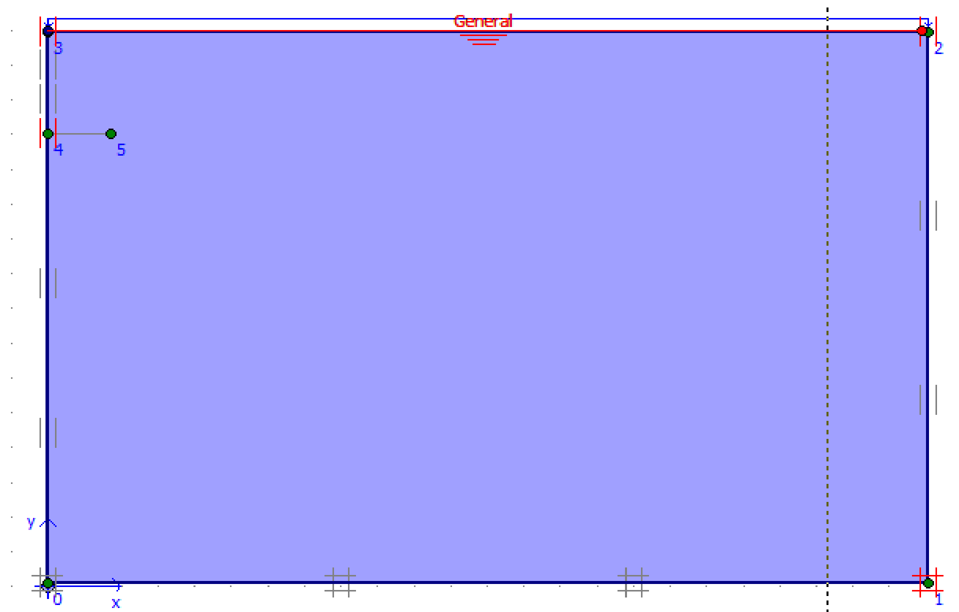

Figure 3. 4: Water Table demarcation

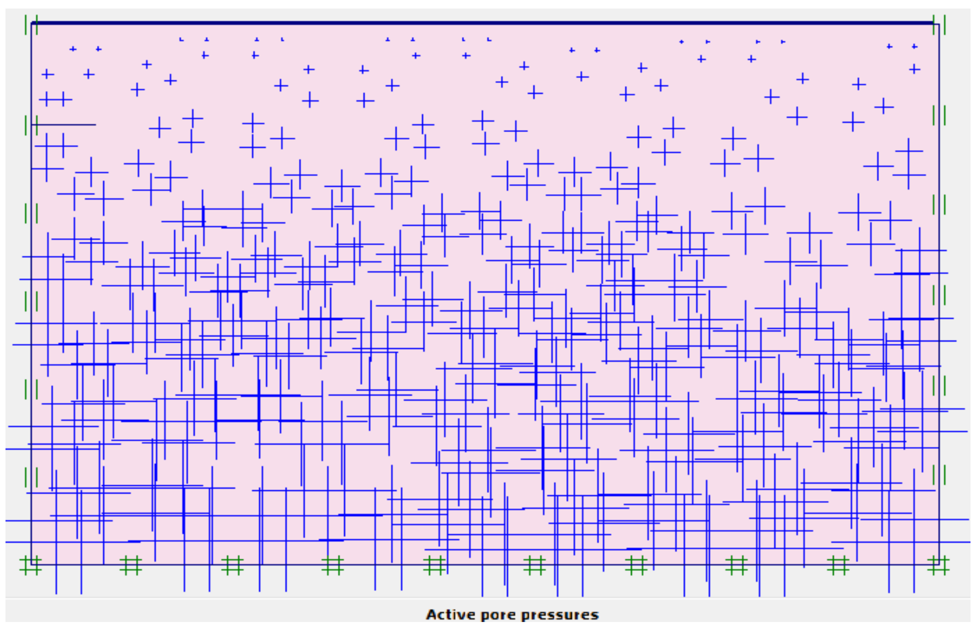

Figure 3. 5: Pore Pressure

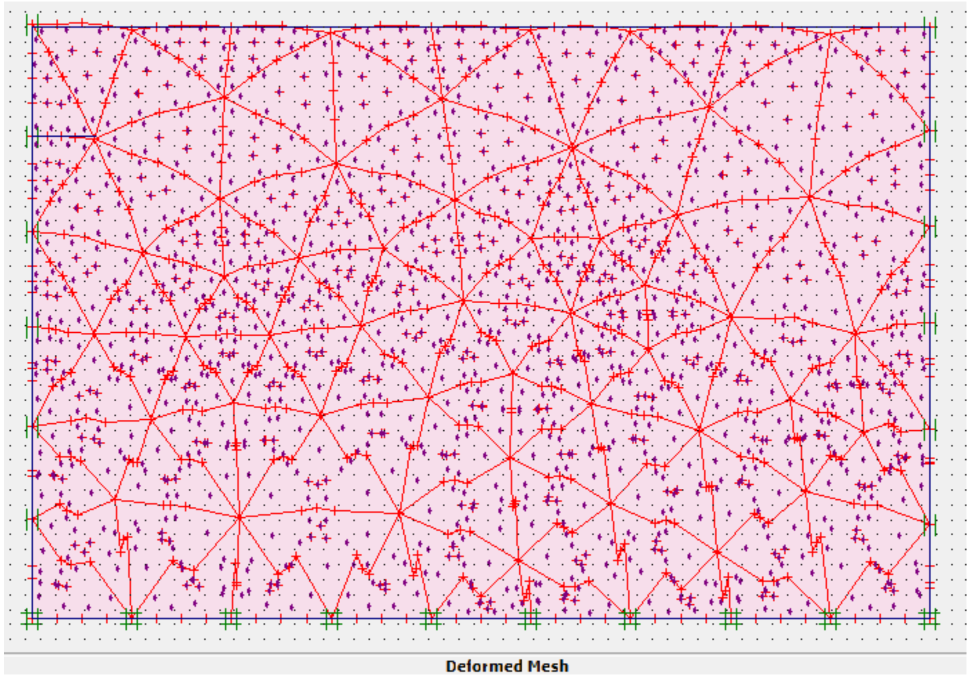

Figure 3. 6: Deformed Mesh

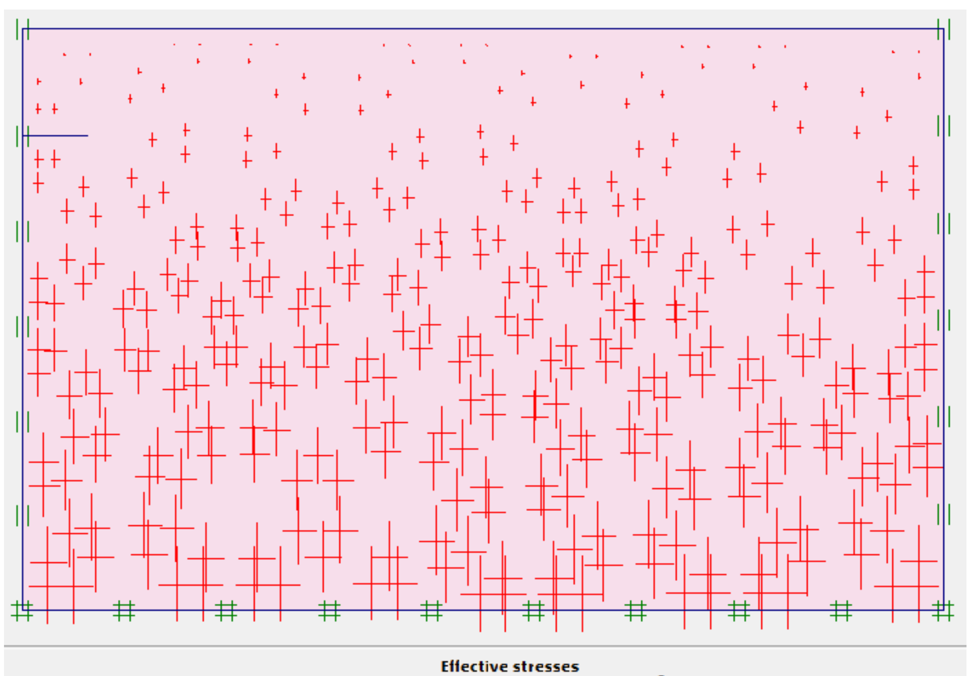

Figure 3. 7: Effective stress generation

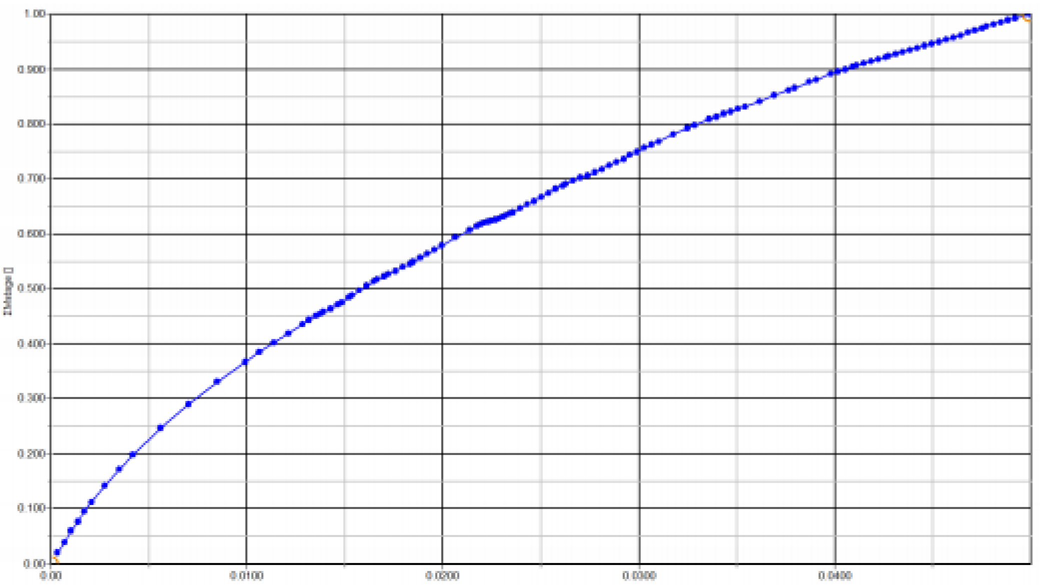

Figure 3. 8: Load Displacement curve for the footing

3.7 Digitization of Bore Hole Points:

Forty BH locations of Banepa and Thirty two BH locations of Dhulikhel have been taken including primary and secondary data. The Bearing capacity calculations for shallow foundations are done at these locations. The numerical modelling is also done to compare the data. Ten Locations are chosen for primary data for further verifications. 1.5m, 3m depths and 1.52m by 1.52m foundation area have been taken for calculation of Bearing capacity. The minimum value is taken among the approaches and plotted using GIS software.

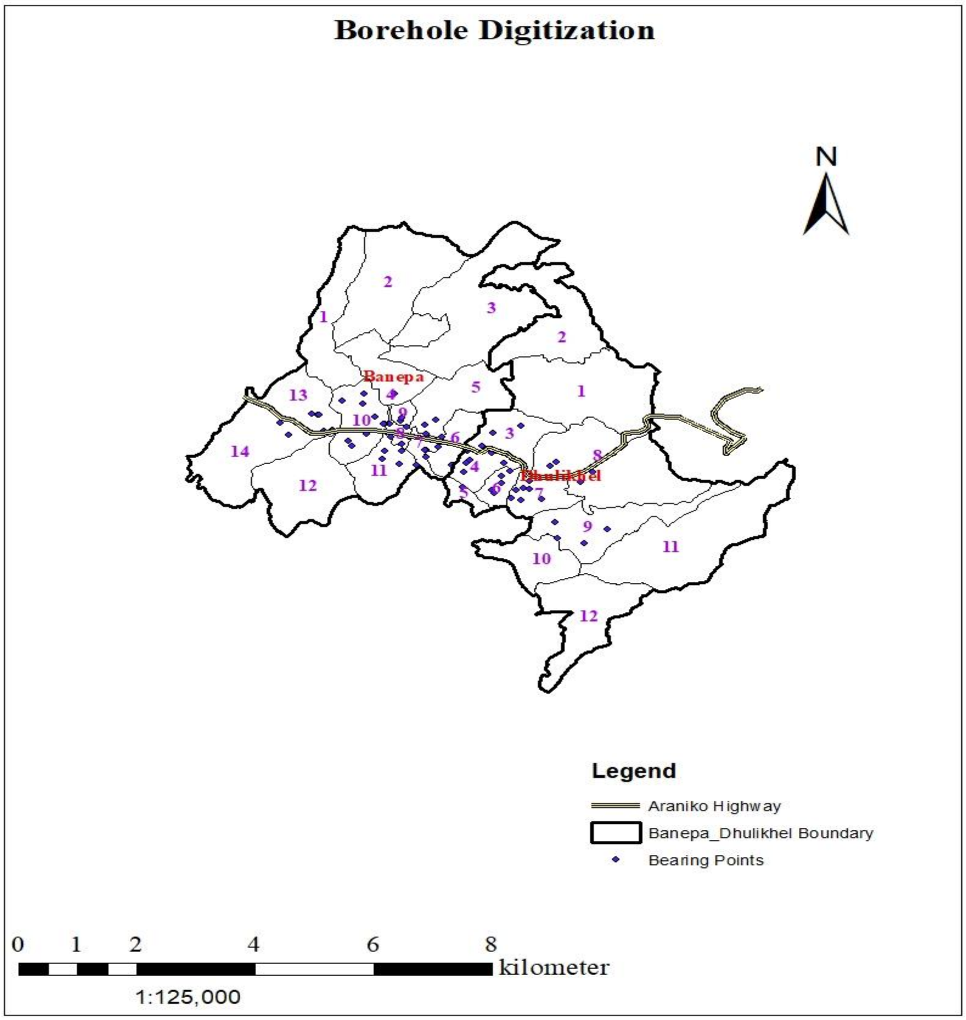

Figure 3. 9: Digitization of BH points of Banepa and Dhulikhel urban areas at Araniko Highway periphery

4. RESULTS AND DISCUSSION

This research determined the Bearing capacity for shallow foundations of Dhulikhel and Banepa urban areas at Araniko Highway periphery from different theoretical approaches and numerical modelling. The goal was achieved through soil investigation data with boring logs and N-SPT from several locations of the municipalities. Ten locations were chosen randomly for soil sampling and tested in lab. The Bearing capacity was evaluated from Terzaghi (1943), Meyerhof (1963), Hansen (1970), Vesic (1973) approaches from shear failure criteria whereas Meyerhof (1965), Bowels (1987) approaches used in Settlement criteria. The zonation map along with contour map was prepared taking minimum bearing capacity among various approaches for each location using GIS software. Then examination was done if the numerical modelling values are representative and realistic.

Bearing capacity zonation map will at least be helpful to the geotechnical designers for the preliminary choice of location and illustration of strata encountered. The map saves time and expenses as it gives basic idea about the primary design of foundation including tentative cost. The planning of thorough investigation for major projects can be done during desk study. Preparing feasibility study reports will not be a hectic task. The most important thing is we can prepare ourselves for devastating situation. Bearing capacity zonation map will provide a clear idea even for the planned settlement in future. The centralized settlement is very much necessary in Nepal. The world today has limited resources and time. Hence, we need to be economical.

4.1 Works achieved:

4.1.1 Bearing capacity values at Banepa:

The research shows that allowable Bearing capacity of Banepa ranges from 134 kPa at Banepa-10 (27.641141N, 85.505769 E) to 282 kPa at Banepa-4 (27.64252 N, 85.520248 E) for 1.5 m depth from Shear Failure Criteria.

Table 4. 1: Bearing capacity values at 1.5 m depth from Shear Failure criteria (Banepa) for footing size 1.5m X 1.5m

S. No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Terzaghi (1943)	134	Banepa-10(27.641141N, 85.505769 E)	183	Banepa-4(27.64252 N, 85.520248 E)
2.	Meyerhof (1963)	184	Banepa-10(27.641141N, 85.505769 E)	248	Banepa-11(27.623785N,85.516919 E)
3.	Hansen (1970)	172	Banepa-10(27.641141N, 85.505769 E)	248	Banepa-4(27.64252 N, 85.520248 E)
4.	Vesic (1973)	179	Banepa-5(27.635798 N, 85.53183 E)	281	Banepa-4(27.64252 N, 85.520248 E)

Table 4. 2: Bearing capacity values at 1.5 m depth from Settlement criteria (Banepa) for footing size 1.5m X 1.5m

S.No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Meyerhof (1965)	58	Banepa-7(27.625971 N, 85.528348 E)	92	Banepa-10(27.641141 N,85.505769 E)
2.	Bowels (1987)	94	Banepa-7(27.625971 N, 85.528348 E)	149	Banepa-10(27.641141 N,85.505769 E)

Table 4. 3: Bearing capacity values at 3 m depth from Shear Failure criteria (Banepa) for footing size 1.5m X 1.5m

S.No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Terzaghi (1943)	202	Banepa-10(27.636 039N,85.514641 E)	292	Banepa7(27.625971N, 85.528348 E)
2.	Meyerhof (1963)	305	Banepa-8(27.630397 N, 85.524064 E)	433	Banepa-11(27.623785 N, 85.516919 E).
3.	Hansen (1970)	297	Banepa-8(27.630397 N, 85.524064 E)	411	Banepa-11(27.623785 N, 85.516919 E).
4.	Vesic (1973)	311	Banepa-8(27.630397 N, 85.524064 E)	439	Banepa-11(27.623785 N, 85.516919 E).

Table 4. 4: Bearing capacity values at 3m depth from Settlement criteria (Banepa) for footing size 1.5m X 1.5m

S.No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Meyerhof (1965)	55	Banepa-10(27.6360 39 N, 85.514641 E)	414	Banepa-7 (27.625971N,85.5283 48 E)
2.	Bowels (1987)	70	Banepa-10(27.63 6039N,85.514641E)	405	Banepa-10 (27.626266 N, 85.528687 E)

4.1.2 Bearing capacity values at Dhulikhel:

The research shows that Allowable Bearing capacity of Dhulikhel ranges from 83 kPa at Dhulikhel-3 (27.63 1433N,85.547190E) to 285 kPa at Dhulikhel-4 (27.6256N, 85.5400E) for 1.5 m depth from Shear Failure Criteria.

Table 4. 5: Bearing capacity values at 1.5 m depth from Shear Failure criteria (Dhulikhel) for footing size 1.5m X 1.5m

S.No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Terzaghi (1943)	83	Dhulikhel-3(27.63 1433N,85.547190E)	198	Dhulikhel-4(27.6256N, 85.5400E)
2.	Meyerhof (1963)	152	Dhulikhel-6(27.631 433N,85.547265E)	274	Dhulikhel7(27.610757 N, 85.554606E)
3.	Hansen (1970)	151	Dhulikhel3(27.6325 40N, 85.554919E)	271	Dhulikhel727.610757 N, 85.554606E)
4.	Vesic (1973)	157	Dhulikhel3(27.6325 40N, 85.554919E)	301	Dhulikhel-4(27.6256N, 85.5400E).

Table 4. 6: Bearing capacity values at 1.5 depth m from Settlement criteria (Dhulikhel) for footing size 1.5m X 1.5m

S.No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Meyerhof (1965)	58	Dhulikhel-9 (27.60 4322N,85.563393E)	92	Dhulikhel-4(27.62 6144N, 85.539744E)
2.	Bowels (1987)	93	Dhulikhel-9(27.604 322 N, 85.563393 E)	149	Dhulikhel-4(27.6215 52N, 85.550067E).

Table 4. 7: Bearing capacity values at 3 m depth from Shear Failure criteria (Dhulikhel) for footing size 1.5m X 1.5m

S. No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Terzaghi (1943)	109	Dhulikhel-3 (27.631 433N, 85.547190E)	314	Dhulikhel-4(27.623149N, 85.540707E)
2.	Meyerhof (1963)	233	Dhulikhel-3 (27.63 1433N,85.547190E)	417	Dhulikhel-4(27.623149N, 85.540707E)
3.	Hansen (1970)	233	Dhulikhel-3 (27.63 1433N,85.547190E)	396	Dhulikhel-4(27.623149N, 85.540707E)
4.	Vesic (1973)	243.62	Dhulikhel-3 (27.63 1433N,85.547190E)	447	Dhulikhel-6 (27.616487N, 85.549325E).

Table 4. 8: Bearing capacity values at 3 m depth from Settlement criteria (Dhulikhel) for footing size 1.5m X 1.5m

S.No.	Approach	Least Value (kPa)	Location	Highest value (kPa)	Location
1.	Meyerhof (1965)	58	Dhulikhel-3(27.62 6752N,85.544253E)	404	Dhulikhel-9(27.60183 5N,85.578266E).
2.	Bowels (1987)	76	Dhulikhel-8(27.62 118 N, 85.562689 E)	439	Dhulikhel-9(27.601 835N, 85.578266E)

4.1.3 Bearing capacity of Shallow Foundation on slopes of Dhulikhel:

The following table shows the parameters that are taken in consideration such as footing geometry, slope and soil characteristics for the slope land of granular and cohesive soil cases.

Table 4. 9 : Parameters required for BC calculation in slopes

Parameters for Slope			
Parameters	Unit	Dhulikhel-7	Dhulikhel-6
		27°36’49.76’’ N	27°37’10.93’’ N
		85°33’11.65’’ E	85°33’5.78’’ E
B	m	1.52	1.52
Df	m	1.52	1.52
b	m	1	1
H	m	9	10
Length of Slope	m	14	18
Beta	Degree	40	34
Unit wt	kN/m3	14.48	12.92
Phi	Degree	19.02	28.45
C	kN/m2	14.1	3.03
Df/B	Ratio	1	1
b/B	Ratio	0.66	0.66

Case I on Granular soil:

The soil sample falling to soil classification SM with C value 3 kN/m^2 and Angle of Internal Friction value 28 degree was taken into consideration. This soil was taken as granular soil and put in Meyerhof (1957) equation. The comparison was done between the allowable bearing pressure computed considering plain ground with allowable bearing pressure at actual field condition.

Table 4. 10: Comparison of BC on plain and actual slope land (Dhulikhel-6) at 1.5m depth

Location	Allowable Bearing Pressure considering Plain Ground		Allowable Bearing Pressure at Actual Field condition
27°37'10.93'' N 85°33'5.78'' E	Terzaghi (1943) (kN/m^2)	Vesic (1973) (kN/m^2)	Meyerhof (1957) (kN/m^2)
Dhulikhel-6	139	148.33	135

The above result shows that in case of granular soil with soil parameters being same, the actual Bearing capacity is lesser at slopes than in plain ground.

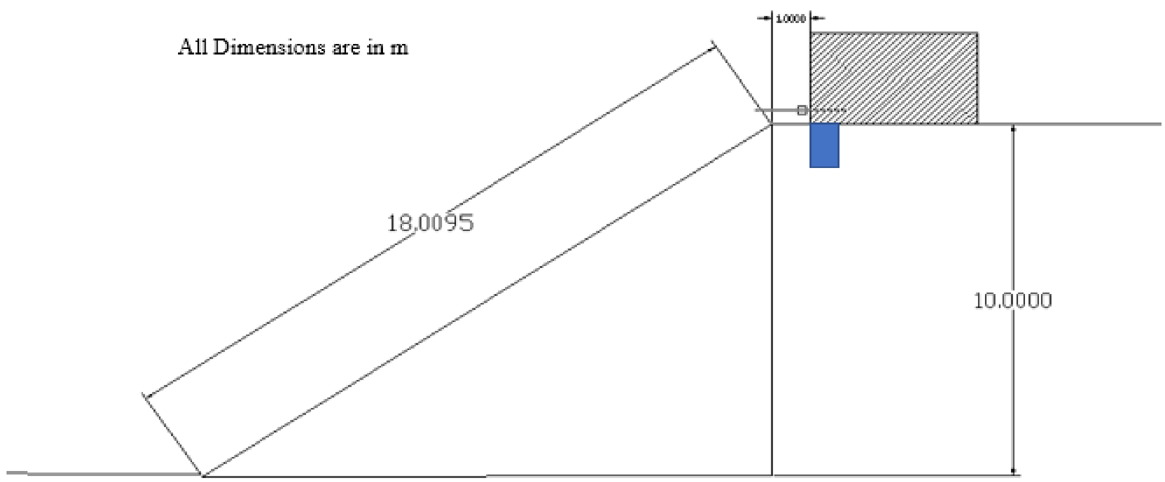

Figure 4. 1: Sketch of the Building (Hatched portion) on slope (Dhulikhel-6)

Case II on Cohesive soil:

The soil sample with C value 14.10 kN/m^2 was taken into consideration. This soil was assumed as cohesive soil and put in Meyerhof (1957) equation. The comparison was done between the allowable bearing pressure computed considering plain ground with allowable bearing pressure at actual field condition.

Table 4. 11: Comparison of BC on plain and actual slope land (Dhulikhel-7) at 1.5 m depth

Location	Allowable Bearing Pressure considering Plain Ground		Allowable Bearing Pressure at Actual Field condition
27°36’49.76’’ N 85°33’11.65’’ E	Terzaghi(1943) (kN/m^2)	Vesic(1973) (kN/m^2)	Meyerhof (1957) (kN/m^2)
Dhulikhel-7	132.93	132.81	53

The above result shows that in case of cohesive soil with soil parameters being same, the actual Bearing capacity is lesser at slopes than in plain ground.

Limitation: The soil sample is not purely cohesive.

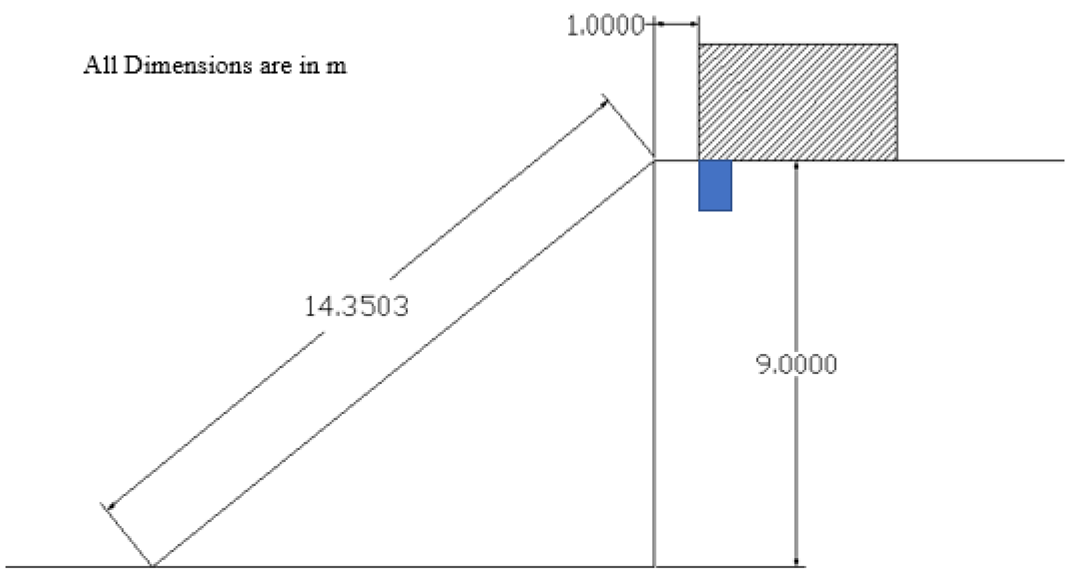

Figure 4. 2:Sketch of the Building (Hatched portion) on slope (Dhulikhel-7)

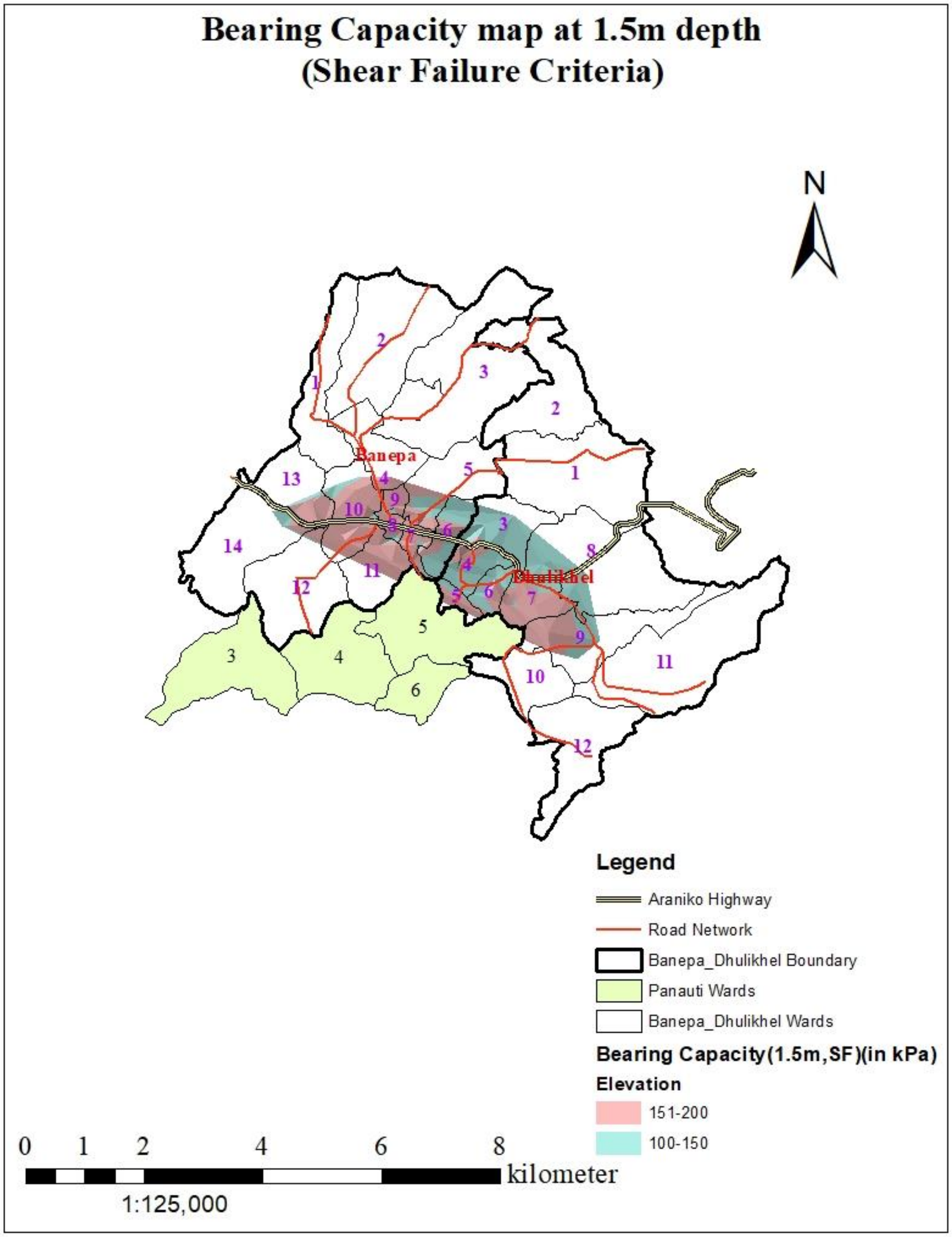

Figure 4. 3: Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Shear Failure Criteria

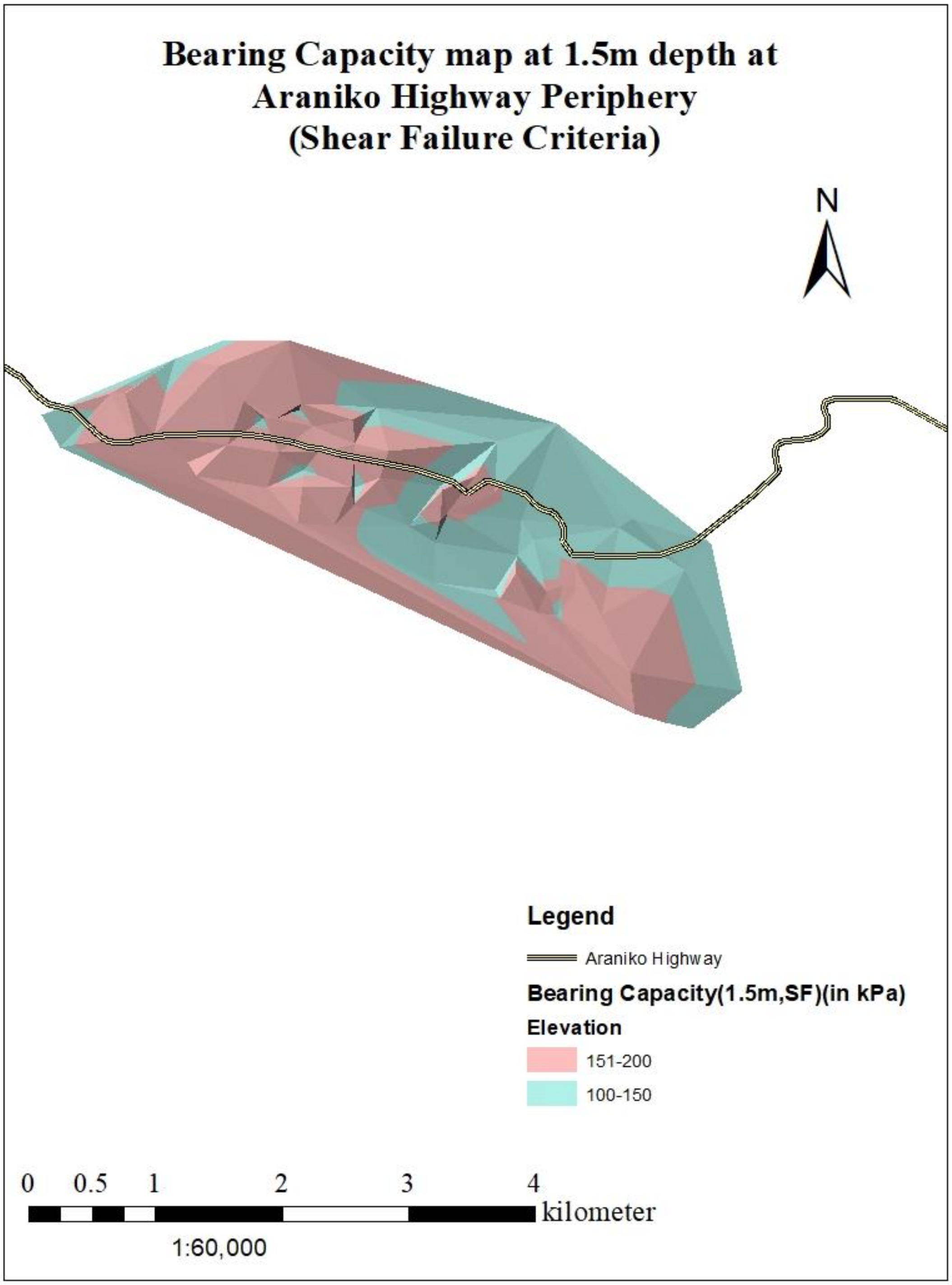

Figure 4. 4: Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Shear Failure Criteria (Scale 1:60000)

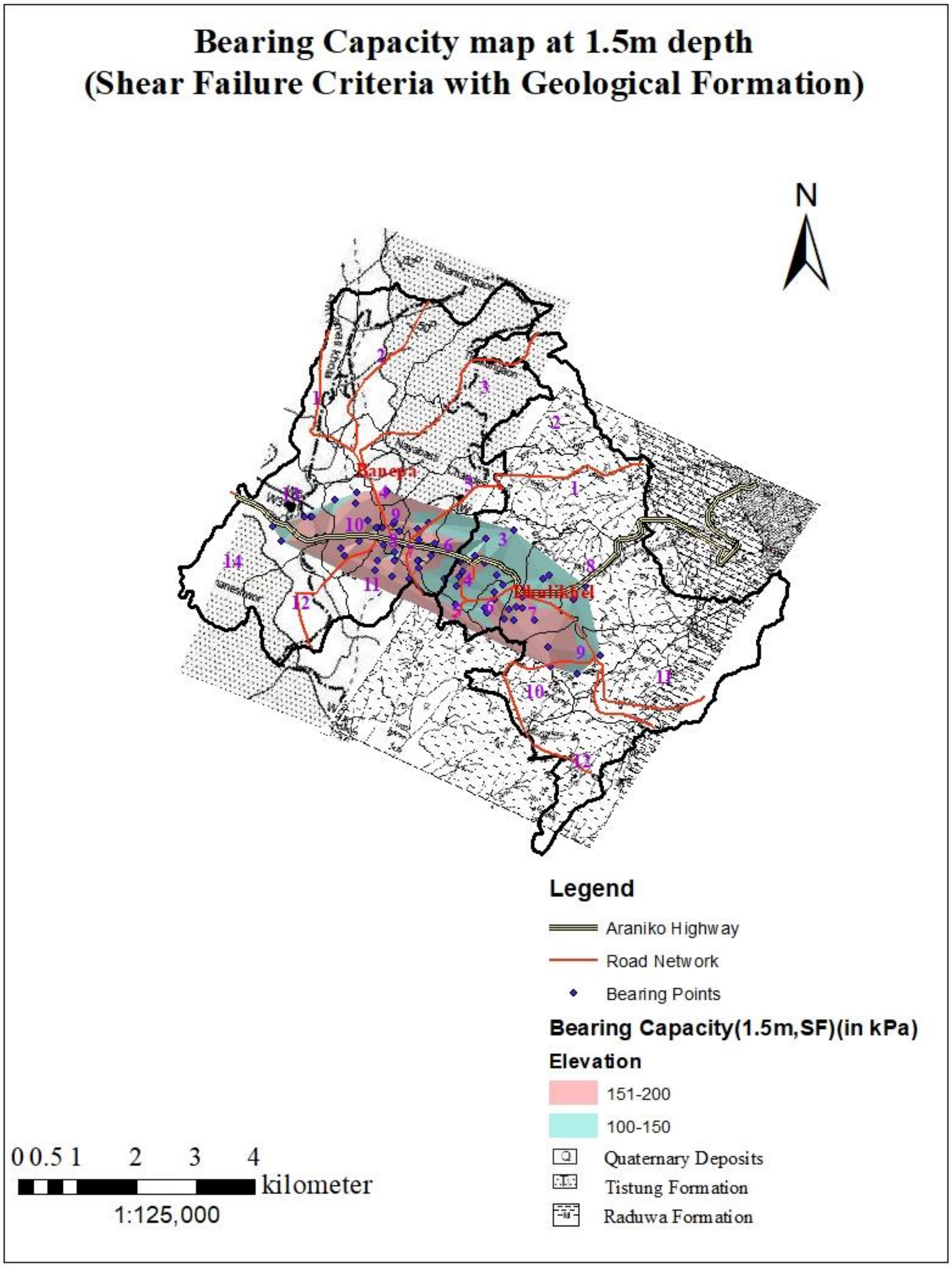

Figure 4. 5: Bearing capacity map of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Shear Failure Criteria with Geological Formation

Table 4. 12: Bearing capacity Zonation at 1.5m depth (Shear Failure Criteria) with Geological Formation and average BC values

S. No.	Municipality	Geological Formation	Approach	Average (kPa)
1.	Banepa	Quatenary	Terzaghi (1943)	158
			Meyerhof (1963)	216
			Hansen (1970)	210
			Vesic (1973)	230
		Tistung	No values till date	No values till date
2.	Dhulikhel	Raduwa	Terzaghi (1943)	140
			Meyerhof (1963)	213
			Hansen (1970)	210
			Vesic (1973)	229

For the shallow foundation, 1.5m depth at the particular locations, Quaternary deposits have higher BC values than in Raduwa formation.

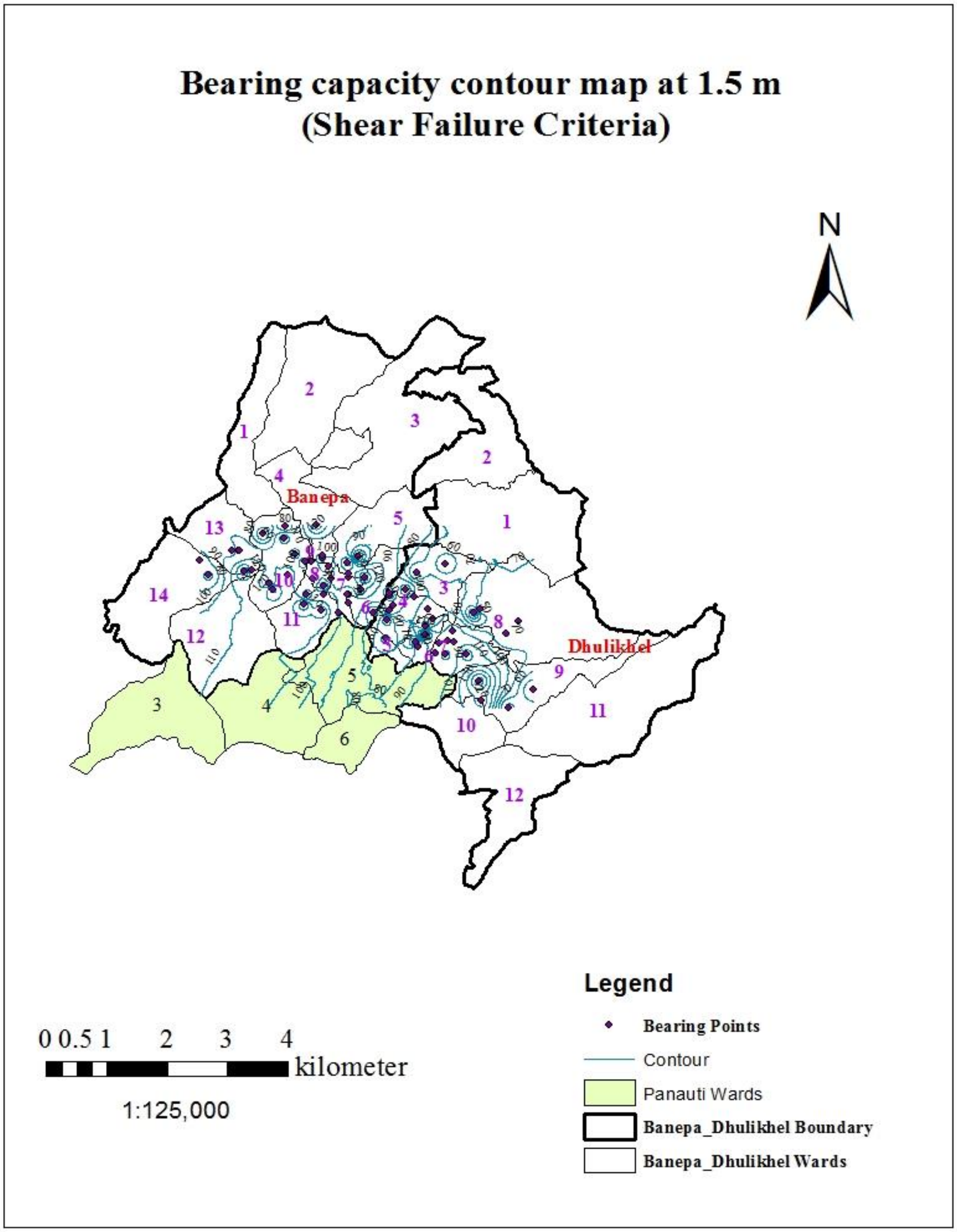

Figure 4. 6: Contour of Bearing capacity of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Shear Failure Criteria

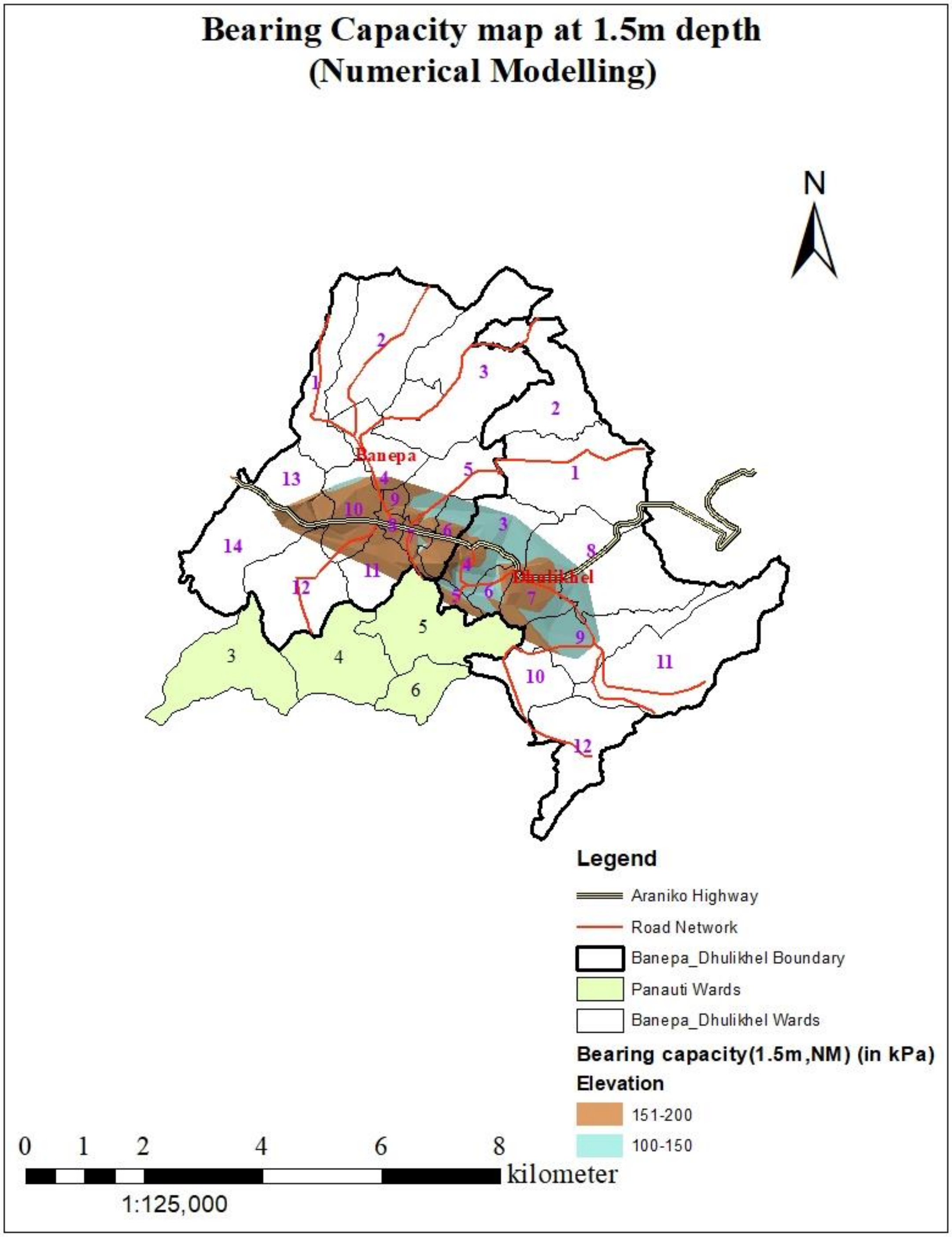

Figure 4. 7 Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Numerical Modelling

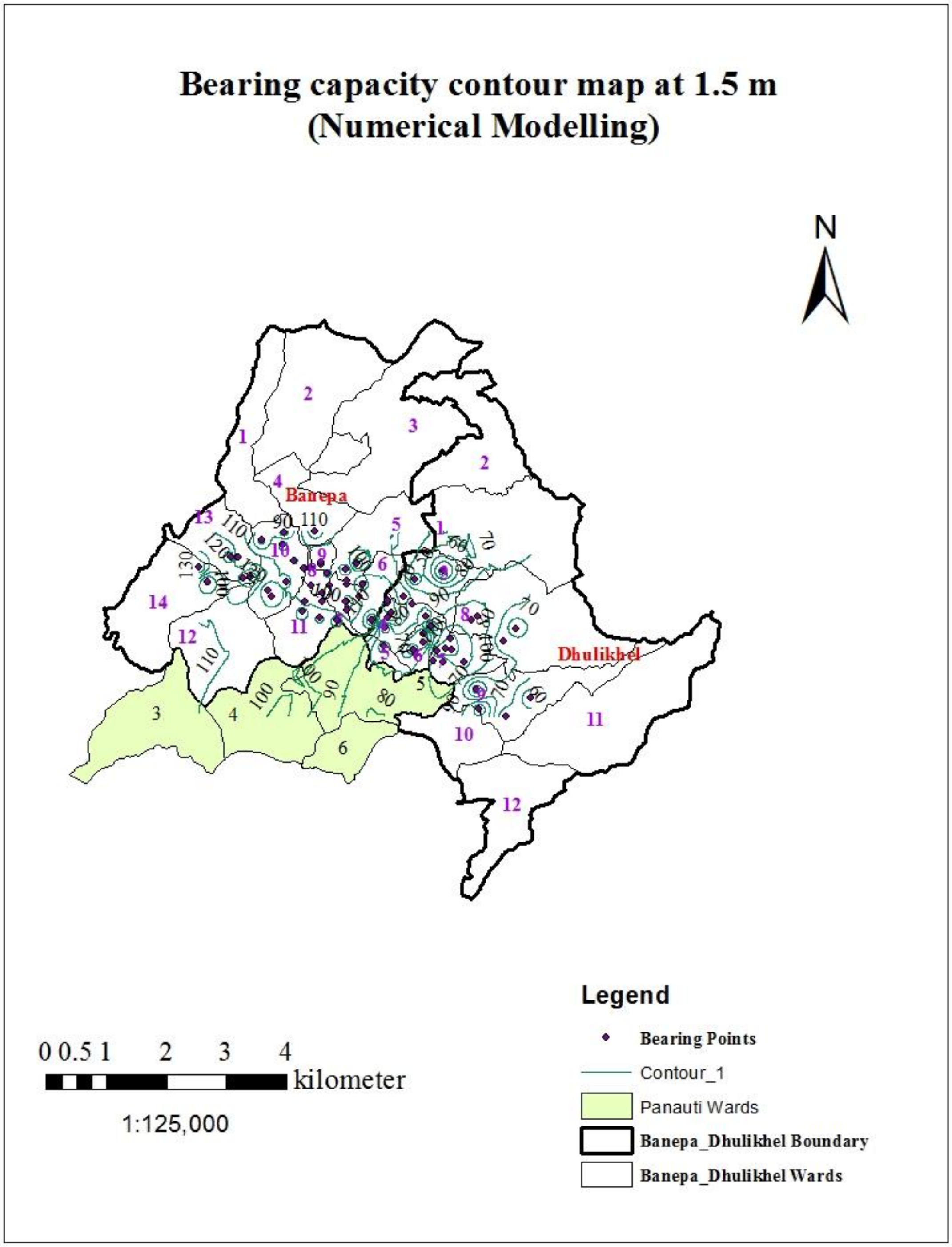

Figure 4. 8: Contour of Bearing capacity of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Numerical Modelling

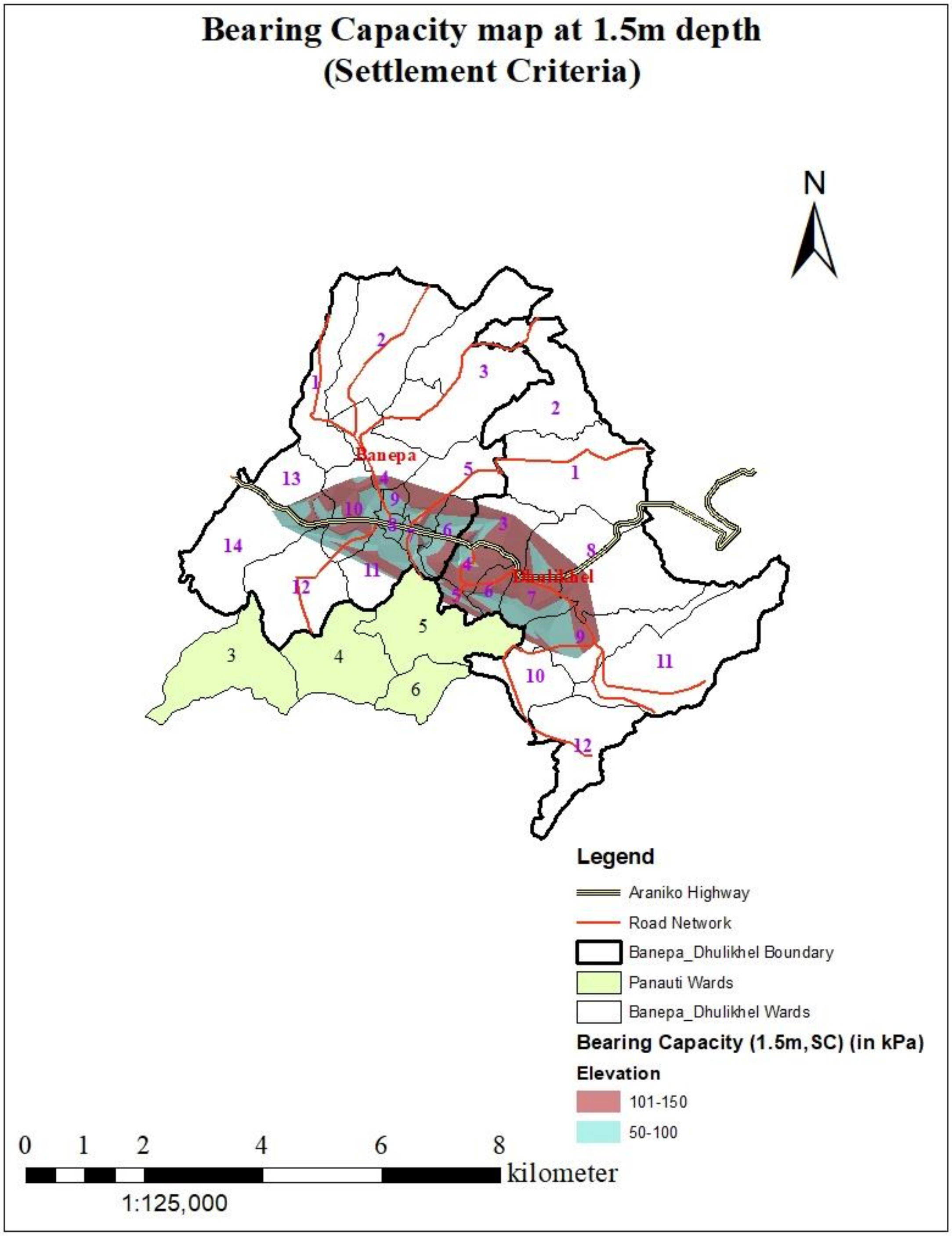

Figure 4. 9: Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Settlement Criteria

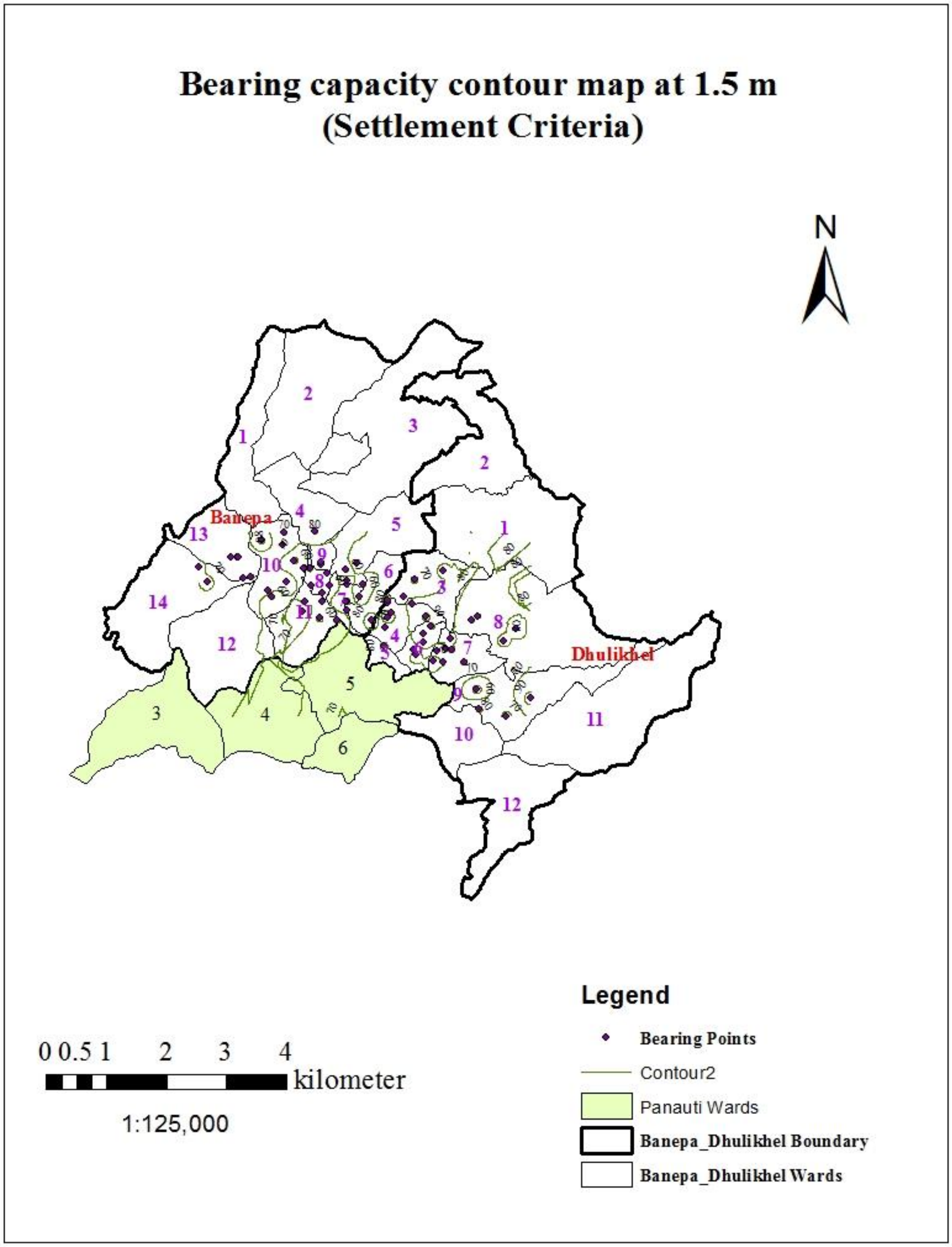

Figure 4. 10:Contour of Bearing capacity of Urban areas of Dhulikhel and Banepa for 1.5 m depth from Settlement Criteria

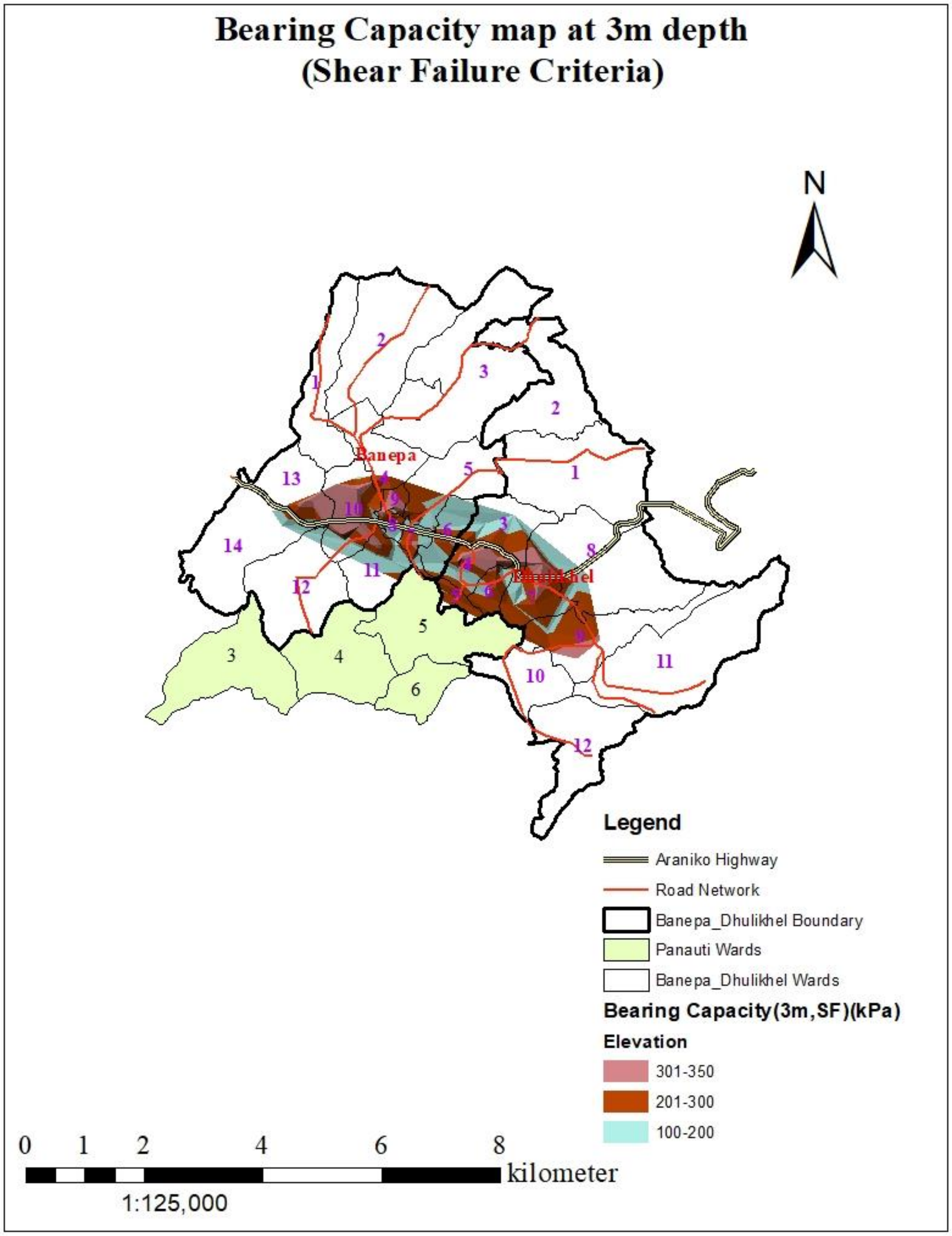

Figure 4. 11: Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 3 m depth from Shear Failure Criteria

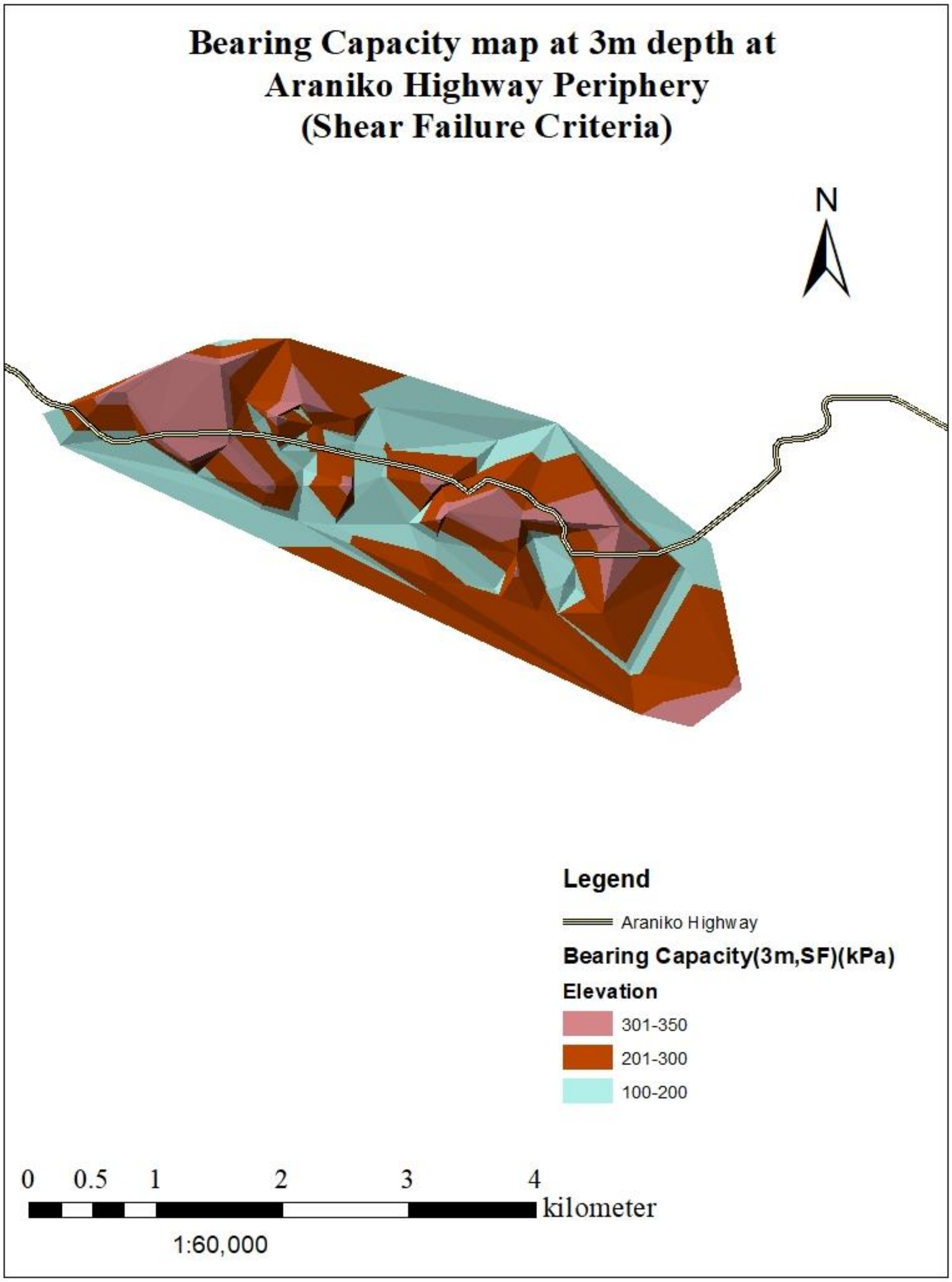

Figure 4. 12 Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 3 m depth from Shear Failure Criteria (Scale 1:60000)

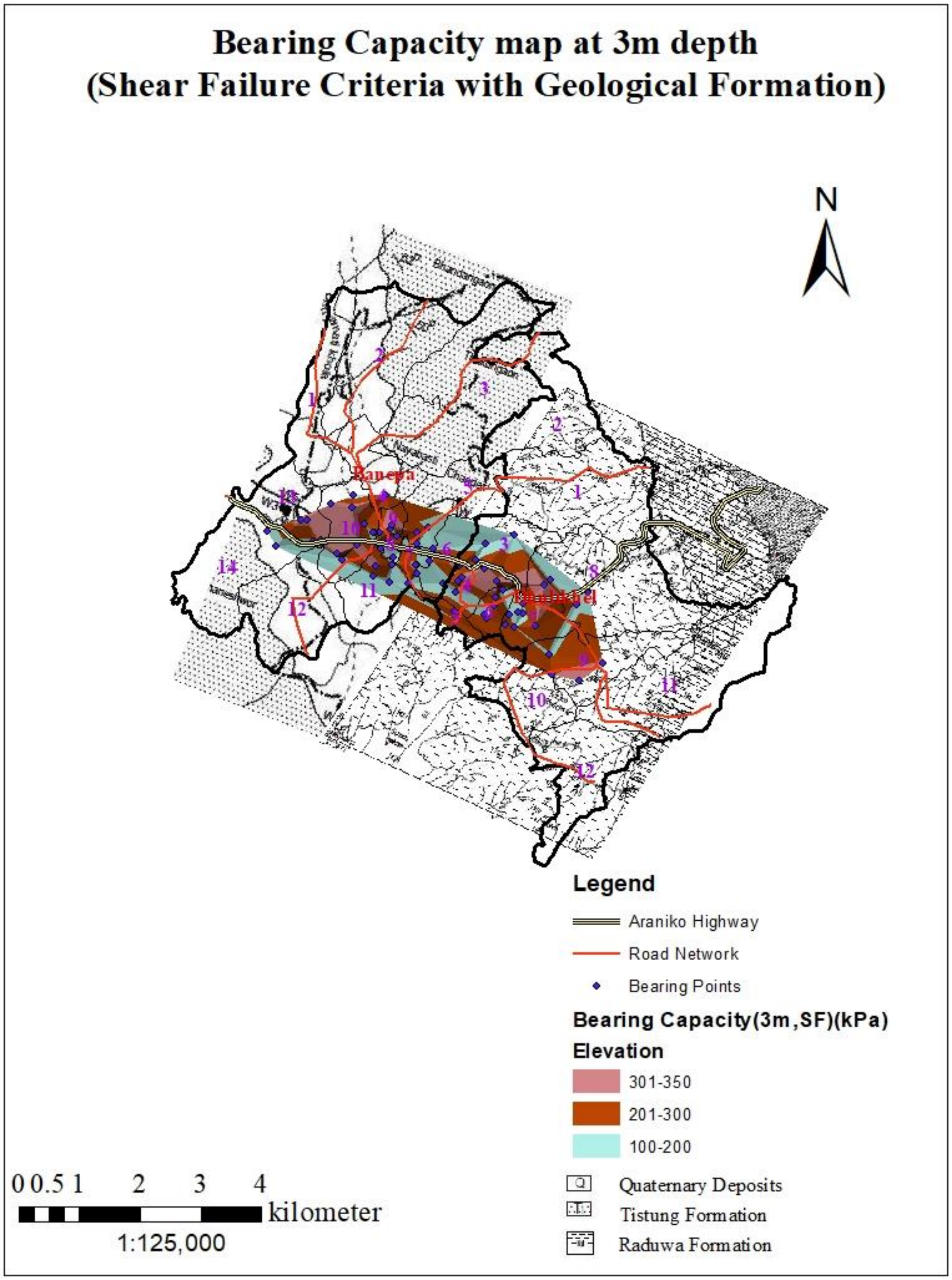

Figure 4. 13: Bearing capacity map of Urban areas of Dhulikhel and Banepa for 3 m depth from Shear Failure Criteria with Geological Formation

Table 4. 13: Bearing capacity Zoning at 3m depth (Shear Failure Criteria) with Geological Formation and average BC values

S. No.	Municipality	Geological Formation	Approach	Average (kPa)
1.	Banepa	Quatenary	Terzaghi (1943)	247
			Meyerhof (1963)	369
			Hansen (1970)	354
			Vesic (1973)	375
		Tistung	No values till date	No values till date
2.	Dhulikhel	Raduwa	Terzaghi (1943)	211
			Meyerhof (1963)	325
			Hansen (1970)	314
			Vesic (1973)	345

For the shallow foundation, 3m depth at the particular locations, Quaternary deposits have higher BC values than in Raduwa formation.

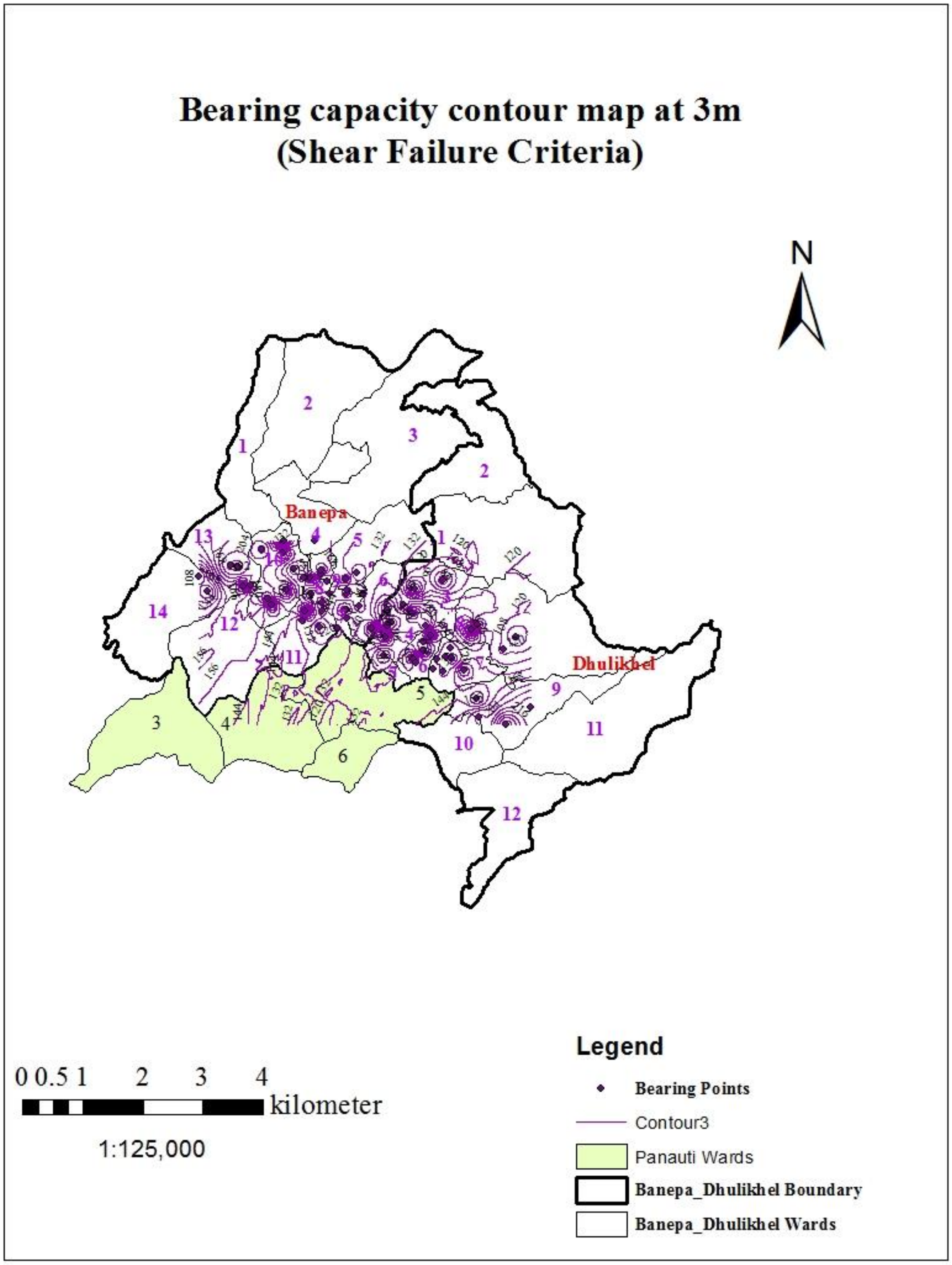

Figure 4. 14: Contour of Bearing capacity of Urban areas of Dhulikhel and Banepa for 3 m depth from Shear Failure Criteria

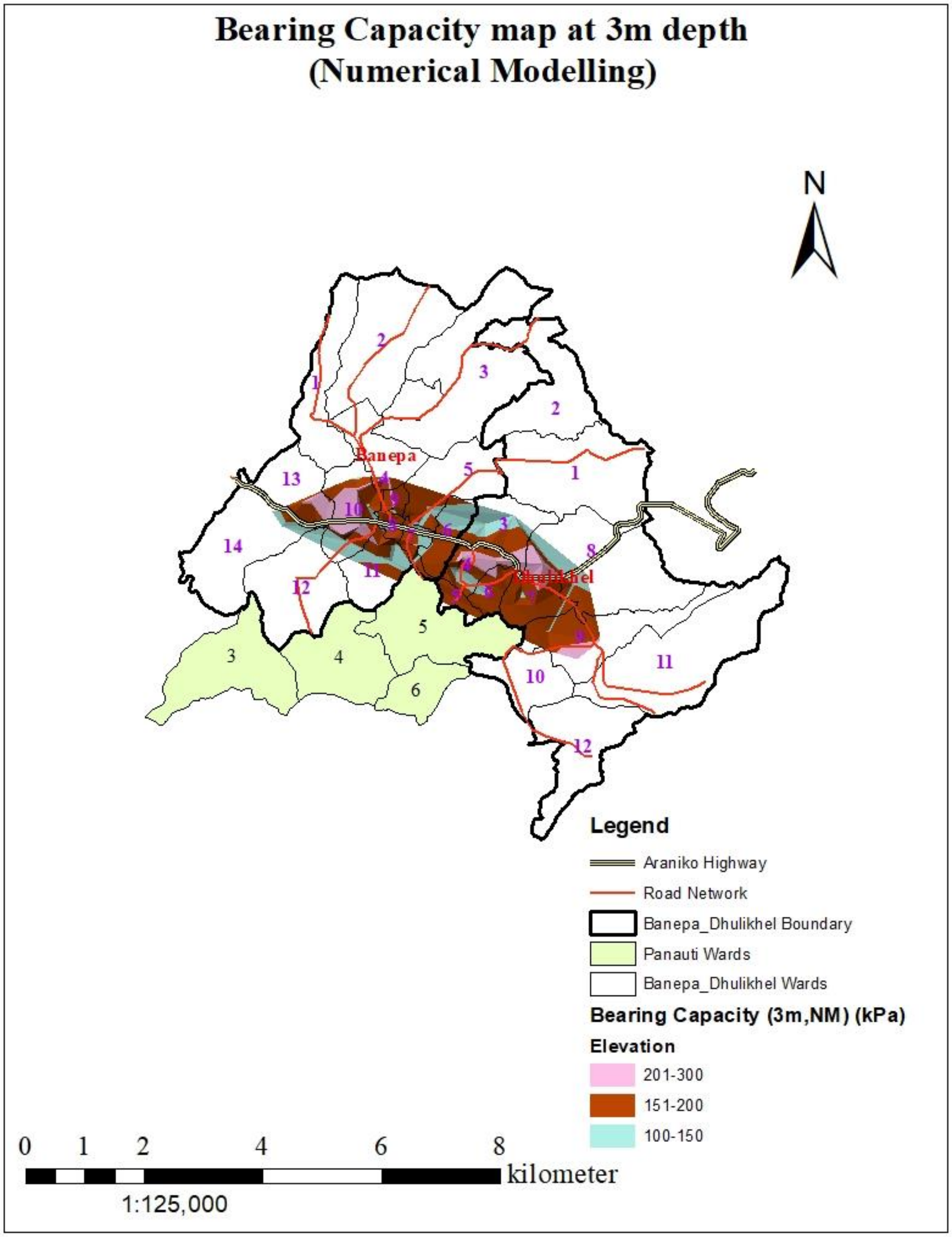

Figure 4. 15: Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 3 m depth from Numerical Modelling

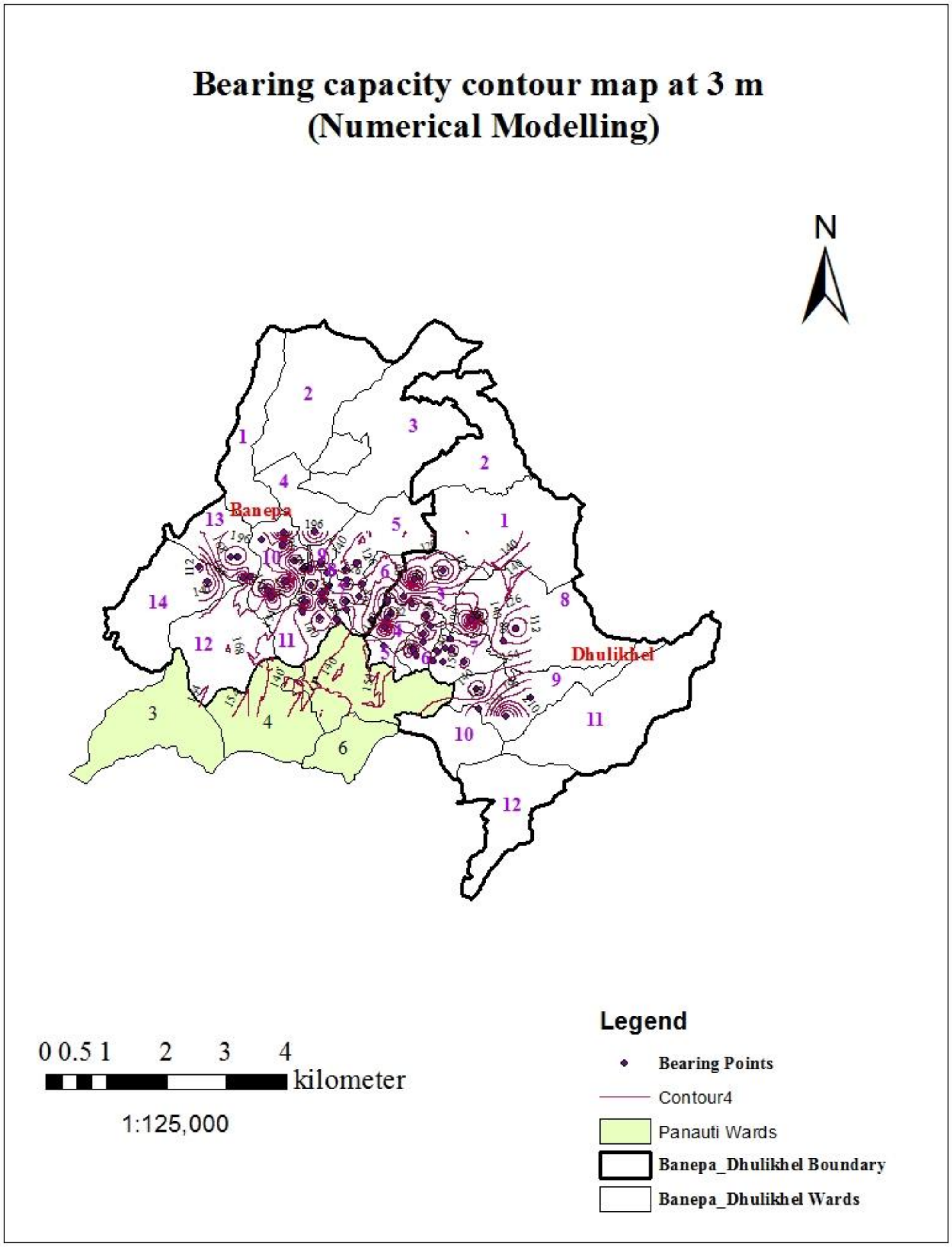

Figure 4. 16: Contour of Bearing capacity of Urban areas of Dhulikhel and Banepa for 3 m depth from Numerical Modelling

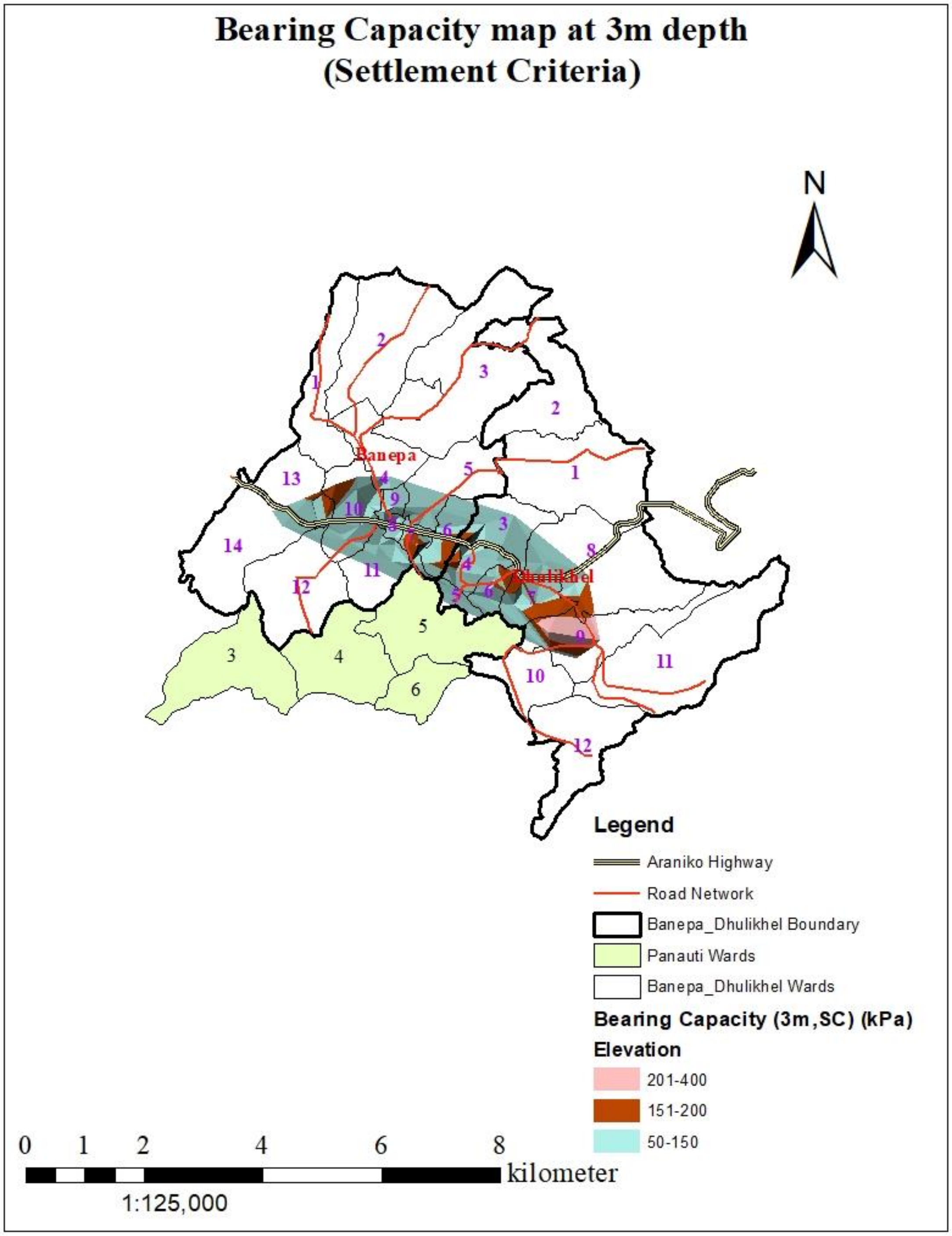

Figure 4. 17: Soil Bearing capacity mapping of Urban areas of Dhulikhel and Banepa for 3 m depth from Settlement Criteria

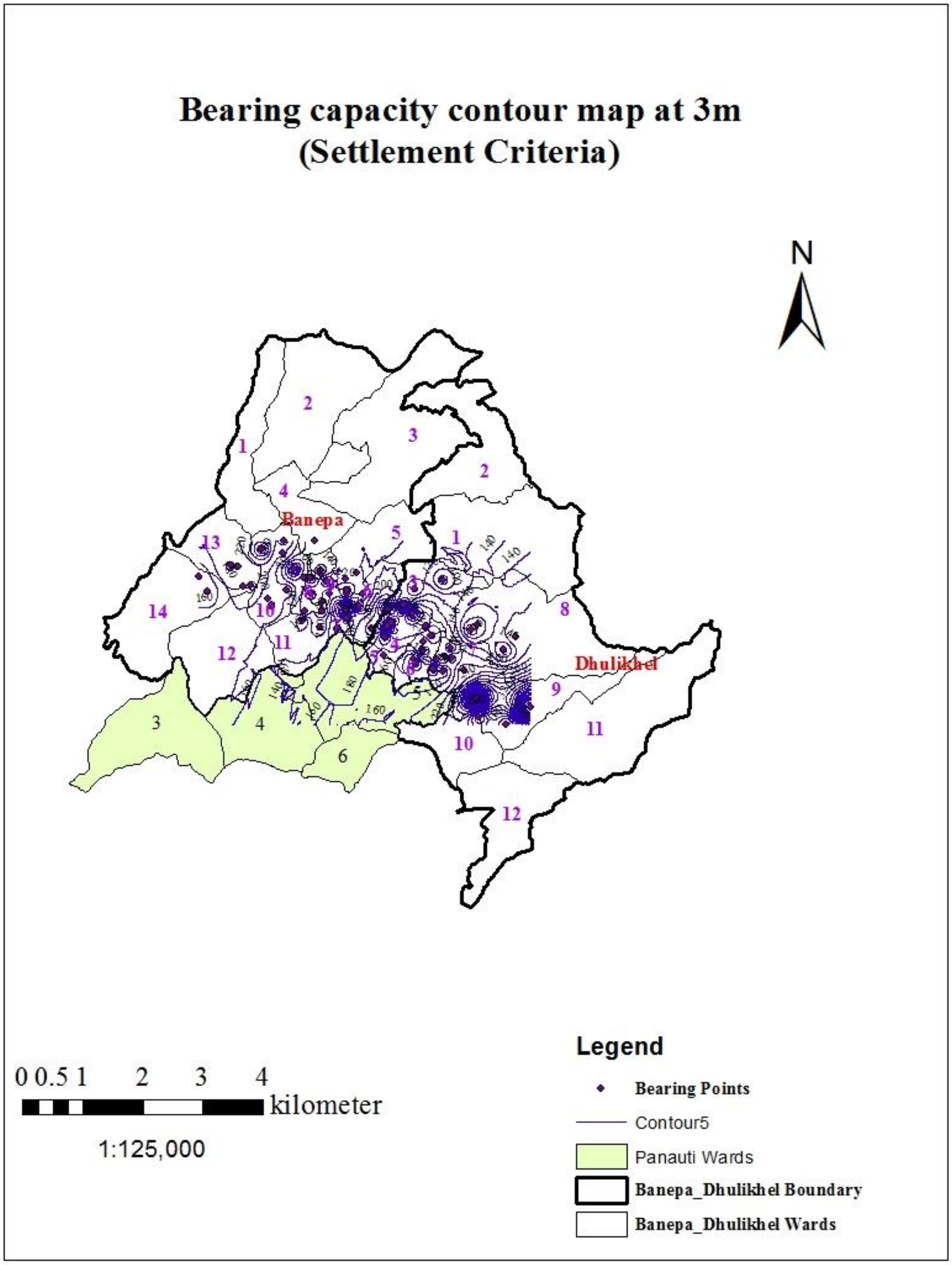

Figure 4. 18:Contour of Bearing capacity of Urban areas of Dhulikhel and Banepa for 3 m depth from Settlement Criteria

Comparing the methods of calculation of Bearing capacity from different theoretical approaches, it is observed that the most conservative values are given by Terzaghi (1943) in comparison to Meyerhof (1963), Hansen (1970) and Vesic (1973). It is observed that site having sand-gravel mixture, stiff to medium clay, sand-clay mixture have high bearing capacity whereas site having very soft clay, fine sand has low bearing capacity. The bearing capacity values from different approaches are different. So, the designer must use at least three approaches and compare with software values.

4.1.4 Soil Characterization:

Detailed laboratory experiments have been conducted to characterize the soils collected from ten different locations at Araniko Highway periphery in both Banepa and Dhulikhel. All soil samples were taken from depth 1.5 m from the buildings under construction. Various laboratory tests have been conducted on the soil samples for the determination of Bulk mass density, Dry mass density, Specific gravity, void ratio, saturated unit weight, Plasticity index, Dry unit weight, Cohesion and Angle of internal friction. The table below summarizes the characteristics of soil found at Araniko Highway periphery in Banepa portion and Dhulikhel portion respectively.

Table 4. 14: Representative Table for Soil Characteristics at Araniko Highway periphery in Banepa areas.

S. No.	Site No.		1	2	3	4	5
	Location		27°38'13.554"N	27°38'04.73'' N	27°37'55.92'' N	27°37'38.745"N	27°37'17.635"N
			85°29'50.581"E	85°29'18.72'' E	85°30'10.38'' E	85°30'29.918"E	85°31'33.563" E
1	Bulk Mass Density	g/cc	2.14	2.15	1.94	1.66	1.80
2	Dry Mass Density	g/cc	1.64	1.66	1.68	1.15	1.40
3	Specific Gravity, G	..	2.60	2.65	2.58	2.23	2.5
4	Void Ratio, e	..	0.59	0.60	0.53	0.94	0.79
5	Saturated Unit Weight. γ_sat	kN/m^3	19.71	19.94	19.92	16.02	18.04
6	Plasiticity Index	%	11.76	11.85	23.84	12.74	5.40
7	Dry unit weight	kN/m^3	16.09	16.27	16.51	11.26	13.71
8	Soil Classification		CL	CL	CH	OL	CL
9	Cohesion	kN/m2	11.67	12.97	15.56	5	13.83
10	Angle of Internal Friction	Phi	21.63	19.64	18.97	28	18.97

Table 4. 15 : Representative Table for Soil Characteristics at Araniko Highway periphery in Dhulikhel areas (Contd…)

S. No.	Site No.		6	7	8	9	10
	Location		27°37'17.36'' N	27°36'59.70'' N	27°36'51.75'' N	27°36'49.76'' N	27°37'10.93'' N
			85°32'07.95'' E	85°33'24.84'' E	85°33'19.26'' E	85°33'11.65'' E	85°33'5.78'' E
1	Bulk Mass Density	g/cc	2.08	1.63	1.72	1.64	1.48
2	Dry Mass Density	g/cc	1.64	1.31	1.48	1.48	1.32
3	Specific Gravity, G	..	2.65	2.54	2.50	2.44	2.64
4	Void Ratio, e	..	0.62	0.94	0.69	0.65	1.01
5	Saturated Unit Weight. γ_sat	kN/m^3	19.83	17.58	18.52	18.35	17.83
6	Plasiticity Index	%	8.29	15.45	10.03	27.82	3.64
7	Dry unit weight	kN/m^3	16.09	12.82	14.52	14.48	12.92
8	Soil Classification		CL	CL	CL	CL	SM
9	Cohesion	kN/m2	12.53	13.61	12.97	14.10	3.03
10	Angle of Internal Friction	Phi	19.64	18.63	19.66	19.02	28.45

Quaternary deposits and Tistung formation are found in Banepa whereas Raduwa formation is found in Dhulikhel. The Quaternary sediment consists of black carbonaceous lacustrine clay deposits and alluvial fine to coarse sand and gravel. This black carbonaceous clay indicates lacustrine deposits. The rocks are low grade metasedimentary (phyllite and metasandstone) belonging to the Tistung formation. Tistung consists of thin to thick bedded, laminated, fine grained, micaceous, light grey, sandstone and silt stone interbedded with phyllite horizons. Raduwa formation consists of dark grey, highly foliated, garnetiferous schist and some horizons of thin bedded slabby, white biotite-muscovite quartzite.

Table 4. 16: Recommended ranges of Allowable Bearing capacities(kPa) according to soil type for shallow foundation

Soil Type		Least BC (kPA)	Maximum BC (kPA)
Cohesive	Very soft clays and silts	50	100
	Soft clays and silts	75	100
	Medium stiff clays	75	150
	Stiff clays	100	250
	Very stiff clays	250	350
	Hard stiff clays	250	400
	Very hard clays	350	500
Granular	Very loose sand	50	100
	Loose sand and gravel	50	150
	Medium dense sand, gravel	100	300
	Dense sand and gravel	250	450
	Very dense sand and gravel	350	600

5. VERIFICATION OF RESULT

5.1 Verification from Primary Data

Ten soil samples were taken from ten different areas of Dhulikhel and Banepa. Eight disturbed and two undisturbed samples were taken. The samples were taken to the lab. Various Index and Engineering properties were evaluated. Direct shear test was done. The bearing capacity was found from Terzaghi (1943), Meyerhof (1963), Hansen (1970) and Vesic (1973) approaches. These bearing capacities were compared with the bearing capacity taken from the secondary data and software. The values had difference of 15% maximum.

Table 5. 1: Validation of Research Data from Primary data

Site Location (Source of Primary Data)				Safe Allowable(Shear Failure Criteria)					BC from Secondary Data					Comparision
S.No.	Location Coordinates	Location	Depth (m)	Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum	Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum	Difference% (Terzaghi)
S1	27°38'13.554"N	Banepa-13	1.50	150.78	182.80	205.50	210.60	150.78	158.52	201.63	206.38	219.25	158.52	4.88
	85°29'50.581"E													
S2	27°38’04.73’’ N	Banepa-14	1.50	136.24	158.18	175.94	180.37	136.24	152.24	208.87	195.40	201.85	152.24	10.51
	85°29’18.72’’ E													
S3	27°37’55.92’’ N	Banepa-13	1.50	150.73	188.24	210.22	214.68	150.73	163.84	224.65	223.40	241.54	163.84	8.00
	85°30’10.38’’ E													
S4	27°37'38.745"N	Banepa-10	1.50	168.54	170.63	212.31	221.00	168.54	152.24	208.87	195.40	201.85	152.24	-10.71
	85°30'29.918"E													
S5	27°37'17.635"N	Banepa -11	1.50	131.02	154.65	172.91	176.50	131.02	146.57	201.06	198.81	216.94	146.57	10.61
	85°31'33.563" E													
S6	27°37’17.36’’ N	Dhulikhel-6	1.50	132.26	153.79	170.87	175.25	132.26	126.53	168.21	153.37	159.64	126.53	-4.53
	85°32’07.95’’ E													
S7	27°36’59.70’’ N	Dhulikhel-7	1.50	122.11	154.25	173.17	176.58	122.11	111.42	274.60	271.69	275.97	111.42	-9.59
	85°33’24.84’’ E													
S8	27°36’51.75’’ N	Dhulikhel-7	1.50	130.47	151.27	168.04	171.85	130.47	132.94	171.52	180.21	190.08	132.94	1.86
	85°33’19.26’’ E													
S9	27°36’49.76’’ N	Dhulikhel-7	1.50	132.93	153.98	171.05	174.78	132.93	111.42	274.60	271.69	275.97	111.42	-19.31
	85°33’11.65’’ E													
S10	27°37’10.93’’ N	Dhulikhel-6	1.50	139.00	175.96	183.88	194.44	139.00	147.15	196.20	199.25	251.65	147.15	5.54
	85°33’5.78’’ E													

5.2 Calculation of Bearing Capacity from Software

The bearing capacity values from different theoretical approaches were compared with the values obtained from Plaxis 2D. The minimum value from different approaches were taken and compared with the Software values. The values were close to minimum of the approaches. The percentage difference in values was maximum 15%.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion:

Forty BH locations of Banepa and Thirty two BH locations of Dhulikhel were chosen. These places are the urban areas at Araniko Highway periphery of the municipalities. The bearing capacity was calculated from both shear failure criteria and settlement criteria. Terzaghi (1943), Meyerhof (1963), Hansen (1970) and Vesic (1973) approaches have been used to evaluate Bearing capacity from Shear Failure Criteria. Meyerhof (1965) and Bowels (1987) approaches have been used to evaluate Bearing capacity from Settlement Criteria. The results have been verified from Laboratory tests. Least value for BC is taken and plotted in map using GIS. The surface map and contour map have been prepared for the Urban areas. The comparison was done between the allowable bearing pressure computed considering plain ground with allowable bearing pressure at actual field condition at two locations of Dhulikhel. Identification of the geological formation of area and its bearing capacity for shallow foundation was done. The conclusions made are as follows:

- The maps can be useful for the shallow foundation only.
- Plaxis 2D values can be applicable for shallow depths.
- This Bearing capacity map will be useful for the municipalities for preliminary design of foundation, feasibility study, planning of detail investigations of complex structures.
- The maps will reduce the time and cost of the project lapsed in investigations. This will also help in providing planned settlement in future.
- Plaxis 2D is very useful for easy and fast calculation of ultimate Bearing capacity and settlement. The comparison with the theoretical approaches show only difference of maximum 15 percent though there are very few exceptions.
- The Bearing capacity values from Plaxis are close to values from Shear Failure Criteria but not to Settlement Criteria.
- The maps can be a basis only for urban areas of Dhulikhel and Banepa particularly around Araniko Highway Periphery.

- Bearing capacity on slopes is lesser than on plain ground with soil characteristics being same.
- For the shallow foundation at the particular locations, Quaternary deposits have higher BC values than in Raduwa formation.

6.2 Recommendations:

- We can clearly observe that the different approaches for Bearing capacity gives different values. So, proper judgement should be done by the designer in choosing the value and approach. The designer must use at least three approaches and compare with software values for Bearing capacity.
- The soil having very low bearing capacity such as less than 50 kN/m^2 should go for Ground Improvement Technique. The soil can be stabilized or replaced if possible. The construction can be done at the places by increasing the depth and size of footing. If the bearing capacity is too low for shallow foundation from any methods, then we should design mat or deep foundation.
- It is conservative to take the water table at the critical section i.e. almost to the surface.
- It is recommended to have centralized settlement in areas having high bearing capacity.

The recommendations for future works are as follows:

- Only urban areas are taken in this study due to data limitations. The other rural areas can also be taken within scope.
- Plaxis 2D have been used. 3D solutions can be done. Mohr-coulomb model have been used. But other advanced soil models can be used.
- Seismic effects can be added as additional parameter.
- Shape and Depth factor are taken into consideration. Ground factor and base factor can also be taken.

- The mapping can be done for deep foundations.
- Footing subjected to Dynamic load can also be taken.
- Layered soils, soil with irregularities can be considered.

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APPENDIX A

Table A. 1: Location of Secondary, Primary data, Boreholes, manual digging

S.N.	Location	Coordinates	S.N.	Location	Coordinates
1	Dhulikhel-8	85.564441 E 27.621501 N	37	Banepa-8	85.518747 E 27.634434 N
2	Dhulikhel-8, Bhattedanda	85.571187 E 27.615593 N	38	Banepa-8	85.523421 E 27.633188 N
3	Dhulikhel-3	85.547190E 27.631433N	39	Banepa-8	85.519024 E 27.630252 N
4	Dwarika Resort, Dhulikhel-8	85.574494E 27.619188N	40	Bhimsenthan -7, Banepa	85.528352 E 27.62627 N
5	Dulikhel-6	85.546603E 27.613532N	41	Banepa-06, Bhimsen Marga	85.533088 E 27.6295 N
6	Dhulikhel-7	85.554606E 27.610757N	42	Banepa-8	85.521986 E 27.62634 N
7	Dhulikhel-3	85.554919E 27.632540N	43	Banepa-7	85.528348 E 27.625971 N
8	Dhulikhel-8	85.562689E 27.62118 N	44	Banepa-4	85.546635E 27.625087N
9	Dhulikhel-7	85.556997E 27.614013N	45	Banepa-10	85.514641 E 27.636039 N
10	28 kilo Dhulikhel-4	85.5400E 27.6256N	46	Banepa-6	85.532042 E 27.626527 N
11	Dhulikhel-9	85.563393 E 27.604322 N	47	Banepa-8, Mukti Marg	85.517394 E 27.633553 N
12	KU, Dhulikhel-4	85.5386E 27.6195N	48	Banepa-9	85.52163 E 27.635137N
13	Dhulikhel-4	85.539744E 27.626144N	49	Banepa-11	85.521258 E 27.622169 N
14	28 Kilo, Dhulikhel-4	85.540707E 27.623149N	50	Banepa-10	85.517027 E 27.634103 N
15	Dhulikhel-6	85.549325E 27.616487N	51	Banepa-11	85.516919 E 27.623785 N
16	Dhulikhel-4	85.546635E 27.625087N	52	Banepa-5	85.528315 E 27.633688 N
17	Shrikhandapur, 28 Kilo, Dhulikhel-4	85.539683E 27.621815N	53	Banepa-10	85.511663 E 27.631483 N

Table A. 2: Location of Secondary, Primary data; Boreholes, manual digging (Continued)

18	Bapuchha(Upper), Dhulikhel-6	85.547265E 27.612928N	54	Banepa-4	85.520248 E 27.64252 N
19	28 Kilo, Dhulikhel-4	85.550067E 27.621552N	55	Banepa-14	85.490879 E 27.630558 N
20	Dhulikhel-3	85.544253E 27.626752N	56	Banepa-13	85.499341 E 27.636734 N
21	Dhulikhel-4	85.538588E 27.615412N	57	Banepa-5	85.53183 E 27.635798 N
22	Dhulikhel-9	85.578266E 27.601835N	58	Banepa-10	85.511552 E 27.642945 N
23	DAO, Kavre, Dhulikhel-7	85.560301E 27.610693N	59	Banepa-13	85°29'50.581"E 27°38'13.554"N
24	Dhulikhel-11	85.572134E 27.59706N	60	Banepa-14	85°29’18.72’’ E 27°38’04.73’’ N
25	Dhulikhel-9	85.564935E 27.599648N	61	Banepa-13	85°30’10.38’’ E 27°37’55.92’’ N
26	Hospital Road, Dhulikhel -6	85'32'58.19" E 27'37'4.8"N	62	Banepa-10	85°30'29.918"E 27°37'38.745"N
27	Bapuchha (Upper), Ward -7, Dhulikhel	85.551599E 27.611387N	63	Banepa -11	85°31'33.563"E 27°37'17.635"N
28	Banepa-11	85.517458 E 27.626458 N	64	Dhulikhel-6	85°32’07.95’’ E 27°37’17.36’’ N
29	Banepa-8	85.524064 E 27.630397 N	65	Dhulikhel-7	85°33’24.84’’ E 27°36’59.70’’ N
30	Banepa-7	85.528687 E 27.626266 N	66	Dhulikhel-7	85°33’19.26’’ E 27°36’51.75’’ N
31	Banepa-7	85.52865 E 27.62358 N	67	Dhulikhel-7	85°33’11.65’’ E 27°36’49.76’’ N
32	Banepa-10	85.505769 E 27.641141 N	68	Dhulikhel-6	85°33’5.78’’ E 27°37’10.93’’N
33	Banepa-13	85.499106 E 27.637163 N	69	Banepa-8	85.522179E 27.627966N
34	Hansaraj Marg, Banepa-07, Kavre	85.528741 E 27.630145 N	70	Banepa-13	85.500752E 27.631887N
35	Banepa-7	85.528749 E 27.630742 N	71	Banepa-10	85.511485E 27.639745N
36	Banepa-10	85.507272 E 27.62859 N	72	Banepa-9	85.521533E 27.635645N

APPENDIX B

Sample Calculation:

Location: Banepa-11

Coordinates: 27.626458 N, 85.517458 E

Depth of Foundation: 1.5 m

Width of Foundation: 1.52m

C = 1 kN/m^2

Angle of Internal Friction = 31°

Effective Unit Weight = 7.49 kN/m^3

Bearing Capacity Calculation by Terzaghi (1943) approach:

Nc = 40.41

Nq = 25.28

Nγ = 22.65

q = 11.24 kN/m^2

qu = (1.3*1*40.41)+(11.24*25.28)+(0.4*7.49*1.52*22.65)

= 439.82 kN/m^2

qa = 439.82/3 = 146.60 kN/m^2

Bearing Capacity Calculation by Meyerhof (1963) approach:

Nc = 32.30, Nq = 21.20, Nγ = 18.85

sc = 1.62, sq = 1.31, sγ = 1.31

dc = 1.34, dq = 1.17, dγ = 1.17

qu = (1*32.30*1.62*1.34*1) + (11.24*21.20*1.31*1.17*1) +

(0.5*7.49*1.52*18.85*1.31*1.17*1)

= 603.20

qa = 603.20/3 = 201.06 kN/m^2

Bearing Capacity Calculation by Hansen (1970) approach:

Nc = 32.30, Nq = 21.20, Nγ = 17.95

sc = 1.63, sq = 1.51, sγ = 0.60

dc = 1.4, dq = 1.28, d$\gamma = 1$

qu = (1*32.30*1.63*1.4*1) + (11.24*21.20*1.51*1.28*1) + (0.5*7.49*1.52*17.95*0.60*1*1)

= 596.44 kN/m^2

qa = 596.44/3 = 198.81

Bearing Capacity Calculation by Vesic (1973) approach:

Nc = 32.30, Nq = 21.20, Nγ = 26.3

sc = 1.63, sq = 1.60, sγ = 0.60

dc = 1.4, dq = 1.28, d$\gamma = 1$

qu = (1*32.30*1.63*1.4*1) + (11.24*21.20*1.60*1.28*1) + (0.5*7.49*1.52*26.3*0.60*1*1)

= 647.68 kN/m^2

qa = 650.84/3 = 216.945 kN/m^2

Bearing Capacity Calculation by Meyerhof (1965) approach:

qnet = 7.99*6*((3.28*1.5+1)/(3.28*1.5))^2

= 69.40 kN/m^2

Bearing Capacity Calculation by Bowels (1977) approach:

qall = 11.98*6*((3.28*1.5+1)/(3.28*1.5))^2*1+0.33(1.5/1.52)*(25/25.4)

= 136.23 kN/m^2

Location: Dhulikhel-3

Coordinates: 27.632540N, 85.554919E

Depth of Foundation: 3 m

Width of Foundation: 1.52m

C = 1.3 kN/m^2

Angle of Internal Friction = 30°

Effective Unit Weight = 6.89 kN/m^3

Bearing Capacity Calculation by Terzaghi (1943) approach:

Nc = 37.16, Nq = 22.46, Nγ = 19.13, q = 10.34 kN/m^2

qu = (1.3*1.3*37.16)+(10.34*22.46)+(0.4*6.89*1.52*19.13)

= 375.17 kN/m^2

qa = 375.17/3 = 125.05 kN/m^2

Bearing Capacity Calculation by Meyerhof (1963) approach:

Nc =30.13, Nq = 18.4, Nγ = 15.7

sc = 1.6, sq =1.3, sγ = 1.3,

dc = 1.68, dq = 1.34, dγ =1.34

qu = (1.3*30.13*1.6*1.68) + (20.67*18.4*1.3*1.34) +

(0.5*6.89*1.52*15.7*1.3*1.34)

= 912

qa = 912/3 = 304 kN/m^2

Bearing Capacity Calculation by Hansen (1970) approach:

Nc =30.13, Nq = 18.4, Nγ = 15.1

sc = 1.6, sq =1.5, sγ = 0.6,

dc = 1.44, dq = 1.31, dγ =1.34

qu = (1.3*30.13*1.6*1.44) + (20.67*18.4*1.5*1.31) +

(0.5*6.89*1.52*15.1*0.6*1.34)

= 890

qa = 890/3 = 296 kN/m^2

Bearing Capacity Calculation by Vesic (1973) approach:

Nc =30.13, Nq = 18.4, Nγ = 22.4

sc = 1.61, sq =1.57, sγ = 0.6,

dc = 1.44, dq = 1.31, dγ =1.34

qu = (1.3*30.13*1.61*1.44) + (20.67*18.4*1.57*1.31) +

(0.5*6.89*1.52*22.4*0.6*1.34)

= 951

qa = 951/3 = 317 kN/m^2

Bearing Capacity of Foundation in slopes from Meyerhof (1957) approach:

Location: Dhulikhel-7

Coordinates: 27°36’49.76’’ N, 85°33’11.65’’ E

B = 1.52m, Df = 1.52m, b = 1m, H = 10m

Length of Slope = 18m, β = 34° , γ = 12.92 kN/m^3,

ϕ = 28.45°, C = 3.03, Nγq = 43, sq = sγ = 1.281

qu = (0.5*1.52*12.92*43*1.281)

= 540.87 kN/m^2

qa = 540.87/4 = 135.21 kN/m^2

Table B. 1:Lab Test of Primary Data

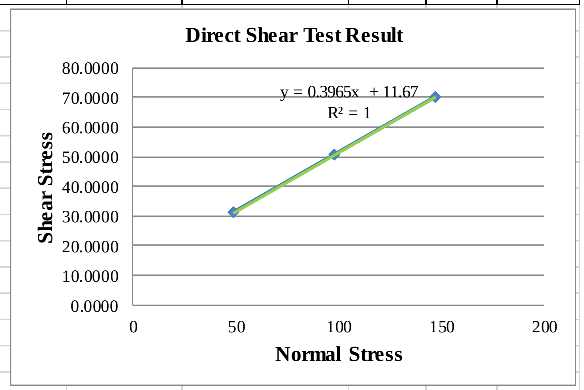
S. No.	Site No.		1	2	3	4	5	6	7	8	9	10
1	Wt. of Empty Container	gm	32.8	39.3	40.5	31.9	25.4	39	36.9	24.9	33	34.5
2	Wt. of Container + Wt. of Wet Soil	gm	68.8	84	58.7	62.3	47.3	71.1	94.3	36.3	92.1	101.3
3	Wt. of Container + Wt. of Dry Soil	gm	60.4	73.8	56.3	52.9	42.4	64.3	82.8	34.7	86.2	93.9
4	Wt. of Water, Ww	gm	8.4	10.2	2.4	9.4	4.9	6.8	11.5	1.6	5.9	7.4
5	Wt. of Dry Soil, Wd	gm	27.6	34.5	15.8	21	17	25.3	45.9	9.8	53.2	59.4
6	Moisture Content	%	30.43	29.57	15.19	44.76	28.82	26.88	25.05	16.33	11.09	12.46
7	Volume of Core Cutter 1	cc	975.23	975.23	975.23	975.23	975.23	974.52	974.52	974.52	974.52	974.52
8	Core cutter + Moist soil	g	3030	3040	2835	2565	2700	2950	2515	2600	2520	2365
9	Mass of Core cutter 1 & 2	g	944	944	944	944	944	922	922	922	922	922
10	Bulk Mass Density	g/cc	2.14	2.15	1.94	1.66	1.80	2.08	1.63	1.72	1.64	1.48
11	Dry Mass Density	g/cc	1.64	1.66	1.68	1.15	1.40	1.64	1.31	1.48	1.48	1.32
12	Specific Gravity, G	..	2.60	2.65	2.58	2.23	2.5	2.65	2.54	2.50	2.44	2.64
13	Void Ratio, e	..	0.59	0.60	0.53	0.94	0.79	0.62	0.94	0.69	0.65	1.01
14	Saturated Unit Weight. γ_sat	kN/m^3	19.71	19.94	19.92	16.02	18.04	19.83	17.58	18.52	18.35	17.83
15	Plasiticity Index	%	11.76	11.85	23.84	12.74	5.40	8.29	15.45	10.03	8.94	3.64
16	Dry unit weight	kN/m^3	16.09	16.27	16.51	11.26	13.71	16.09	12.82	14.52	14.48	12.92
17	Soil Classification		CL	CL	CH	OL	CL	CL	CL	CL	CL	SM
18	Cohesion	kN/m2	11.67	12.97	15.56	5	13.83	12.53	13.61	12.97	14.10	3.03
19	Angle of Internal Friction	Phi	21.63	19.64	18.97	28	18.97	19.64	18.63	19.66	19.02	28.45

Table B. 2: Direct Shear Test Lab Sheet

Banepa

Date:	1/22/2020	
Location:	Banepa	
Sample:	Site-1	
Performed at:	HCOE Lab	
Performed by:	Suvarna Singh Raut	
	Shisir Dhakal	
Dry Dencity (g/c	1.64	
Dry Density (kN	16.09	
Mass of Dry Soil	147.6	gm

Actual Load	Applied Load	Deflection of Dial Gauge		Normal Stress	Normal Stress	Proving Ring Reading	Converted Reading	Shear Load	Shear Stress	Shear Stress
kg	kN	Div		kg/cm2	KN/m2			kN	kN/cm2	kN/m2
0	0	0		0.5	49.05	4.8	24	0.1120	0.0031	31.1188
37.59	0.369	79		1	98.1	7.8	39	0.1820	0.0051	50.5681
75.18	0.738	158		1.5	147.15	10.8	54	0.2521	0.0070	70.0173
112.78	1.106	232.67								
150.37	1.475	320.67								
187.96	1.844	406.33								
225.55	2.213	486.33								



Dimensions of Shear Ring		
Length	6	cm
Breadth	6	cm
Width	2.5	cm
C S Area of Shea	36	cm2
Volume of Shea	90	cm3

Slope (m)	0.3965	
ϕ	21.63	degrees
Intercept (C)	11.67	kN/m2

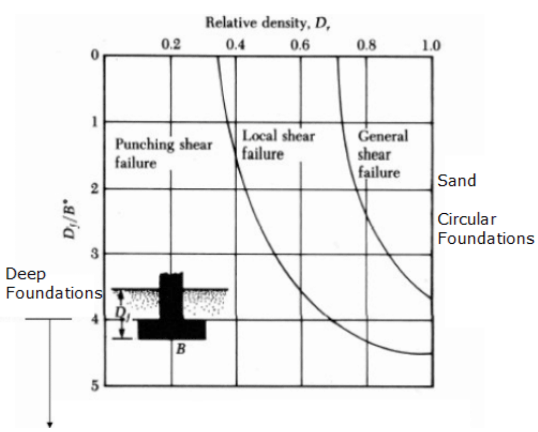


Figure B. 1: Modes of failure at different relative densities and depths of foundation (Vesic, 1963 and 1973)

ϕ' (deg)	N_c	N_q	N_γ^a	ϕ' (deg)	N_c	N_q	N_γ^a
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	16.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	116.31
16	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	161.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	416.14	1072.80
25	25.13	12.72	8.34				

Figure B. 2: Terzaghi's Bearing capacity factors (Das 2016)

ϕ	N_c	N_q	$N_{\gamma(H)}$	$N_{\gamma(M)}$	$N_{\gamma(V)}$	N_q/N_c	$2\tan\phi(1-\sin\phi)^2$
0	5.14*	1.0	0.0	0.0	0.0	0.195	0.000
5	6.49	1.6	0.1	0.1	0.4	0.242	0.146
10	8.34	2.5	0.4	0.4	1.2	0.296	0.241
15	10.97	3.9	1.2	1.1	2.6	0.359	0.294
20	14.83	6.4	2.9	2.9	5.4	0.431	0.315
25	20.71	10.7	6.8	6.8	10.9	0.514	0.311
26	22.25	11.8	7.9	8.0	12.5	0.533	0.308
28	25.79	14.7	10.9	11.2	16.7	0.570	0.299
30	30.13	18.4	15.1	15.7	22.4	0.610	0.289
32	35.47	23.2	20.8	22.0	30.2	0.653	0.276
34	42.14	29.4	28.7	31.1	41.0	0.698	0.262
36	50.55	37.7	40.0	44.4	56.2	0.746	0.247
38	61.31	48.9	56.1	64.0	77.9	0.797	0.231
40	75.25	64.1	79.4	93.6	109.3	0.852	0.214
45	133.73	134.7	200.5	262.3	271.3	1.007	0.172
50	266.50	318.5	567.4	871.7	761.3	1.195	0.131

Figure B. 3: Bearing capacity factors for the Meyerhof, Hansen and Vesic Bearing capacity equations (after Bowels, 1996)

(Note: N_c *and* N_q are same for all three equations; Subscripts identify author for N_γ)

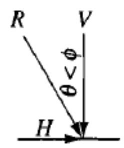
Factors	Value	For
Shape:	$s_c = 1 + 0.2K_p \frac{B}{L}$	Any ϕ
	$s_q = s_\gamma = 1 + 0.1K_p \frac{B}{L}$	$\phi > 10°$
	$s_q = s_\gamma = 1$	$\phi = 0$
Depth:	$d_c = 1 + 0.2\sqrt{K_p}\frac{D}{B}$	Any ϕ
	$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}\frac{D}{B}$	$\phi > 10$
	$d_q = d_\gamma = 1$	$\phi = 0$
Inclination:	$i_c = i_q = \left(1 - \frac{\theta°}{90°}\right)^2$	Any ϕ
	$i_\gamma = \left(1 - \frac{\theta°}{\phi°}\right)^2$	$\phi > 0$
	$i_\gamma = 0$ for $\theta > 0$	$\phi = 0$

Figure B. 4: Shape, Depth and Inclination factors (Correction factors) for Meyerhof's equation (after Bowels, 1996)

Shape factors	Depth factors
$s'_{c(H)} = 0.2\frac{B'}{L'}$ $(\phi = 0°)$ $s_{c(H)} = 1.0 + \frac{N_q}{N_c} \cdot \frac{B'}{L'}$ $s_{c(V)} = 1.0 + \frac{N_q}{N_c} \cdot \frac{B}{L}$ $s_c = 1.0$ for strip	$d'_c = 0.4k$ $(\phi = 0°)$ $d_c = 1.0 + 0.4k$ $k = D/B$ for $D/B \leq 1$ $k = \tan^{-1}(D/B)$ for $D/B > 1$ k in radians
$s_{q(H)} = 1.0 + \frac{B'}{L'}\sin\phi$ $s_{q(V)} = 1.0 + \frac{B}{L}\tan\phi$ for all ϕ	$d_q = 1 + 2\tan\phi(1 - \sin\phi)^2 k$ k defined above
$s_{\gamma(H)} = 1.0 - 0.4\frac{B'}{L'}$ ≥ 0.6 $s_{\gamma(V)} = 1.0 - 0.4\frac{B}{L}$ ≥ 0.6	$d_\gamma = 1.00$ for all ϕ

Figure B. 5: Shape and Depth factors for use in either the Hansen or Vesic (after Bowels, 1996)

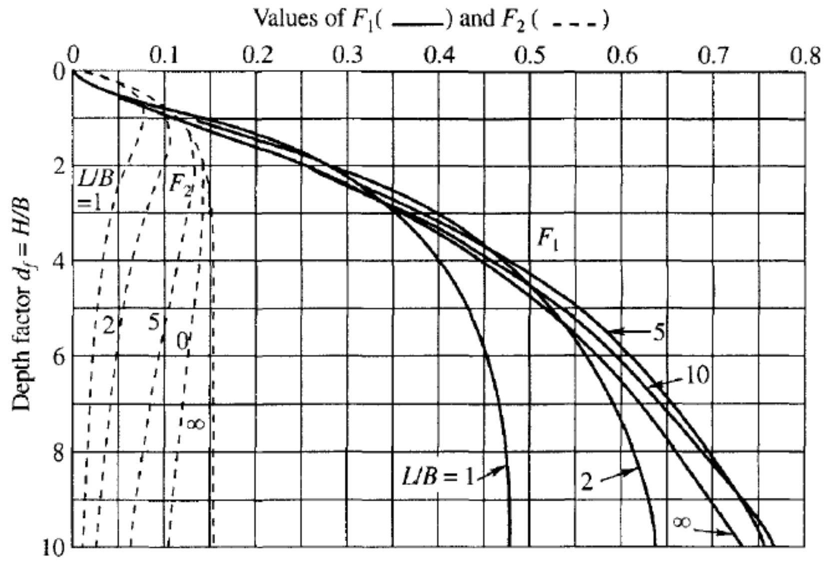


Figure B. 6: Depth Factor vs F1 and F2 (Murthy, 2007)

Shape	I_f (average values) Flexible footing	Rigid footing
Circle	0.85	0.88
Square	0.95	0.82
Rectangle	1.20	1.06
L/B = 1.5	1.20	1.06
2.0	1.31	1.20
5.0	1.83	1.70
10.0	2.25	2.10
100.0	2.96	3.40

Figure B. 7: Influence Factor (Bowels, 1988)

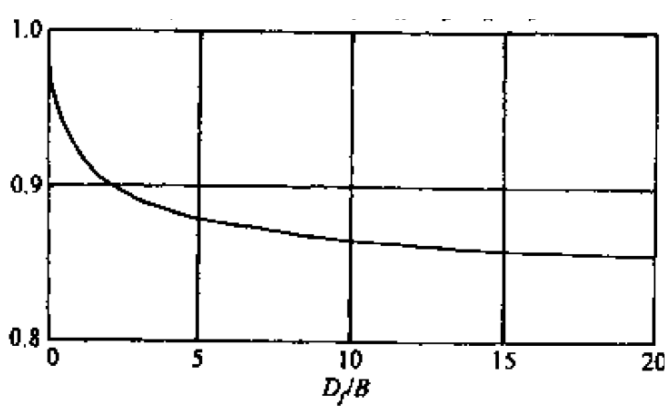


Figure B. 8: Values of A1 on Y-axis for elastic settlement calculation;(After Christian and Carrier, 1978)

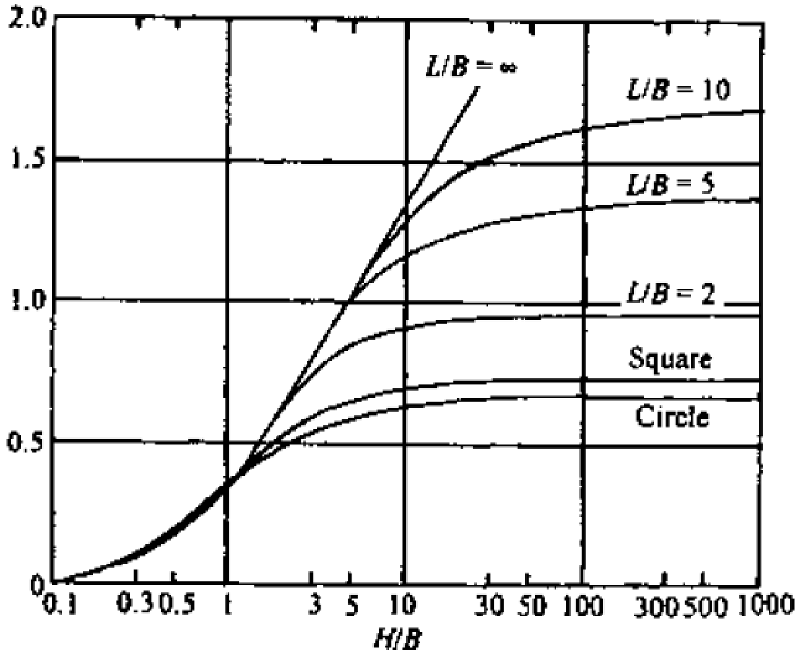


Figure B. 9: Values of A2 on Y-axis for elastic settlement calculation;(After Christian and Carrier, 1978)

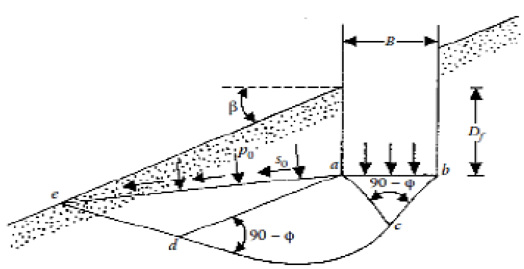
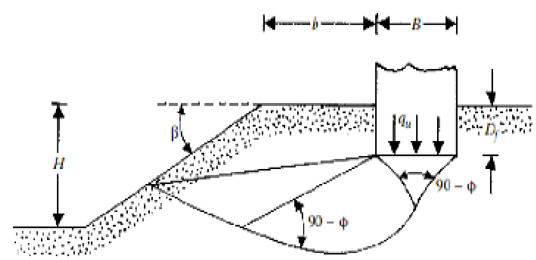
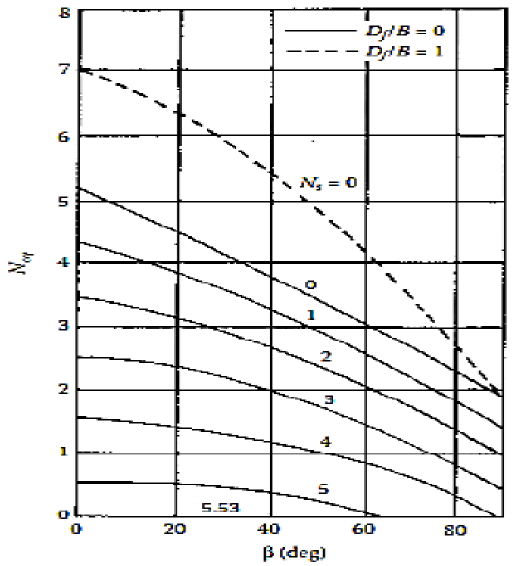
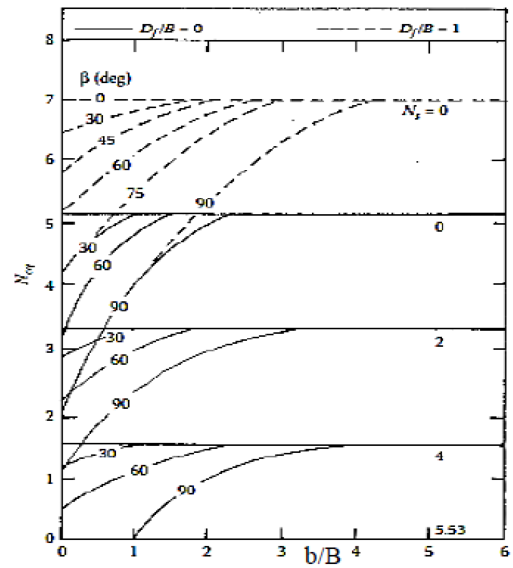
On Face of the Slope	Near Top of the Slope
	
β = slope angle with horizontal, abc = elastic zone, acd = radial shear zone, ade = mixed shear zone, c and φ = shear strength parameters of soil, γ = unit weight of soil, p_o and s_o = normal and shear stresses on plane ae, respectively	D_f = depth of the foundation, H = height of the slope., B = width of foundation, b = distance of foundation from edge of slope.

Figure B. 10: Failure surfaces and Bearing capacity factors (Meyerhof, 1957)

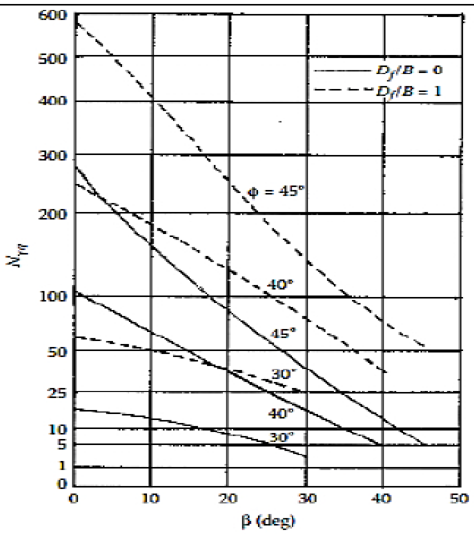


Meyerhof's bearing capacity factor N_{cq} for a purely cohesive soil

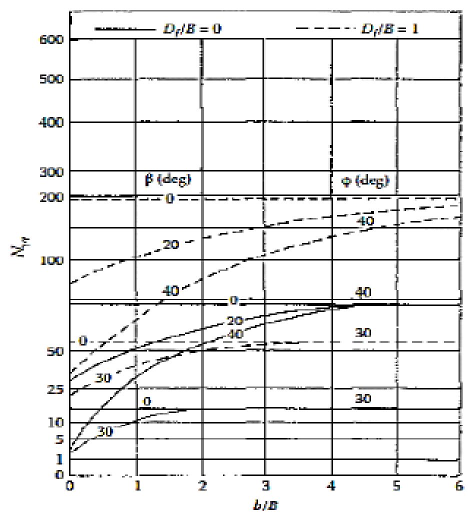


Meyerhof's bearing capacity factor N_{cq} for a purely cohesive soil

Figure B. 11: Meyerhof's Bearing capacity factors for cohesive soil



Meyerhof's bearing capacity factor $N_{\gamma q}$ for a purely granular soil



Meyerhof's bearing capacity factor $N_{\gamma q}$ for a purely granular soil

Figure B. 12: Meyerhof's Bearing capacity factors for granular soil

Major division			Group symbol	Typical name	Classification criteria	
Coarse-grained soils (More than 50% retained on No. 200 ASTM sieve)	Gravels 50% or more of coarse fraction retained on No. 4 ASTM sieve	Clean gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines.	Classification on the basis of percentage of fines. Less than 5% passing No. 200 ASTM sieve—GW, GP, SW, SP. More than 12% passing No. 200 ASTM sieve— GM, GC, SM, SC. 5% to 12% passing No. 200 ASTM sieve—Border-line classification requiring use of dual symbols.	$U = D_{60}/D_{10}$ greater than 4 $C_c = D^2_{30}/(D_{60} \times D_{20})$ between 1 and 3.
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines.		Not meeting both criteria for GW.
		Gravels with fines	GM	Silty gravels, gravel-sand-silt mixtures.		Atterberg limits plot below *A*-line or plasticity index less than 4.
			GC	Clayey gravels, gravel-sand-clay mixtures.		Atterberg limits plot above *A*-line or plasticity index less than 4.
	Sands More than 50% of coarse fraction passes No. 4 ASTM sieve	Clean sands	SW	Well-graded sands and gravelly sands, little or no fines.		*U* greater than 6 C_c between 1 and 3.
			SP	Poorly-graded sands and gravelly sands, little or no fines.		Not meeting both criteria for SW.
		Sands with fines	SM	Silty sands, and-silt mixtures.		Atterberg limits plot below *A*-line or plasticity index less than 4.
			SC	Clayey sands, sand-clay mixtures.		Atterberg limits plot above *A*-line or plasticity index greater than 7.
Fine-grained soils (50% or more passes No. 200 ASTM Sieve)	Silts and Clays (Liquid limit 50% or less)		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.	Check Plasticity Chart	
			CL	Inorganic clays or low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.		
			OL	Organic silts and organic silty clays of low plasticity.		
	Silts and clays (Liquid limit greater than 50%)		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts.		
			CH	Inorganic clays of high plasticity, fat clays.		
			OH	Organic clays of medium to high plasticity.		
Highly organic clays			P_t	Peat, muck and other highly organic soils.	Fibrous organic matter, will char, burn, or glow. Readily identified by colour, odour, spongy feel, and fibrous texture.	

Figure B. 13: Unified Soil Classification System

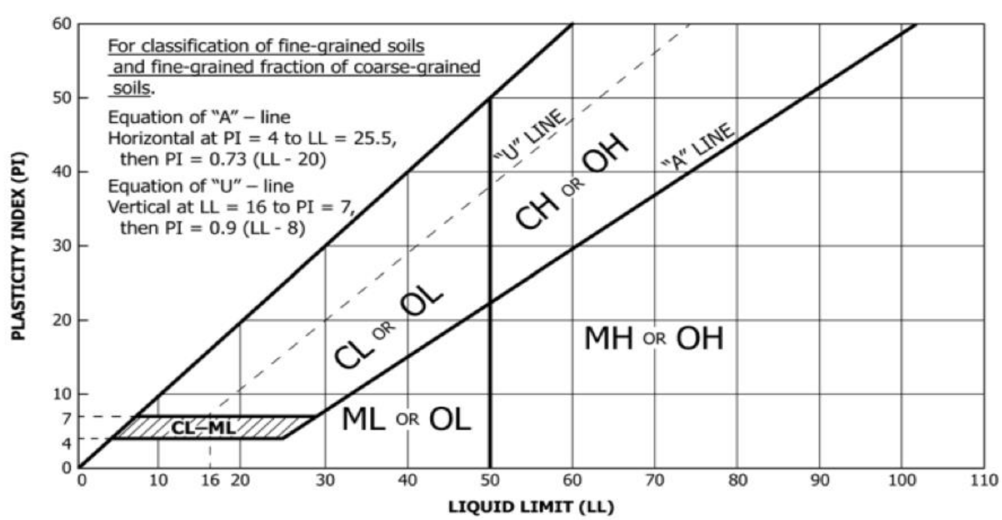


Figure B. 14: Plasticity Chart

APPENDIX C

Table C. 1: Bearing Capacity Calculation Sheet of Banepa at 1.5m and 3m depths

S.No.	Location	Coordinates	Depth (m)	SAFE ALLOWABLE (Shear Failure Criteria)					Plaxis		SAFE ALLOWABLE (Settlement Criteria)		
				Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum (kN/m2)	From Plaxis 8.2	Diff.(%)	Meyerhof (1965) (kN/m2)	Bowels (1987) (kN/m2)	Minimum (kN/m2)
B1	Banepa-11	27.626458 N	1.5	146.57	201.06	198.81	216.94	146.57	126.5	-13.68	69.10	136.23	69.10
		85.517458 E	3	256.58	374.07	361.18	388.39	256.58	265.67	3.54	103.65	209.38	103.65
B2	Banepa-8	27.630397 N	1.5	145.47	187.76	197.55	207.26	145.47	164.08	12.79	57.58	93.69	57.58
		85.524064 E	3	206.21	305.80	297.38	311.21	206.21	225.95	9.57	138.20	279.17	138.20
B3	Banepa-7	27.626266 N	1.5	142.84	196.43	192.82	212.90	142.84	160.91	12.65	92.13	149.90	92.13
		85.528687 E	3	262.56	381.18	371.75	401.86	262.56	155.72	-40.69	299.43	604.88	299.43
B4	Banepa-7	27.62358 N	1.5	158.52	201.63	206.38	219.25	158.52	151.75	-4.27	69.10	112.43	69.10
		85.52865 E	3	252.45	341.92	329.32	348.14	252.45	230.36	-8.75	103.65	209.38	103.65
B5	Banepa-10	27.641141 N	1.5	134.22	184.58	181.19	200.06	134.22	137.30	2.29	92.13	149.90	92.13
		85.505769 E	3	256.59	358.19	349.33	377.62	256.59	290.25	13.12	276.40	558.35	276.40
B6	Banepa-13	27.637163 N	1.5	158.52	201.63	206.38	219.25	158.52	191.39	20.74	80.62	131.16	80.62
		85.499106 E	3	238.66	341.92	329.32	348.14	238.66	222.57	-6.74	207.30	418.76	207.30
B7	Hansaraj Marg, Banepa-07,	27.630145 N	1.5	149.45	196.28	202.48	234.57	149.45	140.80	-5.79	69.10	112.43	69.10
		85.528741 E	3	232.61	330.21	319.14	356.64	232.61	235.82	1.38	92.13	186.12	92.13
B8	Banepa-7	27.630742 N	1.5	150.77	198.05	204.28	236.84	150.77	125.57	-16.72	80.62	131.16	80.62
		85.528749 E	3	219.60	333.62	322.62	360.67	219.60	221.52	0.87	80.62	162.85	80.62
B9	Banepa-10	27.62859 N	1.5	158.52	209.63	206.38	219.25	158.52	181.80	14.69	80.62	131.16	80.62
		85.507272 E	3	247.21	341.92	329.32	348.14	247.21	245.28	-0.78	172.75	348.97	172.75
B10	Banepa-8	27.634434 N	1.5	148.12	202.48	208.77	242.51	148.12	128.40	-13.31	57.58	93.69	57.58
		85.518747 E	3	235.68	342.32	331.32	370.76	235.68	187.62	-20.39	195.78	395.50	195.78
B11	Banepa-8	27.633188 N	1.5	146.57	201.06	198.81	216.94	146.57	123.20	-15.94	69.10	112.43	69.10
		85.523421 E	3	206.21	374.07	361.18	388.39	206.21	216.36	4.92	57.58	116.32	57.58
B12	Banepa-8	27.630252 N	1.5	149.45	202.48	208.77	242.51	149.45	128.40	-14.08	69.10	112.43	69.10
		85.519024 E	3	219.60	342.32	331.32	370.76	219.60	253.69	15.52	80.62	162.85	80.62
B13	Bhimsenthan	27.62627 N	1.5	146.57	201.06	198.81	216.94	146.57	156.62	6.86	92.13	149.90	92.13
	-7, Banepa,	85.528352 E	3	244.23	374.07	361.18	388.39	244.23	260.74	6.76	161.23	325.70	161.23
B14	Banepa-06, Bhimsen	27.6295 N	1.5	154.09	202.48	208.77	242.51	154.09	127.60	-17.19	57.58	93.69	57.58
	Marga	85.533088 E	3	244.92	342.32	331.32	370.76	244.92	265.61	8.45	115.17	232.65	115.17

Table C. 2:Bearing Capacity Calculation Sheet at 1.5m and 3m depths of Banepa (Contd.)

B15	Banepa-8	27.62634 N	1.5	149.45	196.28	202.48	232.57	149.45	129.00	-13.68	69.10	112.43	69.10
		85.521986 E	3	219.60	330.21	319.14	356.64	219.60	204.00	-7.11	80.62	162.85	80.62
B16	Banepa-7	27.625971 N	1.5	155.22	227.46	204.57	225.37	155.22	135.45	-12.74	57.58	93.69	57.58
		85.528348 E	3	292.43	361.01	315.64	341.27	292.43	270.46	-7.51	414.60	407.00	407.00
B17	Banepa-4	27.625087N	1.5	155.42	206.87	193.63	199.98	155.42	140.16	-9.82	80.62	131.16	80.62
		85.546635E	3	229.70	357.86	344.15	365.06	229.70	199.76	-13.04	172.75	348.97	172.75
B18	Banepa-10	27.636039 N	1.5	153.87	225.32	202.85	223.34	153.87	145.80	-5.24	57.58	93.69	57.58
		85.514641 E	3	202.09	357.19	312.30	337.55	202.09	192.84	-4.58	55.00	69.79	55.00
B19	Banepa-6	27.626527 N	1.5	153.87	196.28	202.48	234.57	153.87	140.80	-8.49	57.58	93.69	57.58
		85.532042 E	3	235.04	330.21	319.17	356.64	235.04	231.86	-1.35	103.65	209.38	103.65
B20	Banepa-8,	27.633553 N	1.5	155.22	227.46	204.57	225.37	155.22	135.80	-12.51	57.58	93.69	57.58
	Mukti Marg	85.517394 E	3	241.60	361.01	315.64	341.27	241.60	225.31	-6.74	126.68	255.91	126.68
B21	Banepa-9	27.635137N	1.5	152.24	208.87	195.40	201.85	152.24	136.40	-10.40	69.10	112.43	69.10
		85.52163 E	3	228.45	361.76	348.02	369.22	228.45	215.60	-5.62	115.17	232.65	115.17
B22	Banepa-11	27.622169 N	1.5	177.89	232.72	241.06	272.70	177.89	162.80	-8.48	57.58	93.69	57.58
		85.521258 E	3	228.45	374.61	357.31	394.31	228.45	205.20	-10.18	115.17	232.65	115.17
B23	Banepa-10	27.634103 N	1.5	152.24	208.87	195.40	201.85	152.24	135.89	-10.74	69.10	112.43	69.10
		85.517027 E	3	228.45	361.76	348.02	369.22	228.45	235.22	2.96	115.17	232.65	115.17
B24	Banepa-11	27.623785 N	1.5	181.24	248.25	247.99	266.13	181.24	156.42	-13.69	80.62	131.16	80.62
		85.516919 E	3	284.87	433.43	411.80	439.00	284.87	261.58	-8.18	184.27	372.23	184.27
B25	Banepa-5	27.633688 N	1.5	168.26	220.63	228.00	261.50	168.26	155.85	-7.38	57.58	93.69	57.58
		85.528315 E	3	215.60	364.40	350.28	389.45	215.60	201.52	-6.53	126.68	255.91	126.68
B26	Banepa-10	27.631483 N	1.5	165.57	227.02	225.73	244.10	165.57	158.85	-4.06	80.62	131.16	80.62
		85.511663 E	3	232.69	408.35	390.97	418.54	232.69	240.57	3.39	184.27	372.23	184.27
B27	Banepa-4	27.64252 N	1.5	183.10	239.67	248.12	281.62	183.10	177.60	-3.01	80.62	131.16	80.62
		85.520248 E	3	215.60	388.21	370.99	410.16	215.60	201.70	-6.45	126.68	255.91	126.68
B28	Banepa-14	27.630558 N	1.5	152.24	208.87	195.40	201.85	152.24	135.85	-10.76	69.10	112.43	69.10
		85.490879 E	3	233.52	361.76	348.02	369.22	233.52	215.83	-7.58	138.20	279.17	138.20
B29	Banepa-13	27.636734 N	1.5	163.84	224.65	223.40	241.54	163.84	150.00	-8.45	69.10	112.43	69.10
		85.499341 E	3	229.70	403.75	386.49	413.69	229.70	214.21	-6.74	172.75	348.97	172.75
B30	Banepa-5	27.635798 N	1.5	136.85	187.31	172.77	179.21	136.85	129.61	-5.29	80.62	131.16	80.62
		85.53183 E	3	220.74	334.73	324.72	345.92	220.74	228.65	3.58	138.20	279.17	138.20
B31	Banepa-10	27.642945 N	1.5	152.24	208.87	195.40	201.85	152.24	174.40	14.56	69.10	112.43	69.10
		85.511552 E	3	228.45	361.76	348.02	369.22	228.45	212.79	-6.85	207.30	418.76	207.30

Table C. 3:Bearing Capacity Calculation Sheet at 1.5m and 3m depths of Dhulikhel

S.No.	Location	Coordinates	Depth (m)	SAFE ALLOWABLE (Shear Failure Criteria)					Plaxis		SAFE ALLOWABLE (Settlement Criteria)		
				Terzaghi (1943) (kN/m2)	Meyerhof (1963) (kN/m2)	Hansen (1970) (kN/m2)	Vesic (1973) (kN/m2)	Minimum (kN/m2)	From Plaxis 8.2	Diff.(%)	Meyerhof (1965) (kN/m2)	Bowels (1987) (kN/m2)	Minimum (kN/m2)
D1	Dhulikhel-8	85.564441 E	1.5	151.50	192.31	196.39	209.55	151.50	169.07	11.60	80.62	131.16	80.62
		27.621501 N	3	247.32	332.18	321.55	340.78	247.32	270.00	9.17	115.17	232.65	115.17
D2	Dhulikhel-8, Bhattedanda	85.571187 E	1.5	151.38	187.45	189.27	203.92	151.38	174.40	15.20	80.62	131.16	80.62
		27.615593 N	3	260.59	334.99	324.72	346.39	260.59	225.02	-13.65	115.17	232.65	115.17
D3	Dhulikhel-3	85.547190E	1.5	82.95	214.44	207.02	211.30	82.95	78.80	-5.00	69.10	112.43	69.10
		27.631433N	3	109.86	233.59	233.10	243.62	109.86	104.88	-4.53	115.17	232.65	115.17
D4	Dwarika	85.574494E	1.5	130.86	179.79	177.21	194.37	130.86	148.40	13.40	80.62	131.16	80.62
	Resort,	27.619188N	3	204.88	340.84	330.59	356.34	204.88	225.07	9.85	172.75	348.97	172.75
D5	Dulikhel-6	85.546603E	1.5	126.53	168.21	153.37	159.64	126.53	145.00	14.60	80.62	131.16	80.62
		27.613532N	3	160.00	307.99	300.68	321.29	160.00	181.63	13.52	115.17	232.65	115.17
D6	Dhulikhel-7	85.554606E	1.5	111.42	274.60	271.69	275.97	111.42	101.30	-9.08	69.10	112.43	69.10
		27.610757N	3	127.53	288.68	282.24	292.77	127.53	132.30	3.74	115.17	232.65	115.17
D7	Dhulikhel-3	85.554919E	1.5	125.02	166.21	151.60	157.77	125.02	143.50	14.78	80.62	131.16	80.62
		27.632540N	3	241.84	304.09	296.81	317.13	241.84	220.24	-8.93	92.13	186.12	92.13
D8	Dhulikhel-8	85.562689 E	1.5	96.30	246.02	238.95	243.59	96.30	97.15	0.88	69.10	112.43	69.10
		27.62118 N	3	176.82	265.70	263.87	275.29	176.82	169.12	-4.35	88.25	76.22	76.22
D9	Dhulikhel-7	85.556997E	1.5	183.10	239.67	248.12	281.62	183.10	157.52	-13.97	80.62	131.16	80.62
		27.614013N	3	275.14	388.21	370.99	410.16	275.14	259.11	-5.83	138.20	279.17	138.20
D10	28 kilo,	85.5400E	1.5	197.94	258.71	268.24	301.75	197.94	180.24	-8.94	69.10	112.43	69.10
	Dhulikhel-4	27.6256N	3	299.28	412.02	391.70	430.86	299.28	287.85	26.29	172.75	348.97	172.75
D11	Dhulikhel-9	85.563393 E	1.5	140.52	187.35	190.27	240.31	140.52	155.20	10.45	57.58	93.69	57.58
		27.604322 N	3	284.17	366.47	368.55	427.05	284.17	260.35	-8.38	529.77	407.00	407.00
D12	KU, Dhulikhel-4	85.5386E	1.5	158.44	210.88	197.18	203.71	158.44	157.60	-0.53	80.62	131.16	80.62
		27.6195N	3	259.04	365.67	351.89	373.38	259.04	297.58	14.88	138.20	279.17	138.20
D13	Dhulikhel-4	85.539744E	1.5	150.53	198.47	203.92	241.68	150.53	147.01	-2.34	92.13	149.90	92.13
		27.626144N	3	283.47	347.92	340.19	384.32	283.47	247.38	-12.73	380.05	767.73	380.05
D14	28 Kilo	85.540707E	1.5	175.21	239.95	239.85	257.14	175.21	140.22	-19.97	69.10	112.43	69.10
	Dhulikhel-4	27.623149N	3	313.59	417.33	396.10	422.03	313.59	290.78	-7.27	103.65	209.38	103.65

Table C. 4:Bearing Capacity Calculation Sheet at 1.5m and 3m depths of Dhulikhel (Contd)

D15	Dhulikhel-6	85.549325E	1.5	147.15	196.20	199.25	251.65	147.15	155.20	5.47	92.13	149.90	92.13
		27.616487N	3	292.07	383.77	385.95	447.21	292.07	263.22	-9.88	230.33	465.29	230.33
D16	Dhulikhel-4	85.546635E	1.5	141.12	194.06	190.50	210.33	141.12	160.96	14.06	92.13	149.90	92.13
		27.625087N	3	298.41	376.58	367.26	397.01	298.41	269.98	-9.53	437.63	444.00	437.63
D17	Shrikhanda-pur, 28 Kilo	85.539683E	1.5	132.94	171.52	180.21	190.08	132.94	124.78	-6.14	57.58	93.69	57.58
	Dhulikhel-4	27.621815N	3	292.43	286.64	280.97	295.01	280.97	250.10	-10.99	414.60	407.00	407.00
D18	Bapuchha (Upper), Dhulikhel-6	85.547265E	1.5	118.07	152.28	159.76	169.47	118.07	107.79	-8.71	57.58	93.69	57.58
		27.612928N	3	182.95	261.56	258.49	272.32	182.95	165.35	-9.62	80.62	162.85	80.62
D19	28 kilo	85.550067E	1.5	134.22	184.58	181.19	200.06	134.22	160.69	19.72	92.13	149.90	92.13
	Dhulikhel-4	27.621552N	3	235.68	358.19	349.33	377.62	235.68	205.20	-12.93	195.78	395.50	195.78
D20	Dhulikhel-3	85.544253E	1.5	144.30	186.26	195.98	205.55	144.30	160.39	11.15	69.10	112.43	69.10
		27.626752N	3	206.21	302.83	294.34	307.96	206.21	222.48	7.89	57.58	116.32	57.58
D21	Dhulikhel-4	85.538588E	1.5	135.38	185.31	170.99	177.35	135.38	164.80	21.73	80.62	131.16	80.62
		27.615412N	3	264.49	330.82	320.86	341.76	264.49	286.35	8.26	172.75	348.97	172.75
D22	Dhulikhel-9	85.578266E	1.5	147.15	196.20	199.25	251.65	147.15	155.20	5.47	92.13	149.90	92.13
		27.601835N	3	292.07	383.77	385.95	447.21	292.07	276.06	-5.48	564.32	439.00	439.00
D23	DAO, Kavre	85.560301E	1.5	165.57	227.02	225.73	244.10	165.57	157.80	-4.69	80.62	131.16	80.62
	Dhulikhel-7	27.610693N	3	241.65	408.35	390.97	418.54	241.65	256.27	6.05	218.82	442.03	218.82
D24	Dhulikhel-11	85.572134E	1.5	138.33	189.32	174.54	181.07	138.33	164.80	19.14	69.10	112.43	69.10
		27.59706N	3	247.10	338.63	328.59	350.09	247.10	267.10	8.10	172.75	348.97	172.75
D25	Dhulikhel-9	85.564935E	1.5	165.61	217.09	224.40	256.96	165.61	160.05	-3.36	80.62	131.16	80.62
		27.599648N	3	261.50	357.48	343.32	381.38	261.50	277.61	6.16	161.23	325.70	161.23
D26	Hospital Road,	5'32'58.19" E	1.5	138.33	189.32	174.54	181.07	138.33	155.20	12.20	80.62	131.16	80.62
		27'37'4.8"N	3	252.54	338.63	328.59	350.09	252.54	236.02	-6.54	184.27	372.23	184.27
D27	Bapuchha (Upper), Dhulikhel-7	85.551599E	1.5	132.94	171.52	180.21	190.08	132.94	129.24	-2.78	57.58	93.69	57.58
		27.611387N	3	234.44	286.64	280.97	295.01	234.44	255.42	8.95	80.62	162.85	80.62

APPENDIX D

Photo D. 1: Sample collection and Lab Works

Photo D. 2: Lab Works at Himalaya College of Engineering and CMTL

Date: September 10, 2019

To

The Administrative Chief,

Banepa Municipality,

Dhulikhel, Kavrepalanchowk

Subject: About Providing the Geotechnical Data for Thesis

Dear Sir,

This is in reference to the above-mentioned subject. Mr. Suvarna Singh Raut is currently doing his thesis on "Bearing Capacity Mapping of Dhulikhel and Banepa Municipality" from Pulchowk Campus, IOE to complete his MSc. In Geotechnical Engineering. This map will help in his thesis. Also, this map will be useful for the municipality for preliminary design of foundation, feasibility study, planning of detail investigations of complex formations. It will reduce the time and cost of the project lapsed in investigations. This will also help in providing planned settlement in future.

I would like to request the municipality to help him with the geotechnical data. One copy of color map of mapping shall be provided to the municipality.

Thanking You.

Sincerely Yours,

Dr. Indra Prasad Acharya,

Program Coordinator,

MSc. In Geotechnical Engineering,

Pulchowk Campus, IOE

Photo D. 3: Approved Letter by Banepa Municipality for Geotechnical Data

Date: September 10, 2019

To

The Administrative Chief,

Dhulikhek Municipality,

Dhulikhel, Kavrepalanchowk

Subject: About Providing the Geotechnical Data for Thesis

Dear Sir,

This is in reference to the above-mentioned subject. Mr. Suvarna Singh Raut is currently doing his thesis on "Bearing Capacity Mapping of Dhulikhel and Banepa Municipality" from Pulchowk Campus, IOE to complete his MSc. In Geotechnical Engineering. This map will help in his thesis. Also, this map will be useful for the municipality for preliminary design of foundation, feasibility study, planning of detail investigations of complex formations. It will reduce the time and cost of the project lapsed in investigations. This will also help in providing planned settlement in future.

I would like to request the municipality to help him with the geotechnical data. One copy of color map of mapping shall be provided to the municipality.

Thanking You.

Sincerely Yours,

Dr. Indra Prasad Acharya,

Program Coordinator,

MSc. In Geotechnical Engineering,

Pulchowk Campus, IOE

Photo D. 4: Approved Letter by Dhulikhel Municipality for Geotechnical Data