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Bearing Capacity of 3 types of Foundation on Clayey Soil of Alappuzha District

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***Abstract*:** *The strength of a building lies in its foundation. The main purpose of the foundation is to hold the structure above it and keep it upright. On the contrary, a poorly constructed foundation can be dangerous to the occupants and the neighborhood. With high-rise buildings touching the sky these days, it has become all the more important to have powerful foundations. Therefore, it is highly essential to determine the quality of construction as well as the load bearing soil. According to the construction experts and engineers, the foundation must be able to withstand the "dead" load and "live" loads. The foundation must be firm and must be able to channel the weight of the entire building to the ground. In this paper, a G+1 building is considered for the entire study. Soil specimen from Alappuzha region was collected and subjected to different laboratory tests. The characteristics of soil were thus studied. The total load arising on the entire building was determined for the further calculations. The foundation that is totally convenient for the building as well as the soil is found out through bearing capacity calculation and settlement is deliberated by standard codes.*
Keywords: *Bearing Capacity; Load calculation; Settlement; Stresses in footing.*

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I. INTRODUCTION

Construction of a structure on soft soils will always be a problem to civil engineers. Besides having low bearing capacity, soft soils are also high in compressibility that may result in large settlement, both total and differential settlement. Foundation systems are used to transfer the load safely into the soil ensuring overall stability and serviceability of the superstructures and to anchor the structure deeply into the ground, increasing its stability and preventing overloading. The design and the construction of the foundation is done such that it can sustain as well as transmit the dead and the imposed loads to the soil. This transfer has to be carried out without resulting in any form of settlement that can result in any form of stability issues for the structure. Differential settlements can be avoided by having a rigid base for the foundation. These issues are more pronounced in areas where the superimposed loads are not uniform in nature. Isolated, strip and raft foundations are in general economic alternatives to plain shallow foundations in situations involving heavy super structural loads to be transmitted to weaker soils.

Isolated footings are commonly used for shallow foundations in order to carry and spread concentrated loads, caused for example by columns or pillars. Isolated footings can consist either of reinforced or non-reinforced material. An isolated footing is used to support the load on a single column. It is usually either square or rectangular in plan. It represents the simplest, most economical type and most widely used footing. Strip foundations are a type of shallow foundation that are used to provide a continuous, level (or sometimes stepped) strip of support to a linear structure such as a wall or closely-spaced rows of columns built centrally above them. Strip footing is a continuous strip of concrete that serves to spread the weight of a load bearing wall across an area of soil. It is the component of a shallow foundation. Strip footings are commonly used as foundations of load-bearing walls. The footing usually has twice the width as the load bearing wall, sometimes it is even wider. The widths as well as the type of reinforcement are depending on the bearing capacity of the foundation soil. Raft foundations provide support for structures, transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics. A raft foundation is often used when the soil is weak, as it distributes the weight of the building over the entire area of the building, and not over smaller zones (like individual footings) or at individual points (like pile foundations). This reduces the stress on the soil. Raft foundations (sometimes referred to as raft footings or mat foundations) are formed by reinforced concrete slabs of uniform thickness (typically 150 mm to 300 mm) that cover a wide area, often the entire footprint of a building. They spread the load imposed by a number of columns or walls over the area of foundation, and can be considered to 'float' on the ground as a raft floats on water.

II. OBJECTIVES

This study aims to fulfill the following objectives

- To study the behavior of 3 types of foundations in clayey soil.
- To determine the bearing capacity of each foundation.
- To determine the settlement of each foundation.
- To check which type of foundation is best for the selected soil.

III. STUDY AREA

Alappuzha is a city and a municipality in Kerala with an urban population of 174,164 and ranks third among the districts in literacy rate in the state. The city is situated 28km from Changanacherry, 46km from Kottayam, 55km from Kochi. Alappuzha is located at 9.54ºN76.40ºE. The average elevation is 1 metre. The place consists of soils with surface textures ranging from sandy loam to clayey loam and moderatetly supplied with organic matter like nitrogen and potassium.

IV. METHODOLOGY

4.1. MATERIAL CHARACTERISATION

Information on subsurface conditions at the site was studied through ground borings to depths of 16m each using rotary drilling. Both disturbed and undisturbed samples were collected for visual examination, laboratory testing and classification. Standard penetration test(SPT) were conducted to determine the penetration resistance values of cohesionless soils at specific depths within the bore holes. Requisite laboratory tests were also carried out on soil samples to determine bearing capacity and settlement calculation. The water table at the site was observed to vary from about 0.8m- 1.1m below the existing ground level.

4.2. DETAILS OF SOIL PROFILE

The first bore hole is terminated up to 16 meter depth. In this bore hole, soil up to 3.5mdepth is fine sand with N-values 10, 11 and >50 at 1m, 2m and 3m depths. From 3.7m to 705m it is clay with average N-value 2.from 7.5m to 8.5 m it is sandy clay with N-value 10. Below 8.5m it is soft clay with average N-value <2. The second bore hole is terminated up to 16m depth. In this bore hole soil up to 3m depth is fine sand with average N-value 9. From 3m to 3.6m it is fine sand with clay and N-value is 2. From 3.6m to 7m it is fine sand with N-values 39 and >50 at 4.5m and 6m depths. Below 7m it is clay and sandy clay with N-values varying from 3 to 7.

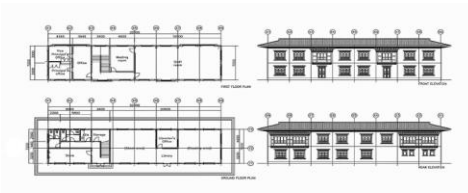

Fig 1: Plan of Building

This is the plan and elevation of a G + 1 school building of 4960 square feet.

V. CHARACTERISTICS OF SAMPLE

5.1. MOISTURE CONTENT

The method covers the laboratory determination of the moisture content of the soil sample as a percentage of its oven-dried weight. The method is based on removing soil moisture by oven oven-drying a soil sample until the weight remains constant. The moisture content(%) is calculated from the sample weight before and after drying.

5.2. SPECIFIC GRAVITY

Specific Gravity is the ratio the density of any substance to the density of some other substance taken as standard, water being the standard for liquids and solids, and hydrogen or air for gases. The knowledge of Specific Gravity is needed in the calculation of void ratio, degree of saturation, etc. Test was conducted by Density Bottle Method.

5.3. GRAIN SIZE DISTRIBUTION

Particle Size distribution is an index indicating what size of particles are present in what proportions in the sample of the soil to be measured. Particle size distribution can greatly affect the strength and efficiency of the soil. Wet sieve analysis and Hydrometer analysis is conducted. Hydrometer is used for determination of suspension at different depths and particular intervals of time.

5.4. ATTERBERG'S LIMITS

The water content at which the soil changes from one state to other is known as consistency limits or Atterberg's Limits. The water content at which soil changes from liquid state to plastic state is known as liquid limit. The water content at which soil becomes semi solid is known as plastic limit. The water content at which soil changes from semi solid state to the solid state is known as shrinkage limit.

5.5. UNCONFINED COMPRESSION TEST

The unconfined compressive strength is the load per unit area at which the cylindrical specimen of a cohesive soil fails in compression. This test is most popular method of soil shear testing because it is one of the fastest and cheapest methods of measuring shear strength. The method is used primarily for saturated, cohesive soils recovered from thin-walled sampling tubes.

5.6. COMPACTION TEST

Compaction is the process of densification of soil by reduction of air voids. The degree of compaction of soil is measured in terms of dry density, which is maximum at a water content called Optimum moisture content. The optimum water content and maximum dry density is obtained by conducting standard proctor test.

The values of tests conducted on sample is given in the table

TABLE 1 PROPERTIES OF SOIL

Tests Conducted	Values
Moisture Content	72%
Specific Gravity	2.65
Liquid Limit	80%
Plastic Limit	41.58%
Plasticity index	39.4%
Shrinkage Limit	18.6%
Shear strength	$9KN/m^2$
Unconfined compressive strength	$18.05KN/m^2$
Max. dry density	1.71g/cm3
Optimum moisture content	31.50%
Degree of saturation at OMC	84.53%

VI. IS CODE RECCOMENDATION FOR BEARING CAPACITY

IS 6403 1981 recommends that for the computation of ultimate bearing capacity of a shallow foundation in general shear failure equation may be used.

$$q_{nu} = CN_S S_c d_c i_c + q(N_q-1)S_q i_q d_q + 0.5\text{Ɣ}BN_\text{Ɣ}S_\text{Ɣ}d_\text{Ɣ}i_\text{Ɣ}W'$$

In this equation q_{nu} refers to the net ultimate bearing capacity Nc N_q and $N_\text{Ɣ}$ bearing capacity factors recommended by Vesic (1973).). W' is a factor which takes into account the effect of water table W' = 1 if the water table is likely to remain permanently at or below a depth (D_f + B) below ground level or for $D_W' \geq B$ where D_W' is the depth of water table measured from the base of the foundation. For $D_W'=0$, W' = 0.5, W' can we linearly interpolated between 0 and 1 if $0< D_W'<B$. This amount to the same as using an equivalent value of Ɣ as given to determine R_W'. The influence of water table is taken care of by taking q as the effective surcharge at level of the base of the footing.

VII. SETTLEMENT THEORY

The immediate settlement beneath the centre or corner of a flexible loaded area is given by:

$$S = qB\frac{(1-\mu 2)}{E}If$$

Where;

q= Net foundation pressure
B= Width of foundation
μ= Poissons's ratio
E= Young's modulus

I_f= Influence factor(depends on length L to B ratio of the footing)

Values of E shall be determined from the stress strain curve obtained from triaxial consolidated undrained test. Consolidation pressure adopted in triaxial consolidation test should be equal to the effective pressure at the depth from which the sample has been taken. The values of I may be determined for clay layers with various H_t/B ratio from table 7.2 for clay layers of semi-infinite extent.

TABLE 2 VALUES OF I FOR CLAY LAYERS OF SEMI-INFINITE EXTENT

SHAPE	INFLUENCE FACTOR(I_f)		
	CENTRE	CORNER	AVERAGE
CIRCLE	1.00	0.64	0.85
SQUARE	1.12	0.56	0.95
RECTANGLE:			
L/B = 1.5	1.36	0.68	1.20
L/B = 2	1.53	0.77	1.31
L/B = 5	2.10	1.05	1.83
L/B = 10	2.52	1.26	2.25
L/B = 100	3.38	1.69	2.96

VIII.LOAD CALCULATION

8.1. LOADS ON BUILDING

Loads acting on the buildings are generated either by force or nature or manmade. The natural forces are due to temperature, air, earthquake, gravitational force etc. To meet the requirement that design strength be higher than maximum loads, building codes prescribe that, for structural design, loads are increased by load factors. These load factors are, roughly, a ratio of the theoretical design strength to the maximum load expected in service. They are developed to help achieve the desired level of reliability of a structure based on probabilistic studies that take into account the load's originating cause, recurrence, distribution, and static or dynamic nature. Manmade forces are generated by movement of people, impact loads etc. The loads considered in this study include Dead Load and Live Load.

8.1.1. Dead Load

All permanent constructions of the structure form the dead load. Dead loads shall be calculated on the basis of unit weights which shall be established talking into account the material specified for construction from IS 875 (Part 1) 1987.

8.1.2. Live Load

The imposed loads to be assumed in the design of building shall be the greatest loads that probably will be produced by the intended use or occupancy, but shall not be less than the minimum loads specified in IS 875 (Part 2) 1987.

8.2. LOADS ON BUILDING

8.2.1. Dead Load Calculation

1. GROUND FLOOR

i. Self-weight of Slab

Dimension of Slab = 32m×7.2m×0.12m
Number of Slab = 1
Unit weight of Concrete = 25KN/m^2
Self-weight of slab = 1×32×7.2×0.12×25=692KN

ii. Self -weight of Beams

- Longitudinal Beam

Beam dimension =32m×0.5m×0.3m
Number of beams = 3
Unit weight of Concrete = 25KN/m^2
Self-weight of Beams = 3×32×0.5×0.3×25=360KN

- Cross Beams

Beam dimension=7.2m×0.5m×0.3m
Number of beams = 9
Unit weight of Concrete =25KN/m^2
Self-weight of Beams =243KN
Total Self-weight of Beams =360+243=603KN

iii. Self-weight of Columns
Dimension of Column=3m×0.3m×0.3m
Number of Columns =10
Unit weight of Concrete =25KN/m^2
Total self-weight of columns=67.5KN

iv. Floor finish load
Thickness of Floor Finish=50mm
Unit weight of Cement Mortar=20KN/m^3
Dimension of floor=32m×7.2m
Floor finish load=0.05×20×32×7.2=230KN

v. Partition wall load

- On Beam

Thickness of Partition wall= 100mm
Height of wall =3000mm
Unit weight of brick masonry=20KN/m^3
Number of Partition wall=5
Partition wall load=5×0.1×3×20×5=30KN

- On Slab

Consider 1KN/m2 on the entire slab
Partition wall load= 32×7.2×1=230.4KN
Total Partition wall load=30+230.4=260.4KN

vi. Main wall load
Thickness of Main wall load=200mm
Height of wall=3000mm
Unit weight of Brick masonry =20KN/m^2
Number of Main walls=4
Main wall load=4×0.2×3×20=48KN

vii. Sunken slab load
Thickness of Sunken slab=250mm
Unit weight of filling material=8KN/m^3
Dimension of toilet=2.2m×2.5m
Sunken slab Load =0.25×8×2.2×2.5=11KN

viii. Staircase Load
Thickness of waist slab=150mm
Thickness of Riser=150mm
Thickness of Tread=300mm

a) Loads on going

- Self weight of waist slab=$0.15\times25(\sqrt{R^2+T^2})/T$
  =0.15×25(√0.152+0.32)/0.3=4.19KN/m^2
- Self weight of Steps=25×(1/2)×0.15=1.875KN/m^2
- Floor finish=0.05×20=1KN/m^2
- Live Load on steps =3KN/m^2

Total Load On going=10.06KN/m^2

b) Loads on Landing

- Self weight of steps=25×0.15=3.75KN/m^2
- Floor Finish=0.05×20=1KN/m^2
- Live Load on steps=3KN/m^2

Total Load on Staircase =17.81KN/m^2
Total Load on Ground Floor =1929.71KN

2. FIRST FLOOR

i. Self-weight of Slab
Dimension of Slab = 32m×7.2m×0.12m
Number of Slab = 1
Unit weight of Concrete = 25KN/m^2
Self-weight of slab = 1×32×7.2×0.12×25=692KN

ii. Self -weight of Beams

- Longitudinal Beam

Beam dimension =32m×0.5m×0.3m
Number of beams = 3

Unit weight of Concrete = 25KN/m^2
Self-weight of Beams = 3×32×0.5×0.3×25=360KN

- Cross Beams

Beam dimension=7.2m×0.5m×0.3m
Number of beams = 9
Unit weight of Concrete =25KN/m^2
Self-weight of Beams =243KN
Total Self-weight of Beams =360+243=603KN

iii. Self-weight of Columns

Dimension of Column=3m×0.3m×0.3m
Number of Columns =10
Unit weight of Concrete =25KN/m^2
Total self-weight of columns=67.5KN

iv. Floor finish load

Thickness of Floor Finish=50mm
Unit weight of Cement Mortar=20KN/m^3
Dimension of floor=32m×7.2m
Floor finish load=0.05×20×32×7.2=230KN

v. Partition wall load

- On Beam

Thickness of Partition wall= 100mm
Height of wall =3000mm
Unit weight of brick masonry=20KN/m^3
Number of Partition wall=5
Partition wall load=5×0.1×3×20×5=30KN

- On Slab

Consider 1KN/m2 on the entire slab
Partition wall load= 32×7.2×1=230.4KN
Total Partition wall load=30+230.4=260.4KN

vi. Main wall load

Thickness of Main wall load=200mm
Height of wall=3000mm
Unit weight of Brick masonry =20KN/m^2
Number of Main walls=4
Main wall load=4×0.2×3×20=48KN

vii. Parapet wall load

Thickness of parapet wall = 200mm
Height of wall=1200mm
Unit weight of Brick masonry=20KN/m^3
Total parapet load=0.2×1.2×20×32×7.2=1105.92
Total Load on first floor=3366.82KN
Total Dead load on the Building=5297KN
8.2.2. Live Load Calculation
For educational buildings Live Load on floor =4KN/m^2 (IS 875 Part 2)
Live load on roof = 2KN/m^2
Total live load = 4 x 32 x 7.2 + (2 x 32 x 7.2) = 1383KN

8.2.3. Total Load On Building

Total Load on Building =Total Dead Load on Building + Total Live Load on Building
=5297+1383=6680KN

Total Factored Load=1.5×Total Load on Building
=1.5×6680=10020KN

IX. STRESSES IN FOOTING

Foundation is to be strong enough to bear that all loads without any settlement, So for spreading the vertical load to large area footings are constructed. Depending on Soil bearing capacity of a particular location different Types of Footings are selected and constructed.

Different types of Foundations:-

a. Shallow Foundations

b. Deep foundations

If depth of the footing is equal to or greater than its width, it is called deep footing, otherwise it is called shallow footing.

Here we are considering three types of footings mainly, they are:

a. Isolated footing

Footing size=1.5m×1.5m

Number of Columns=10

Total Load on Footing=10020KN

Load on each footing=10020/10=1002KN

Load intensity on footing=1002/(1.5×1.5)= 445.33/m^2

b. Strip footing

Footing size= 32m×1.5m

Total load on one side=10020KN

Load on one side=10020/2= 5010KN

Load intensity on footing =5010/(32×1.5)=104.375KN/m^2

c. Raft footing

Footing size =(32+2)×(7.2+2)=34m×9.2m

Total Load on Footing =10020KN

Load intensity on footing =10020/(34×9.2)=32KN/m^2

X. BEARING CAPACITY AND SETTLEMENT CALCULATION

10.1. BEARING CAPACITY CALCULATION

10.1.1. Isolated Footing

Net Ultimate Bearing Capacity,

$q_{nu} = CN_S\, S_c d_c i_c + q(N_q-1)S_q\, i_q d_q + 0.5ƔBN_Ɣ S_Ɣ d_Ɣ i_Ɣ W'$

Safe bearing capacity, $q_s=q_{nu}/FOS$

Size of isolated footing =1.5m×1.5m

For sand, Cohesion, C=0

Based on N=10 value, Angle of internal friction, Ø=27.52°

Ø is less than 32. There for failure is Local shear failure

Revised Ø = Tan^{-1}(0.67×Tan 27.52) = 19.24°

Unit weight of Soil, Ɣ=17KN/m^3

Depth of cutting= 0.5m

Effective Surcharge, q=17×0.5=8.5KN/m^2

Bearing Capacity Factors for Ø =19.24°

Ns=6.40 Nq=6.40 $N_Ɣ$=5.39

Shape Factors:

Sc=Sq=$S_Ɣ$=1

Inclination Factors

ic=iq=iƔ=1

Depth Factors

dc=dq=dƔ=1.05

Correction factor for location of water table, W'=0.5

q_{nu}=0+8.5(6.40)×1×1×1.05+0.5×17×1.5×5.39×1×1.05×1×0.5=85KN

Factor of safety=2.5

q_s=85/2.5=34KN/m^2

10.1.2. Strip Footing

Net Ultimate Bearing Capacity,

$q_{nu} = CN_S\, S_c d_c i_c + q(N_q-1)S_q\, i_q d_q + 0.5ƔBN_Ɣ S_Ɣ d_Ɣ i_Ɣ W'$

Safe bearing capacity, $q_s=q_{nu}/FOS$

Size of isolated footing =1.5m×1.5m

For sand, Cohesion, C=0

Based on N=10 value, Angle of internal friction, Ø=27.52°

Ø is less than 32. There for failure is Local shear failure

Revised Ø = Tan^{-1}(0.67×Tan 27.52) = 19.24°

Unit weight of Soil, Ɣ=17KN/m^3

Depth of cutting= 0.5m
Effective Surcharge, $q=17\times0.5=8.5KN/m^2$
Bearing Capacity Factors for Ø =19.24°
$N_s=6.40$ $N_q=6.40$ $N_\gamma=5.39$
Shape Factors:
$Sc=Sq=S_\gamma=1$
Inclination Factors
$ic=iq=i\gamma=1$
Depth Factors
$dc=dq=d\gamma=1.05$
Correction factor for location of water table, W'=0.5
$q_{nu}=0+8.5(6.40)\times1\times1\times1.05+0.5\times17\times1.5\times5.39\times1\times1.05\times1\times0.5=85KN$
Factor of safety=2.5
$q_s=85/2.5=34KN/m^2$

10.1.3. Raft Foundation
Net Ultimate Bearing Capacity,
$q_{nu} = CN_S\, S_c d_c i_c + q(N_q-1)S_q\, i_q d_q + 0.5\gamma BN_\gamma S_\gamma d_\gamma i_\gamma W'$
Safe bearing capacity, $q_s=q_{nu}/FOS$
Size of isolated footing =1.5m×1.5m
For sand, Cohesion, C=0
Based on N=10 value, Angle of internal friction, Ø=27.52°
Ø is less than 32. There for failure is Local shear failure
Revised Ø = $Tan^{-1}(0.67\times Tan\ 27.52) = 19.24°$
Unit weight of Soil, $\gamma=17KN/m^3$
Depth of cutting= 0.5m
Effective Surcharge, $q=17\times0.5=8.5KN/m^2$
Bearing Capacity Factors for Ø =19.24°
$N_s=6.40$ $N_q=6.40$ $N_\gamma=5.39$
Shape Factors:
$Sc=Sq=S_\gamma=1$
Inclination Factors
$ic=iq=i\gamma=1$
Depth Factors
$dc=dq=d\gamma=1.05$
Correction factor for location of water table, W'=0.5
$q_{nu}=8.5\times5.4\times1\times1.05\times1+0.5\times17\times9.2\times5.39\times1\times1.05\times1\times0.5=270KN$
Factor of safety =2.5
$q_s=270/2.5=108KN/m2$

10.2. SETTLEMENT CALCULATION
The settlement under the footing is given by:

$$S = qB\frac{(1-\mu^2)}{E}If$$

$q= 32KN/m^2$
$B= 9.2m$
$\mu= 0.5$
$I_f= 2$
$E = \frac{12\times Esand+2\times Eclay}{14} = 22200KN/m^2$
$S = 32\times9.2\frac{(1-0.5^2)}{E}\times2 = 19.89mm$

XI. CONCLUSIONS

In the present paper, the geotechnical behavior of three different foundations were investigated theoretically and compared with each other.
From the theoretical results it can be concluded that:

- When comparing the bearing capacity value, the raft footing possesses high value.
- The settlement is less for the raft footing.
- The load carrying capacity of raft footing is higher than both isolated footing and strip footing.

- So the raft footing which possess high bearing capacity and lowest settlement can be selected for the selected building on the specific soil.

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